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Department of the Environment, Climate and Communications

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An Assessment of Geothermal Energy for District Heating in Ireland

Geological Survey Ireland

Geological Survey Ireland is a division of the Department of the Environment, Climate and Communications

1.1

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Glossary

4GDH	4th Generation District Heating
Capex	Capital expenditure
CHP	Combined Heat and Power
DCCAE	Department of Communications, Climate Action and Environment
DDHS	Dublin District Heating System
DH	District Heating
DSGW	Deep Geothermal Single Well
EGEC	European Geothermal Energy Council
EGS	Enhanced Geothermal System
ETS	Emissions Trading Scheme
GHG	Green House Gases
GSHP	Ground Source Heat Pump
GSI	Geological Survey Ireland
HDR	Hot Dry Rock
LCo(E)	Levelised cost of (electricity/energy)
NMP	National Mitigation Plan
MWh	1,000 kilowatts of electricity used continuously for one hour
MWth	Megawatts of thermal energy (heating or cooling)
Opex	Operational expenditure
RES-H	Renewable Energy Sources-for Heat
SEAI	Sustainability Energy Authority of Ireland
TDHS	Tallaght District Heating System

Executive Summary

This document reviews Ireland's geothermal energy resources and, in particular, geothermal energy for district heating in Ireland. The document has been compiled by Geological Survey Ireland, a division of the Department of the Environment, Climate and Communications (DECC) in fulfilment of a commitment under the All of Government Climate Action Plan of 2019. This assessment will support the Department's non-technical *Roadmap for a Policy and Regulatory Framework for Geothermal Energy in Ireland.*

Geothermal energy resources are proven to be secure, environmentally sustainable, effectively carbon-neutral and cost-effective over long-term periods and can play an important role in decarbonising Ireland's heat energy sector. 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 comparable 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. In addition, 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. The aim of this document is to provide background information about geothermal energy in general, with an explanation of the science and terminology. Importantly this has been written in terms of Ireland's geological setting, including the latest research relevant to this topic. In addition to explaining geothermal energy, it's potential in Ireland is examined with a comparison of international examples and a high level examination of the economic context for geothermal energy for district heating in Ireland. Barriers, opportunities, risks and mitigation measures are also assessed.

There are currently no district heating/cooling geothermal projects in operation in Ireland. This is attributed to barriers such as; lack of public awareness about Irish geothermal resources, capital costs for geothermal projects, and a lack of publicly available deep subsurface geological data. All of these factors contribute to the levels of risk inherent in geothermal projects.

In issuing this document and the non-technical roadmap, DECC hopes to inform the debate regarding potential use of geothermal energy in Ireland and supported by ongoing research by academic and industry based groups in Ireland, support the development of a clear policy and regulatory framework to allow Ireland realise its geothermal potential.

Koen Verbruggen

Director
Geological Survey Ireland
October, 2020

1 Introduction

Geothermal energy is heat energy stored below the surface of the Earth which can be used as heat or to generate electricity.

Geothermal energy is a secure, environmentally sustainable and cost-effective source of renewable energy that is growing in popularity across the world. Geothermal installations are commonly used across the globe to heat and cool homes and businesses, as well as in industrial and agricultural applications. Ireland has untapped geothermal energy resources that could provide a significant proportion of the country's heating needs. The production of electricity from geothermal resources is more advanced in places where geological conditions give rise to high heat flow from the Earth's interior (e.g., volcanic areas such as Iceland, Italy and New Zealand); however, recent advances in technology have made the production of geothermal electricity possible across a wider range of geological settings. These higher temperature natural resources are usually accessed by drilling deep boreholes, which can be several kilometres deep. New drilling technologies and our improved understanding of the subsurface mean this energy source could now be viable in Ireland

Approximately one-third of our energy demand is in the heating sector. SEAI estimates approximately 32% of energy consumed in Ireland is used for heat, the vast majority of which is powered by fossil fuels including oil, gas, coal and peat (Figure 1). Ireland's consistently low share of renewables in the heat sector (RES-H) is a key factor in our poor performance towards our renewable energy targets[1]. Geothermal energy is a renewable, low-to-zero carbon emission resource, therefore by tapping into our national geothermal energy resources we could replace some of these fossil fuels with a secure and sustainable heating alternative, thereby increasing our RES-H and reducing GHG emissions.

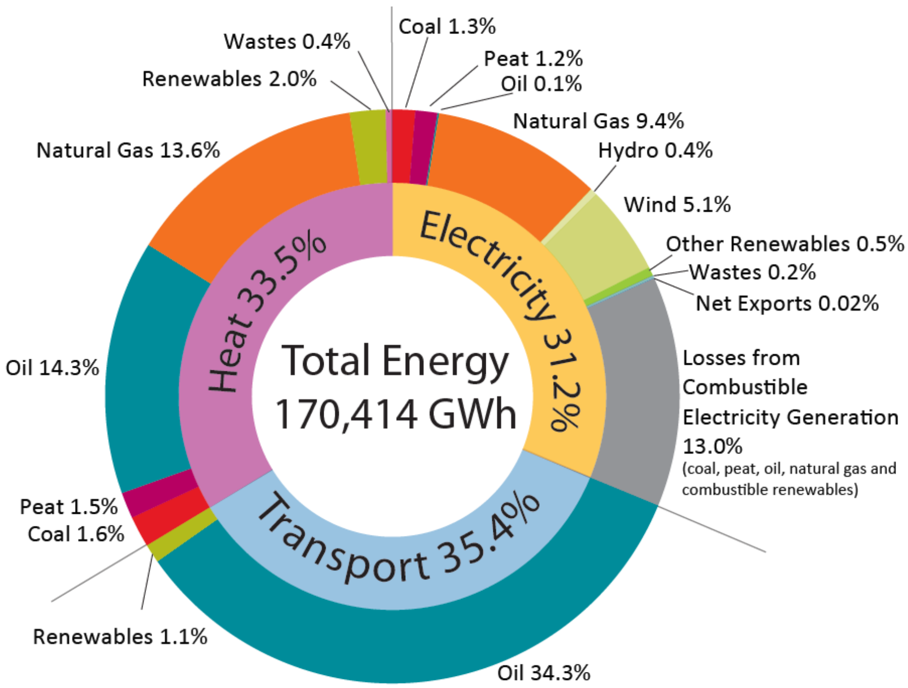

Figure 1 Energy consumption in Ireland highlighting approximately 32% required for heating. (Source: Sustainable Energy Authority of Ireland, 2019[1])

Ireland's geothermal energy resources are currently under-utilised and mostly used for small-scale, individual heating projects (e.g., for single domestic dwellings or industrial heating applications). Our low-temperature, shallow resources (to a depth of approximately 200 m; this depth is not a definition but a guideline for the purposes of this document) have been well documented by GSI and others in a series of geothermal suitability maps and an accompanying Homeowner's Guide to Ground Source Heat. However, Ireland's deeper geothermal resources are poorly understood at present due to a lack of publicly available deep subsurface data.

In this Roadmap we explore how geothermal energy can be used for district heating as a clean, sustainable part of the solution to meeting our energy needs and our goal of climate neutrality by 2050.

1.1 District heating systems

District heating (DH) is a method of transporting heat as hot water through a network of highly insulated pipelines, delivering heat (rather than fuel) directly to buildings. These systems service multiple buildings on a local network with heat exchangers installed in each building to distribute the heat internally (these can be retrofitted to existing heating systems). DH networks have been mainly powered by fossil fuels in the past, but renewable and near-zero Carbon DH networks are common throughout Europe. DH networks are common throughout Europe and have been recognised as the best way to decarbonise the heat sector where the heat demand, or population density, is high enough[2,3]. Modern, high-efficiency, 4th Generation (4G) DH networks can utiilise heat energy from a broad range of lower temperature sources (Figure 2) . Geothermal energy can be used on its own or as part of a mix of energy sources in DH schemes.

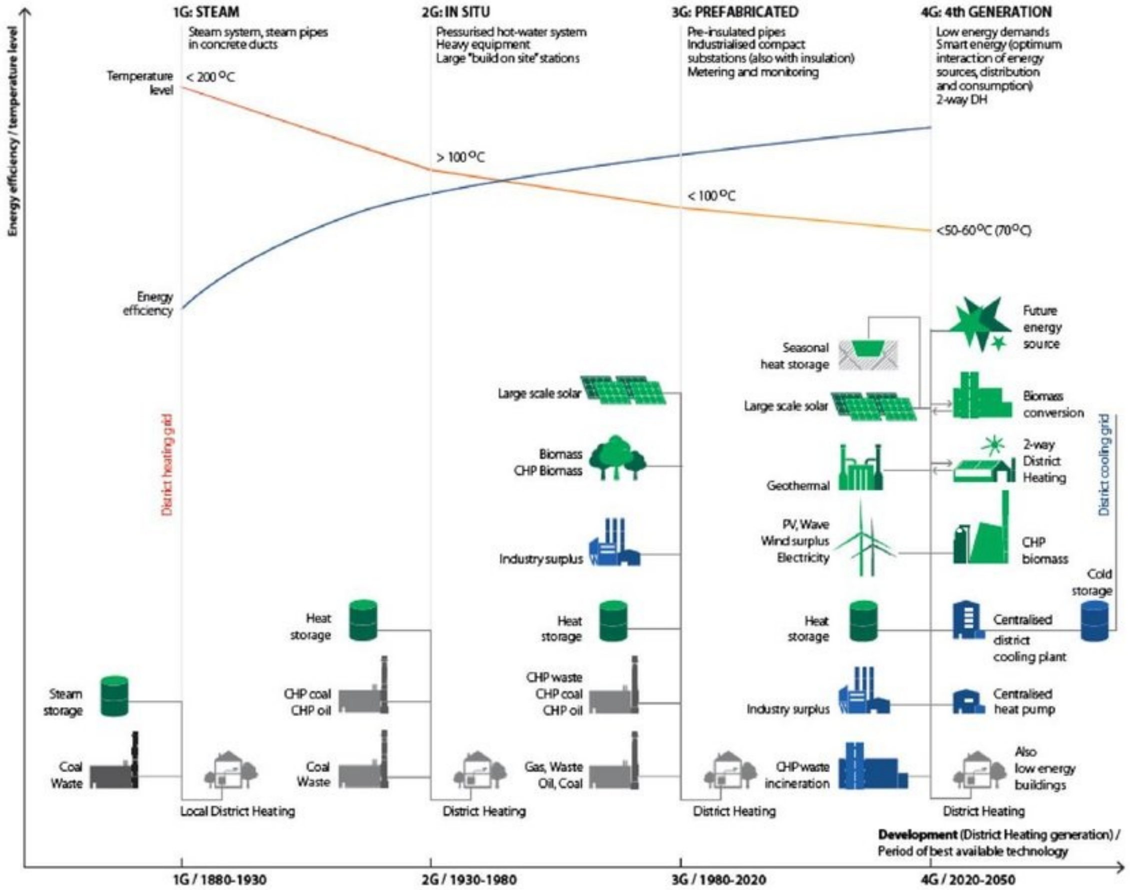

Figure 2 Evolution of fourth generation district heating to include a broad mix of potential heat sources. (Source: Lund et al. 2014[4]).

Geothermal District Heating (geoDH) is defined as the use of one or more subsurface geothermal production fields as a source of heat to supply thermal energy to a group of buildings and/or industries[5]. Across Europe, geoDH systems can range in power from <1 MWth to >50 MWth, and can be installed in new developments on green field sites or retrofitted to existing heat and gas networks. The key advantage of geothermal sources for such networks is the consistent baseload provided without peaks and troughs in energy production due to changes in weather or daylight hours (unlike e.g. wind or solar energy). In 2014 there were approximately 250 geoDH systems in operation in Europe with an installed capacity of about 4,400 MWth and an annual estimated production of approximately 13,000 GWh/y[5]. These included; Paris, France where water between 57ºC and 85ºC is abstracted from depths of between 1.5 and 2 km depth[6], and Southampton, UK where brine with a temperature of 76ºC rises naturally from a depth of 1.8 km to 100 m below the surface[7]. By 2019 the installed capacity of geothermal heating exceeded 10,600 MWth, of which about half was used in DH (other applications included agriculture and industrial processes)[8](Figure 3). Geothermal resources can also be co-generated alongside solar, waste-to-energy facilities, conventional boilers, biomass and industrial waste heat sources, and the local nature and security of supply of geothermal energy can reduce reliance on supply chains.

Ireland is now significantly lagging in both the use of geothermal energy and the installation of DH networks compared to our EU counterparts (Figure 3).

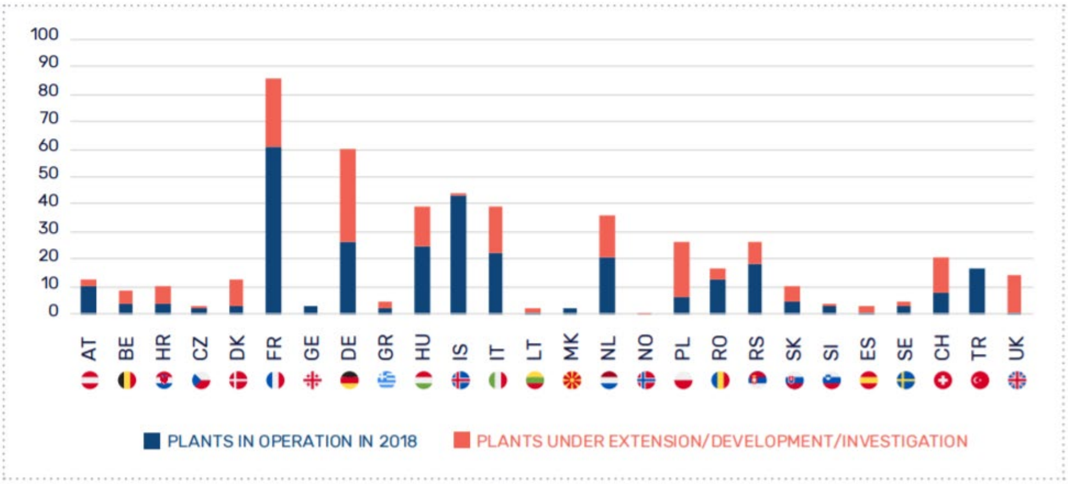

Figure 3 Number of geothermal district heating plants in Europe: installed, planned, in development. (Source: EGEC Geothermal Market Report, 2018[9])

Codema, Dublin's energy agency, and GSI recently conducted an analysis of the potential for geothermal district heating in South County Dublin[10]. **This report concluded that geothermal energy is a feasible source for DH networks in Dublin**[11]. To date there are two DH networks under development for Dublin and geothermal energy is being explored by Geological Survey Ireland as a potential heat source for both Dublin City Centre (Dublin County Council) and Tallaght (South Dublin County Council).

- Dublin City Council has committed to progressing a DH system in the Dublin Docklands and Poolbeg Peninsula with heat provided by the 'waste-to-energy' facility at Poolbeg. In 2015, Codema's Dublin City Spatial Energy Demand Analysis[12] showed that 75% of Dublin City has heat demand densities suitable for district heating, which illustrated that DH feasibility is not confined to the Docklands. The Dublin District Heating System (DDHS) project has now moved to Phase 2 with an operator appointed. In 2018, the DDHS was awarded €20m from the national Climate Action Fund to develop the infrastructure[13].
- (Codema has also partnered with South Dublin Council to investigate the potential for a DH network in Tallaght, the Tallaght District Heating Scheme (TDHS)[14]. Waste heat energy will be provided by a local data centre. This network will service a number of commercial customers and municipal and residential building including the Civic Theatre, Tallaght Institute of Technology, the library, County Hall and homes for over 3,000 residents. The scheme will receive funding of almost €4.5 million through the Government's Climate Action Fund, as well as support from the EU-funded HeatNet NWE[15] project.

There are several other existing small DH schemes in Dublin, including: Charlestown Shopping Centre, Finglas; Leinster House and Dáil Eireann, Dublin City Centre; mixed commercial and residential DH at Elm Park, South Dublin; residential DH at Charlotte Quay, Dublin 4. Outside Dublin, there's also a small-scale scheme in Callan, Co. Kilkenny[16] and Tralee Town Council has been leading the way with a renewable local DH network (fed from a biomass plant) which is servicing a number of municipal buildings and homes – the system is feeding both new and existing, retrofitted, buildings[17].

1.2 Current drivers for the development of geothermal resources in Ireland

The heat energy sector has proved the most difficult to decarbonise in the Irish context, and is currently the focus of national government initiatives to reduce our carbon emissions.

Since 2015 the Government response to energy issues and the climate crisis has consistently included specific, though limited, references to geothermal energy, and its potential contribution as a low-carbon heat source. Some specific mentions of geothermal electricity production have also been made (see policy section 1.3). Geothermal energy is also recognised at a local government level in some, but not all, county councils. Several local authorities have already included geothermal energy in their renewable energy schemes and/or their statements of strategy, such as Dublin City Council, South Dublin County Council, Clare County Council, Roscommon County Council and Mayo County Council. The development of renewable district heating schemes by local authorities, with assistance from national government funding through the Climate Action Fund, is driving research and investigation into local geothermal energy resources.

An increase in the number and scale of geothermal district heating systems for municipal buildings is achievable in Ireland. There are many examples in Ireland of individual municipal buildings connected to ground source heat pump systems[1]. However, increasing capacity through deeper and larger scale geothermal installations is possible. For example, the geothermal system installed in Orly Airport in the Ile-de-France region provides heating and hot water through 35km of a heating network at the airport campus. It was built between 2008 and 2011 at a well cost of €9m for a double well to a depth of 1.8km. The installed capacity is approximately 135MWth and it is estimated that the system has reduced emissions by 8,200-9,000 tons of CO_2 per year compared to the equivalent fossil fuel heat sources[5].

1.3 Irish and EU policy context

A series of reports, action plans, and policy documents to guide Ireland's implementation of the 2020 and 2030 EU policy packages have been published to date. The development of geothermal energy in Ireland can contribute to the overall aims of increasing renewable energy production and reducing green house gas emissions (GHGs).

- The Climate Action Plan 2019[18] aims to deliver a step-change in Ireland's emission performance over the coming decade to meet our EU targets for 2030, but will also meet our mid-century decarbonisation objectives. Action Item 70 directs GSI to examine the potential of geothermal energy to contribute to district heating and to develop this Roadmap.
- The National Mitigation Plan (NMP) 2017[19] details the Government's plans to decarbonise the electricity, built environment, and transportation sectors, and to approach carbon neutrality for agriculture, forestry, and land use sectors. The NMP lists geothermal energy as a possible source for renewable heat and electricity generation and GSI is tasked with assessing Ireland's geothermal potential.

- Ireland's Transition to a Low Carbon Energy Future 2015-2030[20], sets out a comprehensive set of actions with the goal of transitioning from a fossil-fuel based energy system to a low-carbon system while ensuring sustainability, security of supply, competitiveness, and affordability. The report notes the potential contribution of geothermal energy to the residential heating sector.
- The National Renewable Energy Action Plan 2010[21] addresses the EU requirement to prepare a national plan for reaching Ireland's target of 16% renewable energy by 2020. The report notes the government's intention to draft geothermal legislation.

Ireland's 2030, and 2050 energy and climate goals

The immediate impetus for examining geothermal energy as a heat source for district heating is the necessity to cut GHGs to address the climate emergency and to meet Ireland's commitments to the EU's 2030 Climate and Energy Framework. Ireland has also agreed to the EU goal of becoming climate-neutral by 2050 and is a signatory to the Paris Agreement which aims to keep the global temperature increase below 2 °C above pre-industrial levels.

Ireland's binding energy targets for 2030[22] include the following (these may be revised upwards in 2023):

- Ireland has been assigned a binding target of a 30% reduction in GHG emissions below 2005 levels in the non-ETS sector
- The EU has a binding target to produce at least 32% of total energy consumed from renewable sources
- A headline target of increasing energy efficiency by at least 32.5%

It is now essential that Ireland's efforts are amplified to reach the 2030 targets. Ireland is committed to increasing the share of renewable energy, evident by investment into a variety of renewable technologies and methods. Some technologies, such as wind and solar energy, have achieved a significant level of market penetration to become established concepts for policy makers and the public. This has been possible thanks in part to government subsidies and a degree of public awareness and acceptance.

In contrast, geothermal energy is less familiar and therefore its potential has not been fully recognised when developing energy and climate policy for Ireland. The geothermal sector could serve large parts of the residential and industrial heating needs, however, this will require investment over the immediate to medium term similar to the framework applied to the offshore wind energy sector in Ireland. The technology, regulation and legislation will need to be developed in parallel with policies based on robust scientific and engineering information in the context of existing planning regulations, European directives etc., as with the development of the wind energy sector. A comparable multi-disciplinary approach will be required for geothermal energy[23].

1.4 Benefits of geothermal energy

The sustainability of an energy system is often described in terms of a balance between energy security, energy equity (accessibility and affordability) and environmental sustainability (the "energy trilemma" (Figure 4)[24]. Maintaining this balance in the context of rapid and just transition to decentralised, decarbonised, and digital systems is a challenge. Geothermal energy has the potential to satisfy all dimensions of the energy trilemma, and as such could be a key energy source within Ireland's diversified energy mix as we transition away from fossil fuel domination.

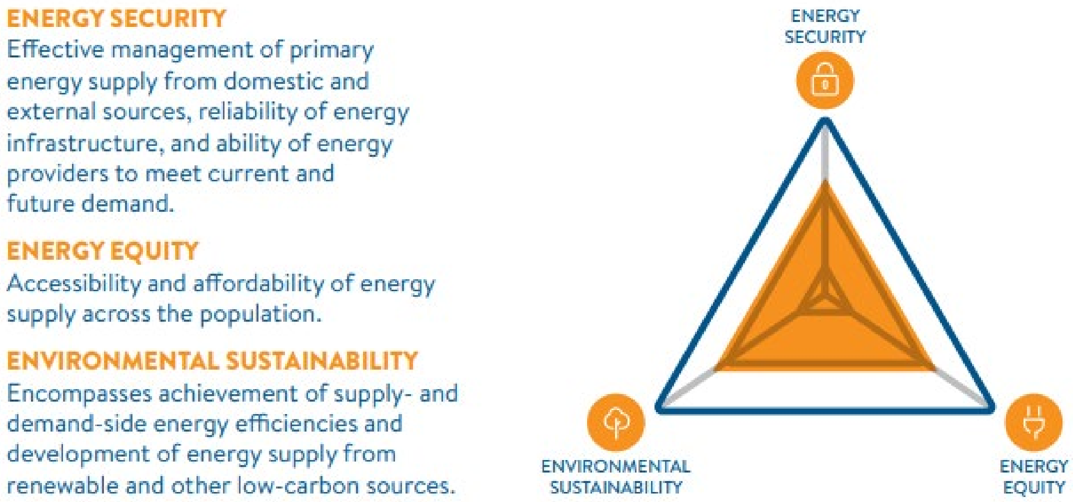

Figure 4: The Energy Trilemma (Source: World Energy Council, 2019[24])

Energy security

Geothermal energy uses a primary resource that is local, constantly available, and not subject to fuel-price fluctuations or weather conditions. This is in contrast to other renewable sources, such as wind and solar, which are dependent on local weather patterns, or bioenergy, which is dependent on fuel supply chains. Geothermal energy provides a practically inexhaustible fuel supply when appropriately managed. When used in a mix of renewable energy sources, as for example in 4th Generation District Heating[25] schemes, the baseload capacities of geothermal energy play a critical role in ensuring the sustainable security of supply of the system. Electrification of our energy system will become increasingly important in the future, and the stable, weather-independent baseload provided by geothermal heat, via Ground Source Heat Pumps (GSHPs), district heating, and perhaps geothermal electricity, will enhance the security of the system. Geothermal DH systems use heat energy directly from source and therefore do not require storage solutions. Geothermal systems can also be used for cooling and to store heat.

Energy equity

Geothermal systems require relatively high capital expenditure (capex) but have very low operating expenditure (opex). The capital investment is also continuously reducing through technological developments. The advantage of low operational costs ensures the cost to the consumer can be low, making it affordable and ideal for municipal housing developments.

The main Capex for space and district heating projects is generated by drilling production and injection wells, down-hole and surface feed pumps, pipelines and distribution grids, monitoring and control equipment, peaking stations, and storage tanks[5]. Drilling costs can account for 30-50% of the total capital costs for a geothermal heat project (up to 70% for electricity), which makes reducing geological uncertainty and drilling costs the most important factor for geothermal energy production to become economically viable. The geothermal industry can benefit from using approaches similar to those used in mining and oil and gas to compile a critical mass of information and data to optimise drilling. The opex consists of electricity for pumping, maintenance, operation and control. The high capex can be offset by the low opex but larger geothermal projects usually requires some form of financial risk management in the form of government subsidies or financial incentives. The payback period can be around 8 years for geoDH schemes[26].

Environmental sustainability

Geothermal energy offers several environmental advantages relative to other energy sources. It is one of the cleanest energy generation technologies, for example, in electricity generation conventional flash geothermal electrical power plants emit just 4% of the sulfur dioxide of conventional coal plants and virtually none of the nitrogen oxides or fine particulate matter[27]. Binary geothermal plants (lower temperature electricity generation) can produce zero emissions if managed properly. In the USA, geothermal electricity annually offsets the equivalent of 22 million tonnes of carbon dioxide, 200,000 tonnes of nitrogen oxide, and 110,000 tonnes of particulate matter from conventional coal-fired plants. At an smaller scale, replacing the need for individual homes to have fossil fuel or solid fuel burning systems also eliminates particulate matter and air pollution and improves air quality.

In the heat sector, geothermal heating schemes (GSHP and geoDH) usually use lower temperature resources than geothermal electricity projects, and are essentially zero-emission at source. The majority of carbon emissions for geothermal projects are generated through the construction and installation of the plant. The electricity required for pumping may also be a source of emissions (if not from a clean, renewable source). Even so, geoDH schemes emit just 7% of the carbon emissions of an equivalent gas-fired boiler[28]).

The land footprint required by geothermal projects is considerably smaller than other renewable energy technologies (Figure 5) and the audiovisual impacts of operational geothermal systems are negligible. For 'open' systems (i.e., those extracting hot water from the ground and reinjecting cool water), good aquifer management is essential. For 'closed' systems, fluids are pumped through closed pipes in heated rock, therefore there is no direct contact between the fluids and the rocks or surrounding ecosystem.

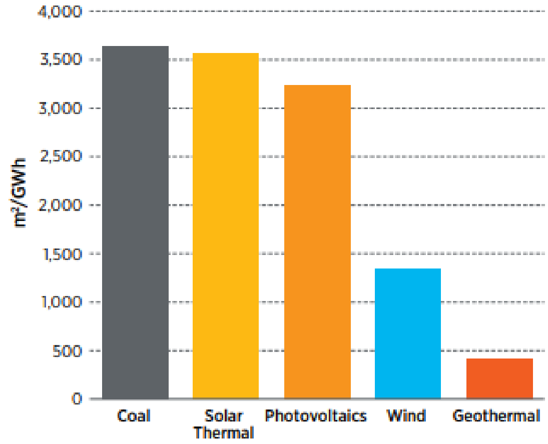

Figure 5 Land footprint by gigawatt hours of electricity (GWhe) for various electricity-generation technologies. (Source: US Dept. of Energy 2019[27] (after Kagel et al. 2007)). *[Coal includes mining, Photovoltaics assumes central station photovoltaic projects, not roofing systems. Wind reflects land occupied by turbines and service roads]*

Case Study: Geothermal District Heating in the Paris Basin, France[29]

Operations commenced:	1970s. Currently rehabilitating old wells and extending their lifespan[30].
Geothermal setting:	Low-medium enthalpy hydrothermal system.
Reservoir:	Jurassic Dogger Limestone
Depth of reservoir:	1.5 – 2 km
Reservoir temperatures:	55 – 85 ^{o}C
Number of installations:	Approx. 40 doublets[31]
Capital investment per installation:	Approx. €10 – 15 million[32] for geothermal wells and plant
Households served:	187,000
Total heat output:	240 MWth[33]
Carbon saved:	240,000 tonnes CO_2 per annum[34]
Carbon saved per household:	1.3 tonnes CO_2 per annum

Case study: Potential carbon savings for Irish geoDH in South County Dublin

Codema, with input from GSI, recently conducted an analysis of the potential for geothermal district heating in South County Dublin as part of the HeatNet project[1]. Through a high-level analysis it was estimated that between 80 and 400 MWth of heat could be provided by 28 geothermal doublets in the limestone reservoir of the Dublin Basin (South Dublin County area). These figures are based on the promising geothermal conditions discovered at Newcastle, Co. Dublin by GT Energy in 2008. Using carbon savings figures (when compared to natural gas) from comparable geoDH schemes in the Paris Basin, France, a geothermal heating capacity of between 80 and 400 MWth could represent carbon savings of between 80,000 and 400,000 tonnes CO_2 *per annum (or between 2,800 and 14,300 tonnes* CO_2 *per annum per doublet). In the French examples, carbon savings per household of 1.3 tonnes* CO_2 *per annum are achieved.*

2 What is Geothermal Energy?

Geothermal energy is a commercially proven and renewable form of energy that can be used for heating, electricity production, or for both heat and power generation combined. The EU defines geothermal energy as "energy stored in the form of heat beneath the surface of solid Earth"[35]. In general, heat flows outwards from the centre of the Earth, and the temperature (and the amount of available energy) increases with depth at an average rate of 25 to 30 °C per kilometre for most places in the world. Heat flow is highest in volcanic regions, i.e., at tectonic plate boundaries (Figure 6) and traditional exploitation of geothermal resources has occurred in these areas where the heat is easily accessible (e.g., Iceland, Italy, New Zealand). Advances in technology over the past century have led to the development of geothermal resources for heating and/or electricity production away from these plate margins in places where the heat flow is not particularly elevated (e.g., France, Netherlands, Belgium, UK, Germany) and geothermal energy could be a viable, significant source of energy in Ireland.

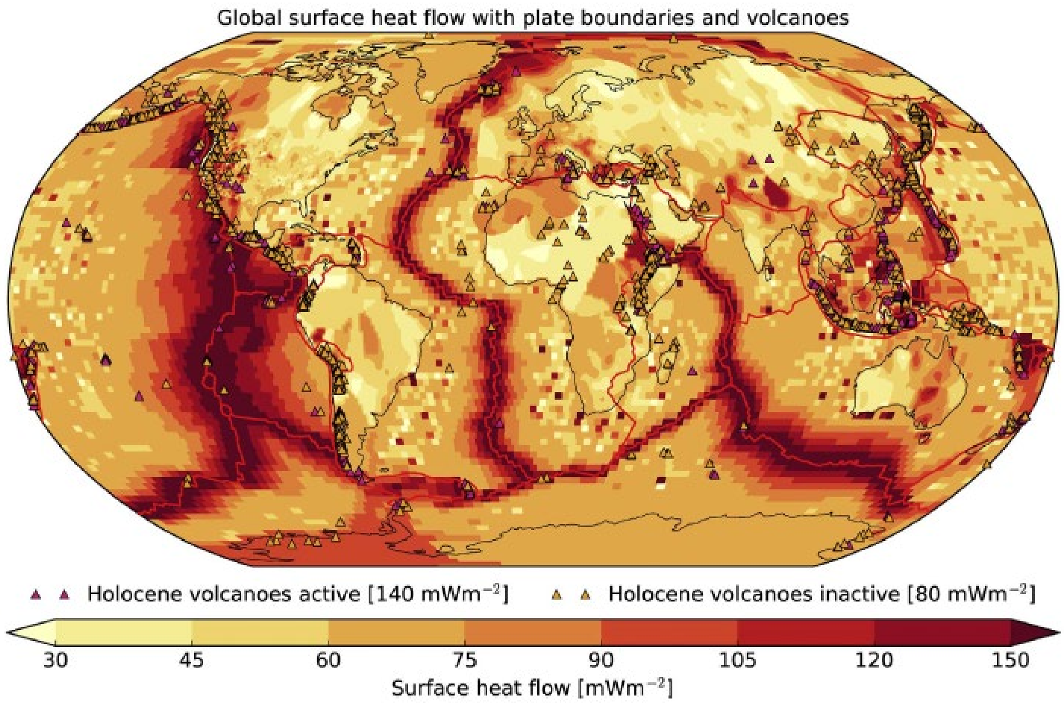

Figure 6 Global surface heat flow. (Source: Limberger et al., 2018[36]).

Geothermal energy can be exploited by a range of different technologies depending on the nature of the resource, the intended use and the amount of heat required (Figure 7). Some degree of drilling is usually required to access geothermal areas of suitable temperature. The exploitation of geothermal resources is usually termed as either direct use (taking energy directly from geothermal fluids[37] such as pore waters for space heating, cooling, balneology or industrial applications) or indirect use (converting heat from geothermal fluids into electricity or for adsorption cooling systems.) Geothermal resources are commonly categorized as either "shallow" or "deep" in the literature; however, a distinction based on depth alone is rather arbitrary and can lead to confusion.

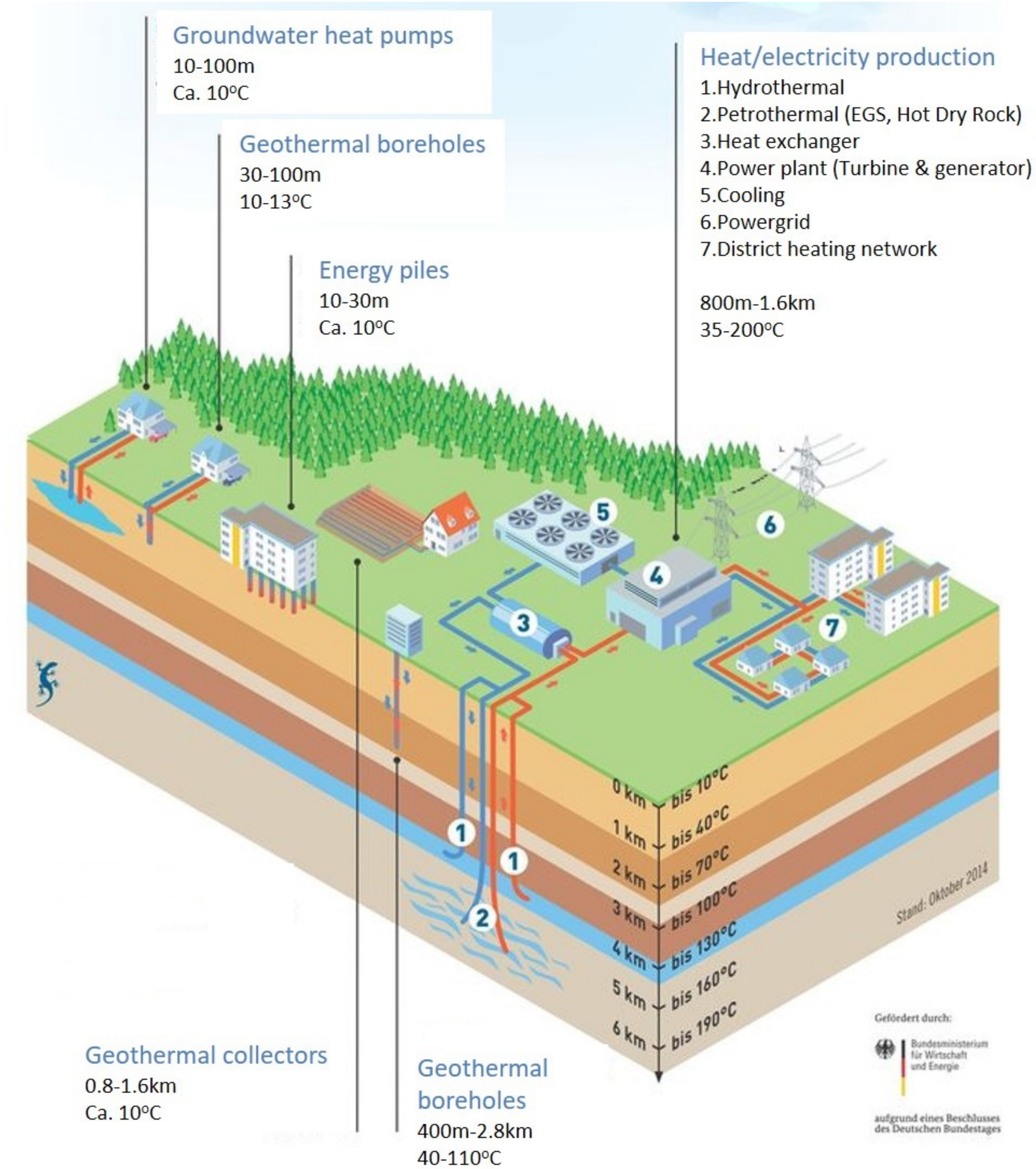

Figure 7 Some common geothermal technologies for heat and power production. (Source: TIGER project, Munich School of Engineering, Munich[38])

2.1 Global geothermal use

Geothermal energy in its most accessible form flows from the surface of the Earth via thermal springs. Possibly the earliest geothermal district heating network was developed in France in the 14th century to use thermal springs to heat the village of Chaudes-Aigues[39]. In the 19th and early 20th centuries, several countries such as Italy, Iceland and the USA began to use geothermal heat for large-scale direct use applications. Geothermal district heating was enthusiastically adopted in France in the 1960s, and increased in popularity in Europe after the oil crisis of 1973. Technological advances coupled with a drive for renewable energy sources have increased the global popularity of low-temperature geothermal heat pumps for residential use since the 1990s.

In the early 20th century, Italy began to use geothermal energy for large-scale electricity production. In 1958, New Zealand became the next country to generate geothermal electricity, followed by the USA in 1960. Significant technological developments and the invention of the binary cycle power plant[40] in the USSR in 1967 have meant that geothermal fluids with much lower temperatures (c. 120°C) can now be used to generate electricity, and geothermal power production is no longer limited to areas with traditional high temperature resources. Improvements in drilling technologies and the use of reservoir imaging techniques (many of which have been adopted from the petroleum industry) have meant that ever-lower temperatures are now economically feasible geothermal resources in heating and power projects around the world. The fast development of global geothermal resources in the 21st century has occurred in response to policy-driven pursuit of secure and renewable energy sources to combat the effects of climate change.

2.2 Classification and applications of geothermal resources

Geothermal resources are commonly described and categorised in terms of depth ("shallow" or "deep") and/or temperature. A more precise way to categorise geothermal resources is by the enthalpy, or total heat content, of the system. Until recently, using this terminology, traditional volcanic geothermal systems have been termed high enthalpy, and any other systems termed low enthalpy. Current uses of geothermal energy encompass very low enthalpy, mid enthalpy, and super critical resources[41]. There are a range of engineering methods used to extract and utilise geothermal energy from each of the different resource classes, depending largely upon the temperature and depth of the resource being targeted (Figure 7). The geothermal reservoir potential of the subsurface is dependent not only on finding an appropriate temperature at an economically accessible depth, but also on the permeability of the rock (a measure of how easily fluid can move through the rock and therefore how easily heat can move in the subsurface). Hydrothermal reservoirs are those where sufficient natural permeability can be found. Permeability can also be artificially created or enhanced through (hydraulic) stimulation of the rock. Geothermal systems that utilise artificial permeability are termed Enhanced Geothermal Systems (EGS) in the USA or are often referred to as Hot Dry Rock in the EU (e.g., Soultz-sous-Forêts, France).

Geothermal energy is currently used around the world for a diverse range of applications involving i) heating (and cooling) at various scales, and/or (ii) electricity production and cooling. Several of these applications are discussed in the boxes below, along with their relevance for the Irish geothermal setting. In general, as the upfront drilling costs are significant in geothermal projects, the most efficient application of geothermal energy occurs when several uses for fluids of decreasing temperatures can be combined in the same area. This "cascade" principle is demonstrated in the Koekoekspolder project[42] in the Netherlands, where seven neighbouring horticulturalists have pooled resources to drill a geothermal doublet (a pair of wells, one to extract hot water, the other to return cooled water underground) for heating greenhouses with differing heat requirements.

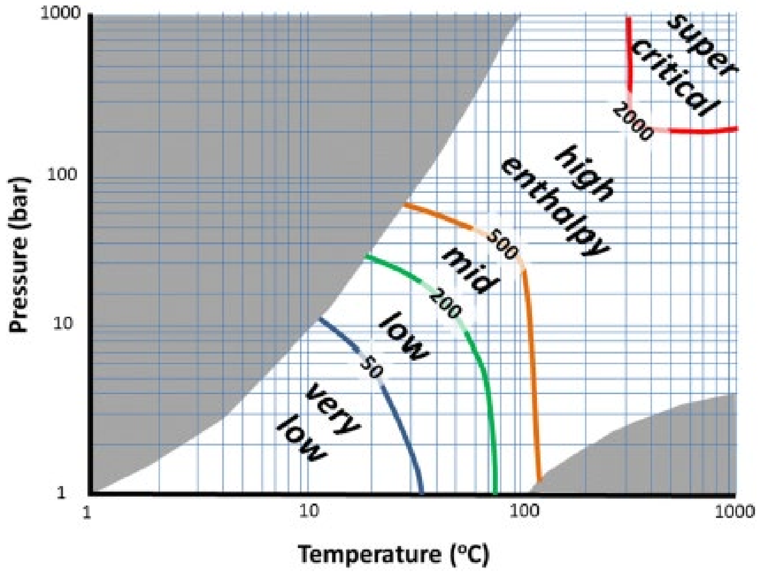

Figure 8 Categorisation of geothermal resources on the basis of enthalpy. The grey shaded areas represent conditions that do not occur in nature. The numbers on the red, orange, green and blue lines dividing the categories are approximate values of enthalpy (kJ/kg). (Source: Younger, 2015[41])

2.2.1 Very low enthalpy resources

The shallow layers of soil and rock beneath the Earth's surface can efficiently store and transmit heat flowing from deep inside the Earth, but also heat that comes from the Sun. Very low enthalpy systems generally only heat a single small building and are not used for district heating purposes. Groundwater and soil temperatures are relatively constant all year round, and typically range from 9.5 to 11.5 °C in Ireland near the surface[43]. These low temperature resources can be used alongside a heat pump for geothermal space heating and cooling; GSHPs are very efficient due to the stable nature of the heat source, and out-perform other ambient-source heat pumps (e.g., air source) in this regard[44]. Depending on the subsurface conditions, the heat is abstracted from the subsurface using either an open-loop or closed-loop collector (Figure 9). In very general terms, an open loop system is more appropriate where there is a plentiful flow of groundwater through the bedrock or soil, and a closed loop system is more suitable where the bedrock or soil is impermeable and relatively dry.

Uses:

Heat and hot water – domestic buildings

Low temperature, shallow geothermal resources are available everywhere in Ireland. They can be exploited in conjunction with a heat pump (GSHP), and the stability of the subsurface temperatures results in highly efficient, low-carbon and economical heating schemes. The use of heat pumps for individual dwellings is recognised as the best way to decarbonise the heat sector in rural areas where there is low density housing and low heat demand, and GSHPs represent the lowest-carbon option for a heat pump.

Recreation

Geothermal waters at a variety of different temperatures have been used throughout human history for bathing and recreation. The use of geothermal waters for balneotherapy is a major tourist industry in many parts of Europe, e.g., Italy, Austria, Germany, Czech Republic and Hungary. In Ireland, the only example of a thermal spring being used for geothermal energy purposes is Lady's Well in Mallow, Co. Cork. There, waters of approximately 21 ^{0}C are used to heat a public swimming pool.

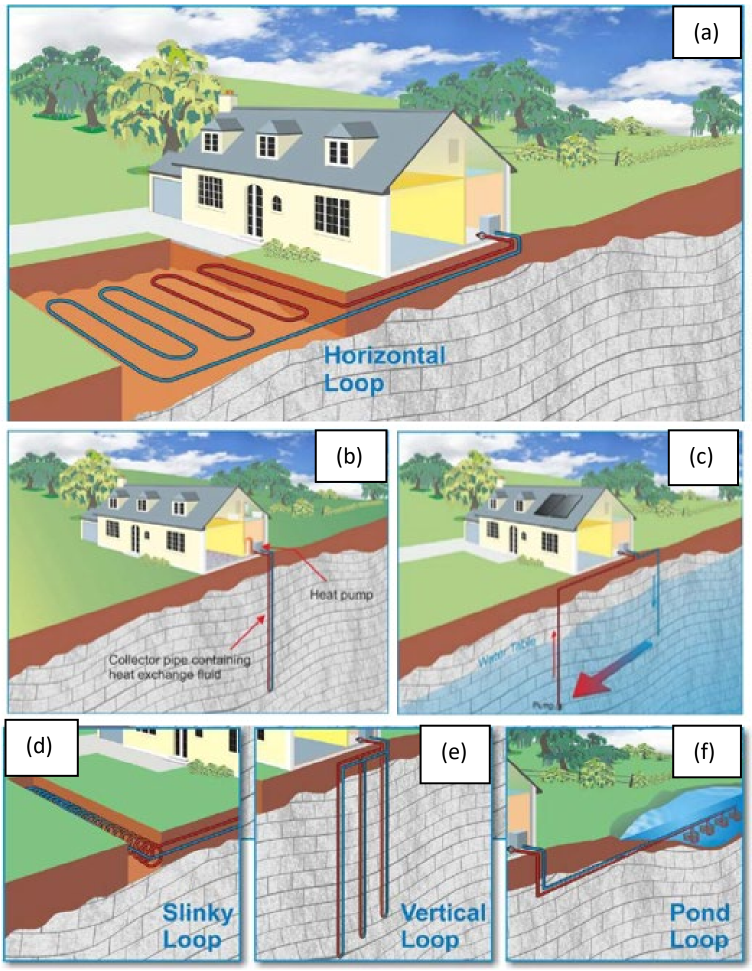

Figure 9 Simple, small scale, closed loop (a, b, d and e) and open loop (c and f) geothermal systems – some of these can be scaled up to supply multiple systems and district heating networks. Systems may include directional drilling i.e. both wells are located together at the surface but at depth may be significantly deviated (e.g. Paris Basin doublets). Vertical systems for large scale or high temperature systems may reach depths >5km (Source: GSI[44]).

2.2.2 Low enthalpy resources

These resources have temperatures in the range of 30°C to 80 °C. Traditionally the term implied the direct use of accessible thermal waters (at or close to the surface, e.g., thermal springs) for heating or recreational purposes. This category includes low temperature fluids used for geothermal district heating (Figure 10), with or without a heat pump[45]. These fluids can be found in intra-continental plate settings such as Ireland, which are far from tectonic plate boundaries, simply by drilling deeper into the crust. Given an average geothermal gradient of 25 to 30 °C per km, geothermal boreholes for district heating or large industrial heat demands will usually reach depths in excess of 1.5 km. Open loop doublets (a pair of wells) are usually used for these systems, although deep closed loop systems (deep geothermal single wells, DGSWs[46]) are also possible and may provide additional environmental benefits in certain situations[47]. In a typical open loop configuration, warm water is abstracted from one well, run through the heating network, and then re-injected through the other borehole at a sufficient rate to preserve pressure in the aquifer (this is important to avoid unwanted stress and strain on the bedrock, which could result in seismicity).

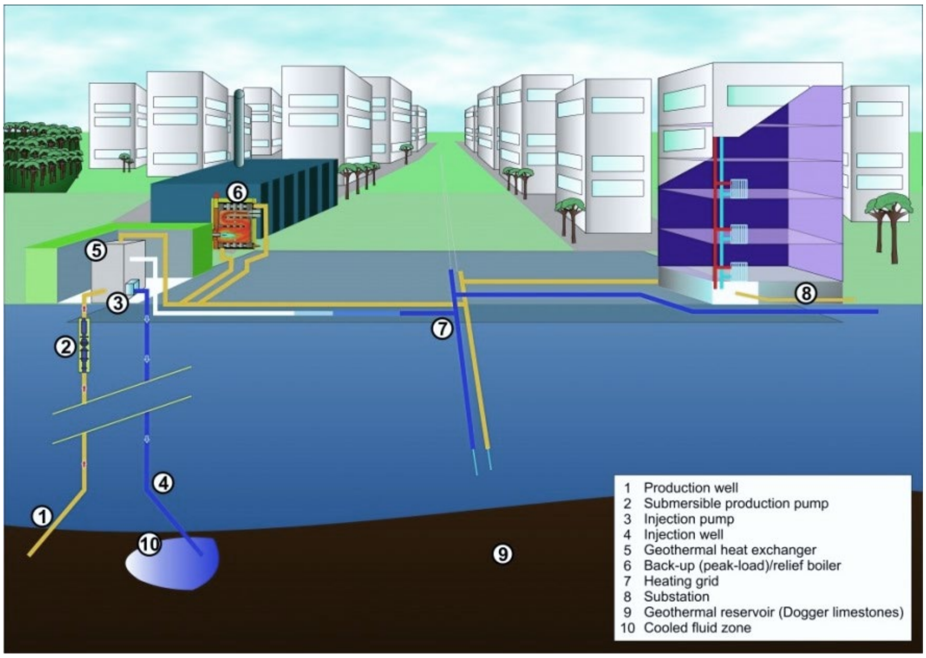

Figure 10 Schematic diagram of a geothermal district heating network e.g. in the Paris Basin, France. Doublets in this region are commonly 2 km deep and abstract waters with temperatures of approximately 70-80 °C. (Source: GeoDH project[48])

Uses:

District Heating

Low enthalpy geothermal district heating is in operation in many locations worldwide. More than 250 geothermal district heating systems were in operation in Europe in 2015, with a total installed capacity of 4,700 MWth. These included; Paris, France, where water between 57^{o} and 85 ^{o}C is abstracted from depths of between 1.5 and 2 km depth, and Southampton, UK where brine with a temperature of 76^{o}C rises naturally from a depth of 1.8 km to 100 m below the surface. Geothermal energy can also be used in a mix of energy sources in district heating schemes. Progressive efficiency improvements in district heating technology towards 4th Generation District Heating has meant that lower temperature inputs are acceptable. This is creating opportunities for geoDH in more regions with lower enthalpy resources, such as Ireland. Studies in South County Dublin have shown that geothermal fluid temperatures in excess of 60 ^{o}C are likely to be achieved at depths of 2.5 km, and such temperatures would enable geoDH to proceed without the use of a heat pump.

Agriculture, food production and food and beverage processing

At very low temperatures, geothermal heat can be used for aquaculture (e.g., Huka Prawn Park, Taupo, New Zealand) and soil warming. Geothermal heating can be effectively used for traditionally energy-intensive horticultural operations such as heating greenhouses to grow fruit, vegetables, flowers (e.g., Slovenia; the Netherlands) and mushrooms (e.g., Oregon, USA). Geothermal heat is used to brew beer in Reykjavik, Iceland and Colorado, USA. Geothermal heat can also be used to dry agricultural products, e.g., tomatoes, chillies, rice, cotton, timber, etc. Dairy processing requires large amounts of energy for heating and cooling, and geothermal energy can be successfully used for processes such as milk pasteurization (e.g., Oregon, USA), and cheese maturation and storage (near Lardarello, Italy).

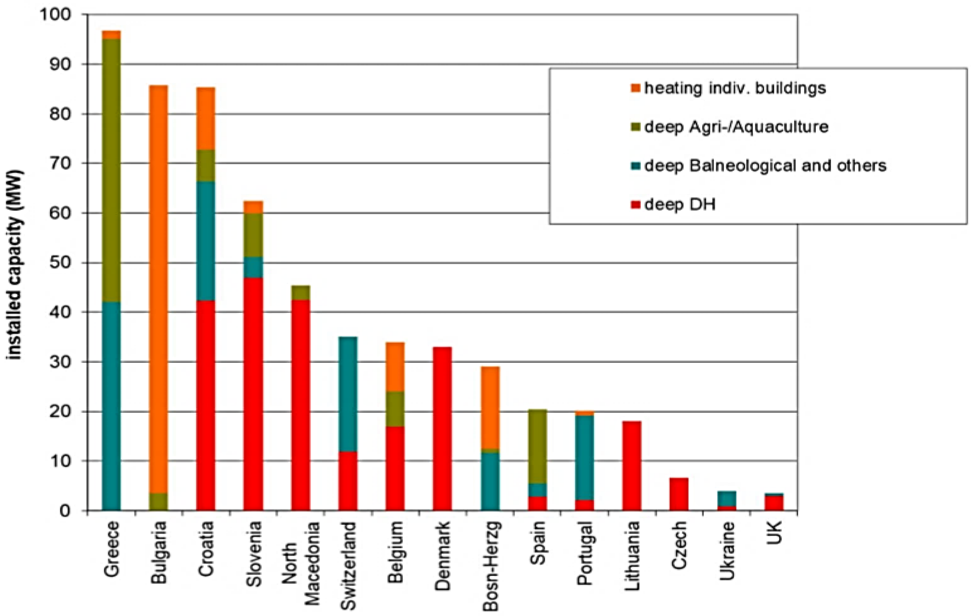

Figure 11 Visualisation of data on installed geothermal capacity and end use, EU countries with capacity <100 MW (after Scanner, 2019[49])

2.2.3 Mid enthalpy resources

These resources have temperatures of approximately 80° to 120 °C, and may be used for heating, electricity production or combined heat and power (CHP). Binary power plants are necessary to produce electricity from fluids with these temperatures. Away from tectonic plate boundaries, these resources may be found by drilling to a depth of several kilometres. Mid enthalpy resources can be found in several geological settings and reservoir types.

Mid-enthalpy temperatures in excess of 100 °C can also be used for indirect cooling when geothermal fluids abstracted from depth are used to evaporate a brine solution in the building's cooling system (within a closed network of pipes). This evaporate absorbs the ambient heat and returns to liquid brine which is then liquid distilled and the heat extracted on site. The waste heat is then expelled (this can be used as an indirect heat source for local district heating systems). The key advantage of this system is that electrical energy and fan systems are not required, considerably reducing energy consumption and noise. This system can be used in facilities with high cooling needs, such as data centres.

Industrial drying processes

Geothermal heat can be used for several energy intensive industrial processes. The drying of wood and plant fibre products (timber, paper, fuel pellets, cotton, fabrics) requires input temperatures of 70° to 150 °C (Figure 12). and so requires mid to high enthalpy geothermal resources. Cement and aggregate drying can also be achieved with geothermal energy, but again requires high input temperatures in excess of around 120 °C. The drying of cement blocks and building materials requires lower input temperatures of around 70 °C, so these kinds of applications may be more suitable for Ireland's low enthalpy geothermal resources. In this way geothermal energy could help to reduce the carbon footprint of Ireland's quarrying and construction material industries.

Industrial cooling

Geothermal energy can be used for cooling in two ways. For direct use systems, cold water can be extracted from surface/subsurface and pumped through cooling systems. Warmed waters are then reinjected (either directly or once cooled). Direct use systems are generally used with electrical cooling systems. Alternatively, indirect systems (adsorption cooling) using geothermal heat can provide large-scale or high demand cooling.

2.2.4 High enthalpy and supercritical resources

High enthalpy refers to resources used traditionally for geothermal electricity production. These resources have fluids (water or steam) with temperatures of between 120° and 300 °C that can be used in conventional geothermal steam plants to produce electricity and for cooling. At the lower end of the high enthalpy temperature scale, technological advances in using intermediate temperature (110 – 160°C) groundwaters in binary-cycle power-plants[50] provide real potential for electricity generation within the range of geothermal gradients observed in Ireland, provided deep (>3 km) source regions can be identified.

Supercritical (very high-temperature) geothermal systems are generally located at depths in the crust where the reservoir fluid is assumed to be in the supercritical state; for pure water this means a temperature in excess of 374°C and pressure of 221 bar. These conditions are often found at the roots of volcanic systems. Ireland does not have supercritical geothermal systems.

Uses:

Electricity generation

Geothermal electricity is traditionally produced where very hot hydrothermal fluids (in excess of 150°C) are found close to the surface. However, improvements in binary cycle power plants have meant that lower input temperatures can also be used for electricity production, with reported temperatures of 57°C used to produce geothermal electricity at Chena Hot Springs in Alaska, US being the lowest ever recorded input temperatures. EGS technology can create and enhance permeability within the subsurface, and geothermal resources may be accessed at depths up to 6 km with existing drilling technology (e.g. in Finland). These technological developments have enabled viable geothermal electricity production in low- to medium-enthalpy areas suited for EGS, such as the demonstration projects that are now operational in Landau, Germany and Soultz sous Forets, France.

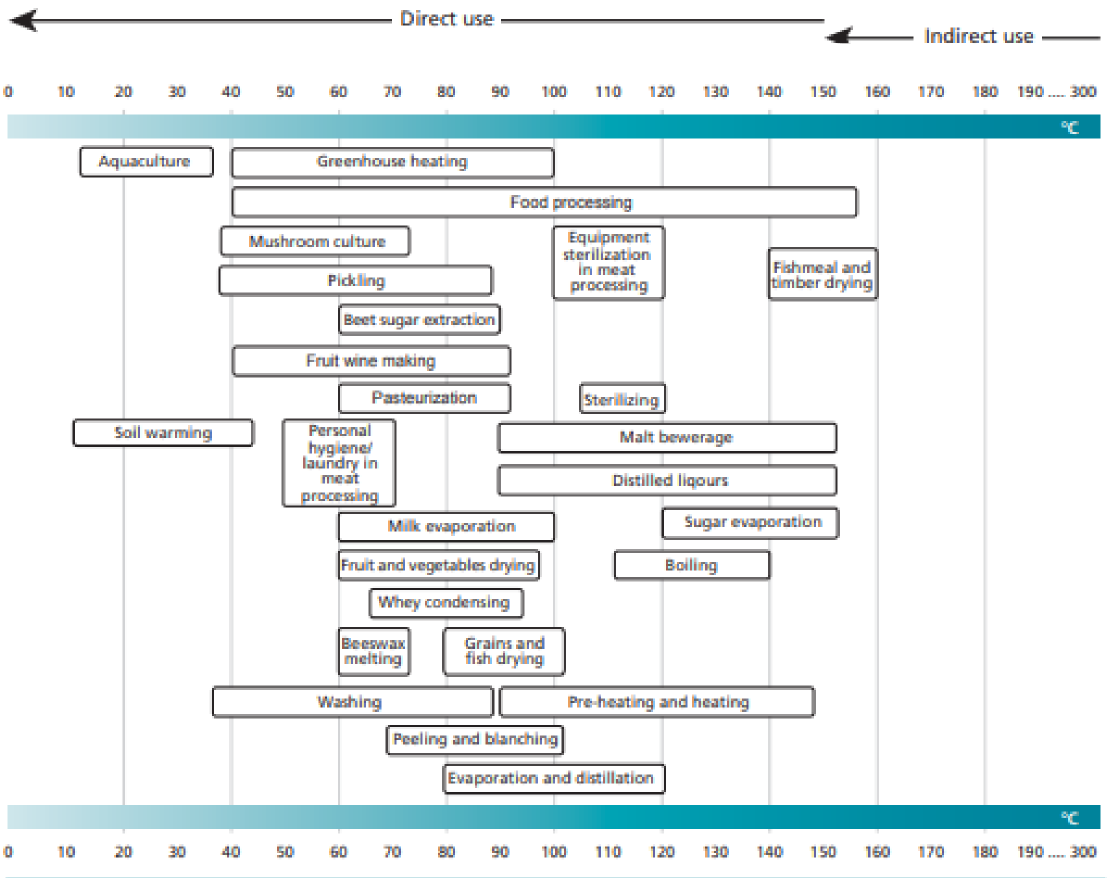

Figure 12 Geothermal applications in the food, agricultural and industrial sectors. (After Van Nguyen et al., 2015[51]).

2.2.5 Additional value streams

Geothermal energy has been proven to provide environmental and economic value in addition to the heat and electricity applications discussed above. For example, hot fluids processed through geothermal electricity production plants could contain economic quantities of dissolved minerals and metals, which could be extracted at a profit under appropriate market conditions. This is currently being investigated for European targets under the EU H2020 project CHPM30[52] ("combined heat power and metal extraction"). Closed-circuit metal extraction like this will generate much less environmental impact than traditional surface or underground mining operations, examples include USA where zinc is extracted in economic amounts[53].

The use of geothermal resources in tandem with other renewable energy sources, such as solar photovoltaics or wind energy, has the potential to optimise the combined environmental and economic attributes of multiple technologies at once. This is largely due to geothermal energy's "always on" status and baseload provision capabilities, where other energy sources are more reliant on external environmental conditions to operate.

3 Geothermal energy potential in Ireland

3.1 Key research to date

Irish geothermal resources have been the subject of several studies since the late 1970s after the oil crisis of 1973 prompted an interest in geothermal energy across Europe. Several studies in the 1980s focussed on Irish thermal springs, and three geothermal exploration holes funded by the EU were drilled[54]. Only one of these sites in Mallow, Co. Cork was developed as a low-temperature geothermal resource (hydrothermal waters from this system are still used today to heat a public swimming pool). Falling oil prices later removed the economic driver for research and development of Irish geothermal resources.

A renewed interest in geothermal energy resources in the late 1990s and early 2000s was precipitated by a transforming Irish energy sector and increased investment in renewable energy technologies. Public funding for geothermal research was made available by Sustainable Energy Ireland (now SEAI) and resulted in the "Geothermal Energy Resource Map of Ireland"[55], a broad assessment of Irish geothermal resources. A series of maps of geothermal parameters were produced for this report, based upon available but very limited data (Figure 13). The lack of quality data has resulted in an overly pessimistic picture of crustal temperatures, particularly in the south of the country where temperatures at a depth of 2.5 km were thought to be around 20 °C. These models and maps have since been included in many subsequent national and EU-level studies since 2004 (e.g., the GeoElec project, 2012[56]; the GeoDH project, 2014[57]; and even the very recent Irish Heat Atlas, 2019[58], have all used data from the 2004 SEI report). **GSI, in collaboration with external researchers, is currently updating these temperature estimates and maps to incorporate more recent research**.

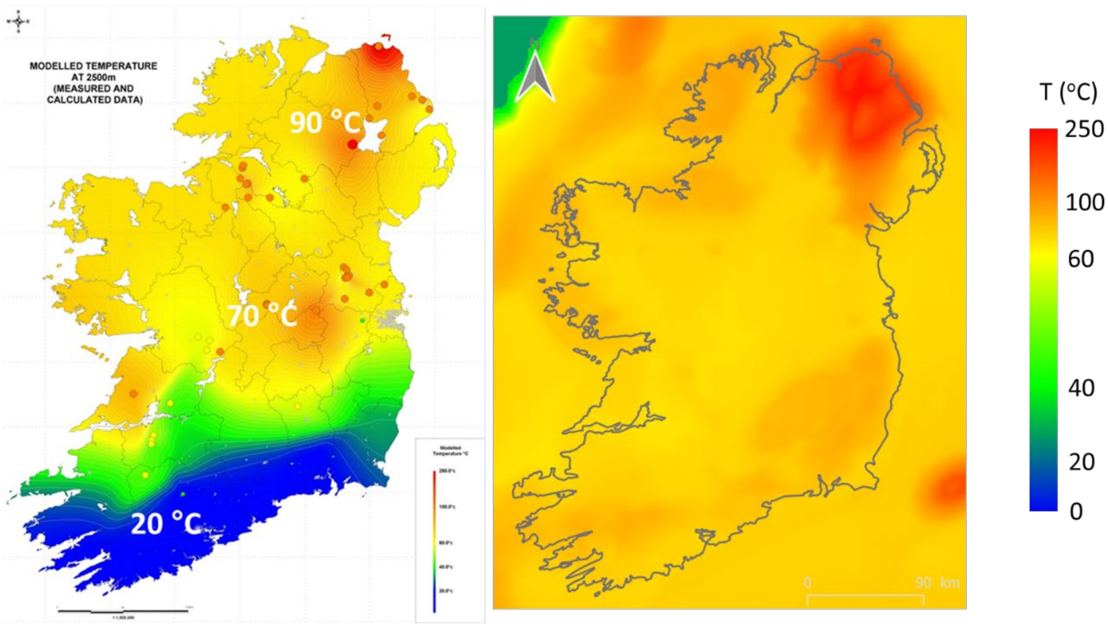

Figure 13 Left: 2004 Geothermal Energy Resource Map of Ireland with interpolated crustal temperatures at 2.5 km depth. The estimated temperatures are cool due to few data points. Right: Revised map including additional data and palaeoclimate corrections (Source: B. Mather, G.O.Therm3D project, 2019 [71)].

In the past decade, there has been a resurgence of interest in geothermal resources in the EU in response to two main drivers: 1) energy security issues raised by the gas crisis of 2009; and 2) increasing societal and political pressure to decarbonise the energy system in response to climate change[59]. As a result, public funding available at EU and Member State level for geothermal research and development and increased. This has been reflected in an increase in geothermal research activity in Ireland since approximately 2010. In 2011, SEAI funded an assessment of Ireland's geothermal resources in the frame of a hydrocarbon play fairway analysis[60], which also demonstrated a useful cross-over of methodologies, knowledge and skills from the petroleum exploration industry. This national-scale analysis found the greatest geothermal potential in sedimentary basins in the north-east, centre-east and south-west of Ireland, where the appropriate configuration of source, reservoir and cap rocks were identified (Figure 14). Buried granites were also highlighted as a potential geothermal heat source, and major structural zones as thermal fluid migration pathways.

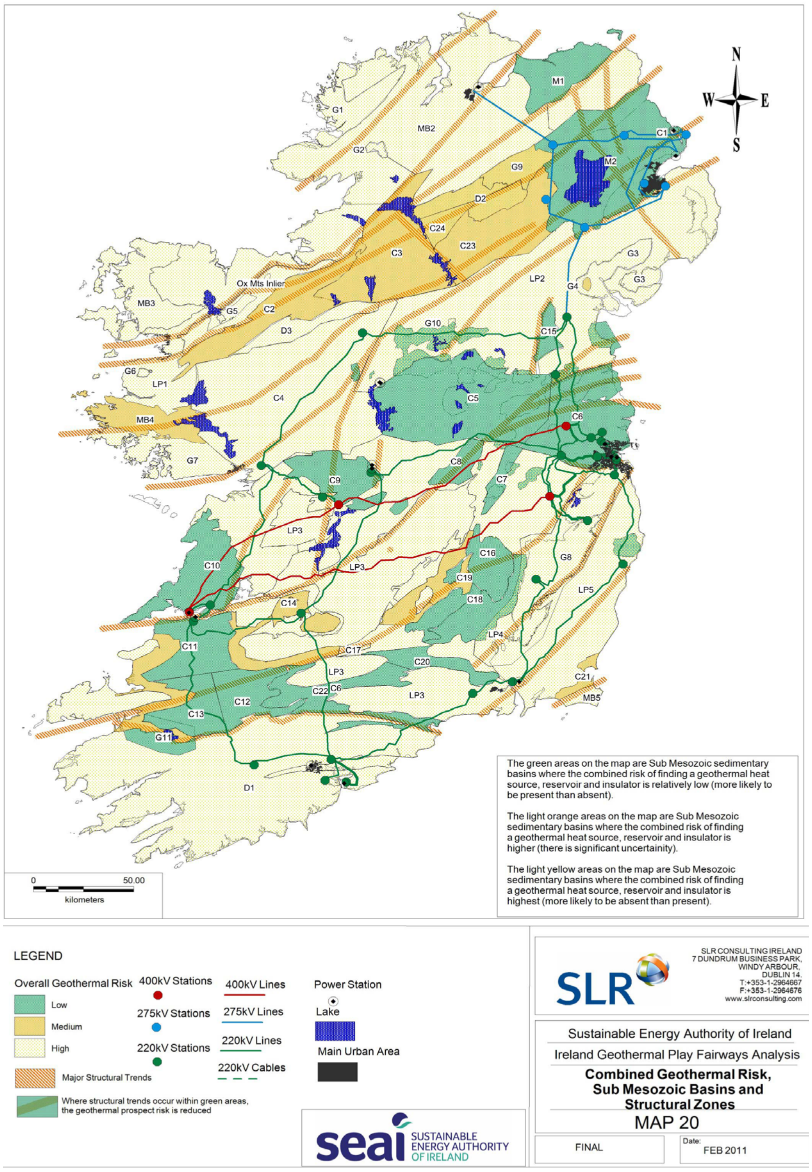

Figure 14 SLR Play Fairways analysis map, 2011[61]

In 2011, Science Foundation Ireland funded the IRETHERM project, a large multi-disciplinary academic research project. IRETHERM brought together academic, government and industry participants between 2011 and 2016 to characterise targeted geothermal reservoirs in Ireland using primarily geophysical and geochemical methods[62]. The IRETHERM project was featured in the government's Ireland's Transition to a Low Carbon Energy Future of 2015[20] The results presented further geophysical evidence for the geothermal potential (deep sandstone reservoirs in Northern Ireland, alongside fractured bedrock targets in the midlands and East of the country) whilst also testing and demonstrating geophysical exploration methods for geothermal resources.

During the past decades, GSI has actively promoted and supported research into Irish geothermal resources, commencing with a project to assist the uptake of low-temperature geothermal heat for home-heating applications. A suite of national geothermal site suitability maps were launched and an accompanying homeowners' manual was published to help the public with the decision to purchase and install a domestic GSHP systems[44]. The project also developed a voluntary database of geothermal heat installations and draft best practise guidelines for installers of these systems.

3.2 Current GSI research

Since 2015, GSI has actively promoted geothermal academic and industrial research and development through the GSI Research Programme. Several geothermal-focussed projects have been funded under the GSI Short Call programme (small-scale projects), and others have been co-funded with partners such as the Irish Research Council, SEAI, and the Geothermica ERA-Net[63]. These project have further developed databases of Irish geothermal parameters and improved our knowledge of the subsurface (e.g., Irish Soils Thermal Conductivity project; Palaeokarst database; G.O.Therm3D[64]). Other research has examined public attitudes to geothermal heating[65] and developed new exploration mathods. Ongoing Irish geothermal research supported by GSI includes:

- 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.

Since 2018 GSI researchers have been directly active in two geothermal ERA-NET (European Research Area Networks) projects;

- Hotlime – this project will map and assess geothermal plays in deep carbonate rocks.
- MUSE - Managing Urban Shallow geothermal Energy. This project is investigating resources and possible conflicts of use associated with the use of shallow geothermal energy in European urban areas

Case study: Hotlime project (2018 – 2022)
Hydrothermal systems in deep carbonate bedrock are among the most promising low enthalpy geothermal plays across Europe. Most deep carbonate bedrock has received relatively little attention, because such rocks are perceived as 'tight'. In order to de-risk these challenging geothermal plays, it is crucial to improve our understanding of geological conditions that determine the distribution and technical recoverability of their geothermal resources. This project is focussed on identifying the generic structural controls in deep carbonate formations, as these control the reservoir potential of deep carbonate reservoirs. GSI has identified two target areas (the Dublin basin and the Lough Allen (Northwest Carboniferous) basin that have been modelled in 3D. Preliminary thermal modelling and "heat in place" estimates of heat in the Dublin basin and the Lough Allen basin is currently underway. ("Heat in place" estimates the total amount of heat present in the basin, and does not take into account how much of that heat might be technically recoverable.)

3.3 Current understanding of Irish geothermal resources

It is clear from research conducted to date that there is significant potential for the increased development of geothermal resources in Ireland. Recent research publications have shown that resources suitable for district heating, commercial and municipal applications[66] are most likely to be found in the deeper parts of the Carboniferous basins in the East, Midlands and Southwest of Ireland.

The southern margin of the Dublin Basin has been explored during feasibility projects in Newcastle, Co. Dublin [67] and the GeoUrban project[68]. Two specific geothermal boreholes were drilled to a depth of 1,400 m in Newcastle 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. The area surrounding Navan in Co. Meath is also identified as having recognised potential for geothermal district heating[69] (the geothermal resources beneath Navan, Co. Meath are relatively well understood as a result of decades of mining operations in the area). This potential was the subject of a proposal in 2013 by Navan Chamber of Commerce to drill a 4.5 km borehole to provide 20 MW of electricity to the national grid, along with district heating to the town. In Northern Ireland, deep sandstone reservoirs in Co. Antrim appear most promising for hydrothermal resources, with some of the highest recorded geothermal gradients and recorded subsurface temperatures (a potential gradient of 35 ^{0}C per km). This gradient is attributed to crustal thinning to the north of the Iapetus Suture Zone as evidenced by the Antrim flood basalts[70].

New 3-D thermal models of the Irish crust from the Go.Therm3D project[71] have indicated that the deep subsurface temperature distribution (> 2,000 m) in the south of the country is probably very different, and much hotter than previously thought (Figure 13). This study jointly modelled regional geology, thermal conductivity, heat production rates, geophysical data, and surface heat flow data to generate a 3-D temperature model of the Irish crust. Importantly, the existing heat flow data was corrected for palaeoclimate effects prior to modelling. The resulting model shows higher temperatures at depth in the southeast and southwest of Ireland than in the midlands (Figure 14). This new model could indicate the presence of deep untapped reservoirs of geothermal heat in Wicklow, Wexford, Waterford and Cork. More deep subsurface data is needed to ground-truth this and future thermal models of the Irish crust.

To improve our understanding of the subsurface and to facilitate geothermal energy development, 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.

3.4 Current usage of geothermal energy in Ireland

It is evident from research to date that Ireland has significant geothermal energy resources that are underutilised. Geothermal heat has the potential to contribute to the decarbonisation of Ireland's heat sector, and offers unique benefits compared to other renewable options in terms of baseload provision (energy stability) and security of supply. Ireland's higher-temperature geothermal resources (obtained by drilling deeper into the crust) could also decarbonise domestic electricity production in the future. Geothermal energy in Ireland is primarily used to heat individual residences or commercial buildings (e.g., 1.5 MWth installed at IKEA, Co. Dublin[72]). There were an estimated 1,805 domestic ground source heat pump installations in Ireland in 2018, plus at least 87 commercial installations for a total energy production of about 260 GWh/yr[73]. District heating in Ireland is estimated to contribute less than 0.8% of the total final thermal demand in Ireland, and serves less than 1,200 people74. There are currently no geoDH projects in operation in Ireland.

3.5 Legislation governing geothermal energy in Ireland

Ireland has no specific legislation covering geothermal energy beyond a definition of "geothermal energy" as "energy stored in the form of heat beneath the surface of solid earth" in Statutory Instrument No. 147 of 2011 (European Communities (Renewable Energy) Regulations), which gives effect to some provisions of EU Directive 2009/28/EC (on the promotion of the use of energy from renewable sources), and the classification of geothermal energy as a renewable energy source in regulations that implement the EU Energy Performance of Buildings Directive (recast) (Directive EU 2018/844).

Ownership of geothermal energy has not been clarified. There is no process for licencing the exploration for, or development and production of, geothermal energy resources. There is no mandatory national or local reporting on geothermal projects beyond requirements under existing environmental and planning regulations.

A draft Geothermal Energy Development Bill was submitted to the government in July 2010 and referred to the Office of the Attorney General and the Parliamentary Counsel, in response to an action item in the 2010 National Renewable Energy Action Plan. The bill was not introduced in the Dáil and the text is not publicly available. One of the action items listed in Ireland's Transition to a Low Carbon Energy Future (2015) is to "Establish a regulatory framework to facilitate the exploration for, and development of, geothermal energy resources" but the framework has not yet been drafted.

While the lack of geothermal legislation does not necessarily preclude exploration for, or development of, geothermal energy, it does increase the level of risk and uncertainty for projects and potential investors (including local authorities/municipal users). Having a regulatory framework for geothermal energy would help to attract interest in developing geothermal energy for all uses, including district heating. The Irish-led GeoThermal Regulations – Heat (GTR-H) [75] project made a series of recommendations in 2009 regarding the licensing and regulation of subsurface geothermal resources. This document requires updating, however some recommendations remain valid.

Other legislation, regulations and activities related to geothermal energy
Many activities integral to developing geothermal energy for district heating or other purposes are dealt with under existing regulations including planning, environment, and health and safety. The following list includes some policy/legislative documents that may apply to geothermal projects for district heating (this list is not comprehensive).

- Planning: The planning system in Ireland is led by the Department of Housing, Planning, and Local Government and is implemented by 31 local authorities. Geothermal projects for district heating would come under the provisions of the Planning and Development Act 2000, and subsequent amendments, and the Planning and Development Regulations.
- Deep drilling: An amendment to the Planning and Development Act 200 (S.I. No. 543 of 2014), which gives effect to EU Directive 2011/92/EU, specifically includes geothermal drilling among the drilling activities that may require an environmental impact assessment if the planning authority or An Bord Pleanála consider the activity would be likely to have significant effects on the environment.
- Water abstraction and discharge: The Environmental Protection Agency (EPA) and local authorities are responsible for monitoring and enforcing surface and groundwater regulations, many of which stem from the EU Water Directive Framework (2000/60/EC). Revisions to the water abstraction regulations are currently under review. At present, abstractions equal to or above 25 cubic metres per day must be registered with the EPA. Discharge licences must be obtained for all discharges to surface waters or to groundwater, with few exemptions.
- Health and safety: The Safety, Health and Welfare at Work Act, 2005, with amendments, sets basic standards for all workplaces. EU Directive 2013/59/EURATOM lists geothermal energy production as one of several industrial sectors that must take account of the risk to workers or the public from naturally occurring radioactive material (Annex VI) when dealing with certain geological materials.

- Standards: The National Standards Authority of Ireland (NSAI) develops and publishes standards for many products and services. Applying international standards for industry is also required (e.g. data, well design, risk, environmental standards).
- General: GSI publications include some specific building, groundwater, health and safety guidelines for individual installations.
- Professional guidelines/codes: Existing guidelines for environmental assessment and well water drilling[76]

Several parameters can be used to describe and/or categorise geothermal resources in the context of legislation and regulation, such as; depth of the resources below ground, temperature, flow rates, pressure, end use, and installed thermal capacity (heating or cooling). In any country developing geothermal energy systems, several key factors (from either existing or new legislation) must be taken into consideration:

- Water/extraction rights
- Exploration permits
- Well construction permits
- Development rights
- Payment of royalties (for private developments)
- Environmental impact assessments
- Environmental permits
- Planning permission for plant and distribution network
- Dismantling/end of life permits

In most regions, these factors are incorporated into the development of any new geothermal legislation and regulatory system. These also need be fair, transparent and efficient if it is to support the development of this technology as part of the transition to low carbon energies[5].

4 Comparison of international geothermal policies

Across the world investment in the development of geothermal resources is growing; in addition to the traditional industry leaders (New Zealand, Iceland and the US) the top 10 countries now also include Indonesia, the Philippines, Mexico and Kenya. European and neighbouring countries Croatia and Turkey are rapidly becoming world leaders in geothermal technology and development or resources (in 2018 Turkey added 219MW of capacity and Croatia added 17.5MW). Turkey ranks fourth globally for cumulative geothermal power capacity, having grown to more than 1 GW of capacity between 2013 and 2018[77].

Ireland currently has no legal or regulatory framework for geothermal energy, therefore it is useful to examine how geothermal energy is legally defined and dealt with in other countries, and how successful the different approaches have been in increasing the uptake of geothermal energy for district heating. Four European countries have been selected here for comparison (Table 1) because of their similarity to the Irish context (either in terms of geology, legal framework or potential market opportunity). France has been a world leader in geothermal district heating since the 1960s with well-established technologies, policies and legislation. Over the past decade the Netherlands has rapidly increased the rate of uptake of geothermal heat, particularly for use in the horticultural/agricultural sector, driven largely by the public availability of deep subsurface databases and by government incentives. The geology of Belgium's geothermal resources is similar to that of Ireland, and the Belgian regions, especially Flanders, are at a more advanced stage of project and policy development than Ireland. Geothermal development in Scotland is less advanced than the other three countries but is still more advanced than Ireland, and with a similar geology to the north and west of Ireland. (A more detailed summary of geothermal sector development for each country is provided in Appendix 1)

Geothermal legislation status	**National data availability**	**Installed geoDH capacity (MWth)**	**Target sectors**	**Financial incentives/supports**
France				
Regulated under national mining code	BRGM (French Geological Survey) geothermal programme	586 (74 geoDH systems)[78]	District heating and cooling	Public-private risk guarantee funds for low- and high-temperature deep projects. Financial subsidies and loan scheme
Belgium				
No national legislation. Flanders has developed policy for deep (>500m depth) sustainable management of the subsurface. Regulated through licensing system and environmental regulations.. In Wallonia and Brussels existing environmental urban and planning legislation covers	Geological Survey of Belgium plus regional organisations (e.g., VITO research institute in Flanders)	24 (Currently 3 heating networks connected to geothermal sources with another due to come online in 2022.)[79]	Urban district heating and cooling. Heat and power pilot plant at Balmatt (Flanders) in advanced development. Industrial use at Janssen site for pharmaceutical processes (heating and cooling), due to be completed in 2020.	In 2018 the Flanders government established a short term risk scheme to cover drilling. This does not include e.g. seismic risk. Developers pay 7% of maximum benefit amount (which is €18.7m and max. 85% of eligible costs). Financing schemes vary for < 5MW, > 5MW and agricultural applications. In 2019 Wallonia established a guarantee scheme for geological risk, applications are assessed on a case by case basis.

geothermal energy production.				
The Netherlands				
Separated to <500m and >500m depth (currently under review with revisions expected in 2021). Deep resources regulated by Mining Act.	Dutch Geological Survey and TNO (Netherlands Organisation for Applied Scientific Research). New seismic programme started in 2019. Data quality means 90% certainty of estimated power output achieved. New Ultradeep (>4km depth) project started in 2017	208 (21 doublets installed)[80]	Urban district heating and cooling. Horticulture/agric ulture; food production (cheese). Commercial use has helped increase confidence in the market	In 2012 'deep' geothermal energy was included in subsidy schemes for renewable energy, including feed-in tariffs. Risk mitigation fund established which pays 85% of well costs is thermal output is lower than expected up to a max of €7.2m. Participants pay 7% of the maximum support to join the scheme.
Scotland				
Heat policy is devolved to Scottish Government but some UK policy applies e.g. energy and electricity. In 2015, a regulatory review group determined that existing regulatory framework for mine waters and hot sedimentary aquifers was sufficient. They did not determine whether EGS (hot dry rock) required new legislation. Other existing planning and environmental legislation apply. The Non-Domestic Renewable Heat Incentive scheme defines "geothermal" as >500m.[81]	AECOM and British Geological Survey produced a 2 volume study for deep geothermal in Scotland..	0 (Previous networks fed from deep, hot mine waters have ceased production)	Urban and residential heat	Currently only research and development funds are available for deep geothermal.

Table 1 Summary of current status of geothermal energy development in countries with comparative geothermal temperatures

Although large-scale geothermal district heating systems are not currently in use in Ireland, there is abundant technical and regulatory experience available in neighbouring countries and across Europe to support existing national expertise. This also includes new and innovative research in areas ranging from exploration to drilling technologies, environmental monitoring, and increased efficiency in plant and distribution systems. Ireland now has an opportunity not only to benefit from decades of knowledge but also to demonstrate the newest and most efficient systems available.

5 Economic context for geothermal energy for district heating in Ireland

Ireland's geothermal energy resources have been recognised since the 1980s, yet there have been no major geothermal heating developments to date. Developers and experts commonly cite the following barriers to large geothermal projects in Ireland: 1) lack of a regulatory and legislative framework for geothermal energy; 2) high upfront costs combined with a lack of a feed-in tariff or other financial support; and 3) geological uncertainty due to lack of public data. (These and other barriers to geothermal district heating will be discussed in detail in Chapter 6.) The legal and technical uncertainty around the resource creates a significant barrier for would-be developers of geothermal projects even though district heating projects offer an ideal market for geothermal heat as the large scale of these projects makes the high Capex feasible and district-scale heat supply contracts would produce a long-term, predictable income stream. In addition, the lack of access to finance is problematic.

As the Irish district heating sector grows and gains momentum, opportunities will be presented for geothermal energy to enter into the mix of renewable heat sources and decarbonise the heat sector. Similar to the wind energy sector, for geoDH to succeed the Irish geothermal sector will need specific supports to overcome barriers and encourage developers, at least initially. Any financial supports could be reduced or withdrawn once key barriers are overcome and the sector becomes self-sufficient. Developing a number of a demonstrator sites would help to increase public awareness and support for geothermal projects. Any supports should be designed with consideration for the following three key, target user groups for geothermal district heating:

(i) Residential and commercial heat via local district heating networks

Growth in geothermal energy for district heating is linked to conditions in the property and energy markets. The number and density of housing in Ireland is projected to grow over the coming decades making the residential sector a suitable target. The National Planning Framework forecasts the need for an additional 550,000 households by 2040, with an emphasis on sustainable development and increased residential density in urban areas [82]; both of these conditions support the development of district heating and geothermal energy. Energy-efficient retrofitting of older housing stock also offers opportunities to incorporate renewable geoDH in the renovations. The government also anticipates economic growth with increased production and employment through 2025[83], though this projection may be affected by the Covid-19 pandemic. Economic growth should lead to more construction in the commercial sector with related demand for heating and cooling systems that could be met by geothermal installations.

(ii) **District heat to municipal and government buildings**

In these systems heat is provided to multiple buildings/facilities as public or public-private projects. For example, multiple buildings within a local authority could be connected to a local heating network (e.g., hospitals, public buildings, swimming pools and sports facilities) or a large, multi-building campus such as a university could be heated/cooled by a doublet and network on site (e.g. Durham University).

(iii) Industrial applications

Large-scale and/or high demand processes could be serviced by geothermal heating networks. In cases where these are on an industrial campus, it may be beneficial for several companies to cost-share, particularly where a range of applications with differing heat requirements could be aligned in a “cascade” heat network[84]. Or, if the facilities are sufficiently large, a single private user could develop a local heating network (a recent example is Beerse, Belgium where Jannsen are installing a 15MWh system to heat and cool their Johnson & Johnson headquarter pharmaceutical processing plant[85]).

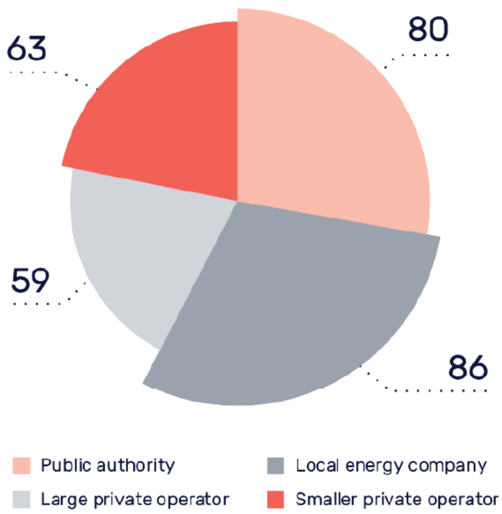

Figure 15 Types and numbers of operators for European geothermal district heating systems. (Source: EGEC market report 2018[9])

These user groups potentially offer a range of private or public-private partnership options. Across Europe there are typically three financing models; public investment by the local or national authority (e.g. Austria, Denmark, Germany), private sector investment with heat being sold directly to subscribers or used by the company (e.g. France and UK) or a mixed solution whereby new entities are established for the development of geothermal resources with capital investment shared by both public and private organisations[5].

One of the biggest challenges for geothermal energy developments is that the greatest risk, (geological and technical uncertainty), and the highest investment (the cost of drilling and pump installation) both occur at the start of a project[86] (Figure 16). A probabilistic, techno-economic analysis of a hypothetical deep geothermal heat system in the Netherlands showed that it would be most sensitive to technical conditions and to the load factor (balance of energy used compared to energy that could be produced) and the model showed some uncertainty about the economic viability of such a system[87]. However, incentives such as grants, loans, risk-insurance programmes,

public-private partnerships, or other policy mechanisms[88,89], and models that take account of goals such as reducing emissions, can change the economic outlook for projects.
Previous geothermal projects have demonstrated that one of the biggest challenges for geothermal energy is that the greatest risk, (geological and technical uncertainty), and the highest (the cost of drilling and pump installation) both occur at the start of a project.

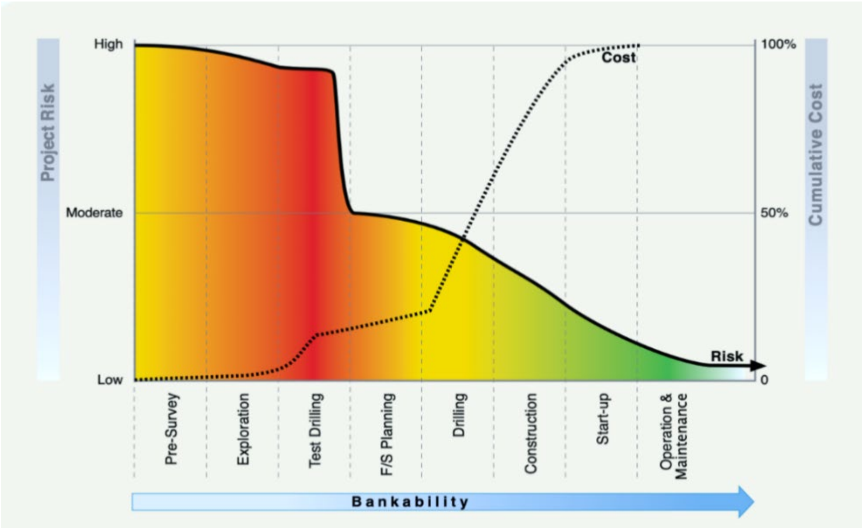

Figure 16 Project cost and risk profile at various stages of development for geothermal power projects (Source: Gehringer & Loksha, 2012[90],[89]).

5.1 The cost of geoDH

In geoDH projects, the estimated cost benefit analysis is usually presented as the Levelised Cost of Electricity (LCoE); this is because figures for geothermal electricity generation are more readily available than for heat, however the capex and opex ratios of these types of projects are comparable. The example in Table 2 indicates very favourable LCoE for geothermal energy compared to other energy systems. Although there is a high capital expenditure, the fixed operations and maintenance costs are in line with other renewable energies, and variable costs are significantly less (this is primarily due to the fact that geothermal provides a local energy source that does not rely on imported fuels, supply chains or weather/light conditions). In 2014 the pan-European GeoDH project and EGEC estimated the levelised costs (LCo) for geothermal district heat to be, on average, €0.6/kWH (Table 3). A predicted increase in targeted geothermal research is anticipated to further reduce these costs in the coming years (primarily to reduce drilling and capex costs).

Once the high capex and initial risk can be overcome, geothermal district heating projects are very economical to run. Table 4 shows an example of the project costs for a geothermal doublet in the Ile de France. This installation cost €14.3 million, and with annual savings of €1.9 million compared to natural gas, the project will have a payback period of less than eight years (the life span of the doublet is expected to be at least 35 years). This doublet will also save almost 17,000 tonnes CO_2 per annum.

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable O&M	Levelized transmis-sion cost	Total system LCOE
Dispatchable technologies						
Ultra-supercritical coal	85	47.57	5.43	22.27	1.17	76.44
Combined cycle	87	8.40	1.59	26.88	1.20	38.07
Combustion turbine	30	16.17	2.65	44.33	3.47	66.62
Advanced nuclear	90	56.12	15.36	9.06	1.10	81.65
Geothermal	90	20.38	14.48	1.16	1.45	37.47
Biomass	83	39.92	17.22	36.44	1.25	94.83
Non-dispatchable technologies						
Wind, onshore	40	29.63	7.52	0.00	2.80	39.95
Wind, offshore	44	90.95	28.65	0.00	2.65	122.25
Solar photovoltaic[2]	29	26.14	6.00	0.00	3.59	35.74
Hydroelectric[3]	59	37.28	10.57	3.07	1.87	52.79

[1]O&M = operations and maintenance.
[2]Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.
[3]As modeled, EIA assumes that hydroelectric generation has seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season.

Table 2 Estimated levelized cost of electricity (LCOE, unweighted) for new electricity generation resources entering service in 2025 (2019 dollars per megawatthour). (Source: US Energy Information Administration, Annual Energy Outlook 2020[91])

LCo of Geothermal Electricity	Costs 2012 Range(€/kWh) (€/kWh)	Average	Costs 2030 Average (€/kWh)
Electricity Conventional – high T°	0,05 to 0,09	0,07	0,03
Low temperature and small high T° plants	0,10 to 0,20	0,15	0,07
Enhanced Geothermal Systems	0,20 to 0,30	0,25	0,07

LCo of Geothermal Heat	Costs 2012 Range(€/kWh) (€/kWh)	Average	Costs 2030 Average (€/kWh)
Geothermal HP	0,05 to 0,30	0,08	0,05
Geothermal DH	0,02 to 0,20	0,06	0,04
Geothermal direct uses[1]	0,04 to 0,10	0,05	0,04

Table 3 Levelised costs (LCo) of geothermal heat (Source: EGEC Policy Paper 2013[92])

Heat power of new doublet	12.2 MW
Depth of reservoir	1.8 km
Production temperature	70°C
Reinjection temperature	40°C
Flow rate	8,400 m^3/d
CAPEX (for doublet and surface plant)	€14.3 million
Annual savings (geothermal v gas)	€1.9 million
Payback	8 years
Lifetime of doublet	35 years + add. 35 years post rehab of casing
Annual CO_2 savings (geothermal v gas)	16,967 tons

Table 4 An economic analysis of the construction of a new geoDH doublet in Val de Marne, in the Paris Basin (data from Hofmeister and Baastrup Holm, 2014[93]).

5.2 Incentives for geothermal energy

The Sustainable Energy Authority of Ireland (SEAI) administers three main programmes of financial support for renewable heat, however these are not yet appropriate for larger scale district networks. The Support Scheme for Renewable Heat is of most relevance to geothermal energy for district heating; it provides grants to non-domestic users of geothermal energy that are outside the Emissions Trading System (ETS). Additional schemes suitable for geothermal district heating will be required to develop the sector further.

There are a number of potential incentive frameworks for the development of geothermal systems by the private sector, for example: feed-in tariffs; CO_2 emissions avoidance (potentially including a system of CO_2 emission credits); grants for feasibility studies; low-interest loans; a national risk insurance scheme; low VAT rates; etc. These have been implemented by other European countries and can be adapted to the Irish context as needed. A recommended structure for long term development of the sector is described in Figure 17.

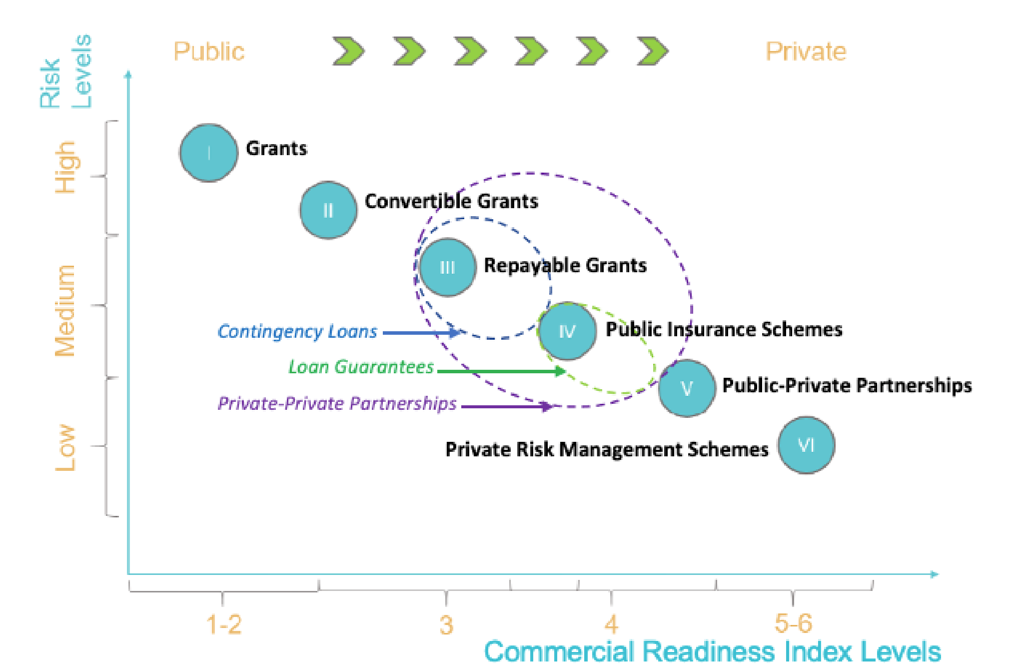

Figure 17 Relationship between Risk Management Schemes and Commercial Readiness Index levels (modified from Seyidov & Weismann, 2020[94]).

The GEORISK project concluded that, to be successful, a support scheme for geothermal projects must align with the market maturity and conditions where it is being implemented[95]. In Ireland the Commercial Readiness Index is low and the risk levels are high, implying that grants may be an appropriate initial support mechanism (Figure 17).

This concurs with the findings of a study by the European Technology & Innovation Platform on Deep Geothermal (ETIP-DG) on financing deep geothermal demonstration projects that highlights the need to customise incentives to match specific circumstances especially in the early stages of developing geothermal energy[96].

A separate modelling study concluded that recoverable loans are the best mechanism to mobilise risk capital while reducing the abandonment rate of geothermal projects after the first well is drilled and reducing the risk of loss-making projects without producing windfall profits[97]. Insurance schemes improve the profitability of projects but the abandonment rate rises significantly, while a heat premium such as a feed-in tariff is a cost-effective way to reduce the abandonment rate but it does not reduce the risk of unprofitability and can produce windfall profits. The authors conclude that the choice of policy instrument is complex and should reflect policy goals.

5.3 A geothermal market for private developers

Currently, it is difficult for private geothermal energy developers to compete with the existing energy options. This is due to oil and gas prices being low, a regulated system, and existing sectors receiving significant subsidies and supports (e.g., wind) or have feed-in tariffs (e.g., solar); therefore they do not reflect the true cost of heat/electricity generation).
For the private geothermal district heating sector to develop in the longer term, it must be financially viable in order to attract investors and provide them with a competitive return on investment. Establishing a predictable market with the reliable long-term (15–20 year) revenue streams required by financial institutions can be challenging in the district heating sector, given its current lack of market development. For any national grant or support schemes to private developers/operators, State Aid rules should also be adhered to; an estimation of the eligible aid intensities, and associated support scheme recommendations, was made by the GeoDH project in 2014[98]

	Notification threshold	**Eligible costs**	INTENSITY AID COMPATIBLE WITH THE INTERNAL MARKET		
			Small enterprise **enterprise**	**Medium-sized enterprise**	**Large**
Aid for environmental studies		The eligible costs are the costs of the studies.	70%	60%	50%
Aid for renewable energies **Aid for cogeneration installations**	EUR 15 million per undertaking per investment project	The counterfactual is a conventional power/ heat plant with the same capacity in terms of effective production of energy.	65%, 100 % if bidding process	55%, 100 % if bidding process	45%, 100 % if bidding process
DH infrastructure	EUR 20 million for DH network		65% 100% if bidding process	55%	45%
			The aid intensities mentioned above may be increased by a bonus of 5% point in regions covered by Article 107(3)c or by a bonus of 15% in regions covered by Article 107(3)a Treaty up to a maximum of 100% aid intensity.		

Table 5 Guidelines for level of State Aid funding for private development of geothermal district heating (GeoDH Final Report 2014[5])

5.4 Jobs, skills and training

Professional training, best practice guidelines, and standards are important in promoting the adoption of unfamiliar technologies and giving the public and investors confidence in geothermal energy as a source of heat for district heating. Some Irish universities, institutes of technology, and independent training organisations provide instruction on geothermal energy, in particular courses on sustainable energy, engineering, and heat pump installation. Engineers Ireland awards Continuing Professional Development accreditation to some geothermal training modules. Several providers, mainly specialist training organisations, deliver programmes that meet the EU Renewable Energy Directive requirement that installers of heat pumps, shallow geothermal systems, and other renewable energy technologies be certified[99]. However these are mostly targeted at small scale/individual installations.

The geothermal energy sector can provide skilled jobs and refocus to new areas of the energy sector in Ireland as part of the 'Just Transition'[100] and new training programmes. Increasing national skills and capacity across a range of technical and engineering area will be key. In addition, there is an opportunity to expand the apprenticeship options in this area. Currently, installers of residential heat pumps and geothermal systems must have a Level 6 qualification, Renewable Energy Installer: Heat pumps from the Further Education and Training Awards Council and the SEAI maintains a register of qualified personnel. A new Geo-Drilling Apprenticeship was established at the Institute of Technology Carlow in 2019 in collaboration with Geoscience Ireland; this will lead to a National Framework of Qualifications Level 6 Higher Certificate for drillers and will include a geothermal component. These, and related, training opportunities (e.g. plant maintenance, fitting of district heating networks, engineering works etc.) will need to be further developed.
Ireland has a small cohort of geothermal experts who work in Ireland and internationally, mainly in the exploration, development, and installation sectors. While there has been some increase in training opportunities and developing codes of practice, few Irish practitioners outside the small group of experts have extensive experience in designing, maintaining, or regulating geothermal systems beyond ground source heat pumps. This provides a new opportunity for skilled workers in the renewable energy sector.
The European Geothermal Energy Council warned in 2007 that the lack of knowledge about renewable heat technologies on the side of architects, planners and installers will delay the broad market penetration of renewables in the heating and cooling markets.[101] A 2020 review of business models for geothermal heat in Scotland delivered the same message, "Finally, and most importantly, awareness of the geothermal heat opportunity needs to be increased among all stakeholders, predominantly within local and national government, but also within the energy consultancy and energy investment communities who often overlook geothermal energy in their energy master plans"[86].

5.5 Development of the SME geothermal sector in Ireland

Ireland has a strong geoscience SME sector with expertise ranging from environmental impact assessment and monitoring, to geoengineering, drilling, renewable energy technologies,

hydrogeology and subsurface resources management. The Geoscience Ireland business cluster was established, and is managed, by Geological Survey Ireland and Enterprise Ireland to develop the skills and market access for their members (mostly small and medium enterprises) to develop business opportunities internationally. Geoscience Ireland members have delivered multiple large scale projects and consortia funded by organisations such as the World Bank and national governments. Several of these projects have included geothermal project development and construction[102].
In addition, Geoscience Ireland is leading a European collaboration of equivalent business clusters to promote geothermal energy development and generate new business for member countries. This project, *Geo Energy Europe*, provides €450,000 in funding from the Competitiveness of Small and Medium-Sized Enterprises (COSME) agency in the European Commission and highlights Ireland's leading international role in business clustering for SMEs. There is now an opportunity to further develop Irish companies in this sector and establish Irish-based SMEs and engineering companies as world leaders in geothermal energy development.

6 Addressing barriers, opportunities, risks & mitigation measures

In 2018, GSI held an open workshop to assess the current status of the geothermal sector in Ireland and identify barriers and opportunities[103]. This was followed by a subsequent meeting of key stakeholders in 2019 in preparation for this roadmap. In addition, several European countries and consortia have investigated existing and potential barrier to the development of geothermal energy (e.g., the Geothermica Project and European Geothermal Energy Council).

Both a national stakeholder workshops hosted by GSI and the GeoDH Project report (2014) identified a number of pre-requisites to support the development of geothermal energy: (i) robust geological data freely available to developers, (ii) a public risk insurance scheme, (iii) a clear definition of procedures and licensing authorities and (iv) adequate national and regional strategies that are integrated with some form of financial support.
The potential barriers to such developments are: (i) markets are sometimes closed to new entrants, (ii) long burdensome administrative procedures, (iii) serious regulatory gaps such as lack of licensing system, (iv) lack of a level playing field (e.g., where supports are available for other energy sources).

For Ireland, risks and related mitigation measures can be allocated to three key categories: geological and environmental, the economy and jobs (particularly in relation to private sector developments) and political and societal risks.

6.1 Geology and the environment

Geological risk

The cost of subsurface drilling can often be 30-50% of the total cost of a geothermal heat project (or more in the case of electricity generation[104]). Therefore it is essential to de-risk this early phases of a project by gathering as much information as possible. Once a project has passed the drilling and testing phase, the probability of success rapidly increases (Figure 18).

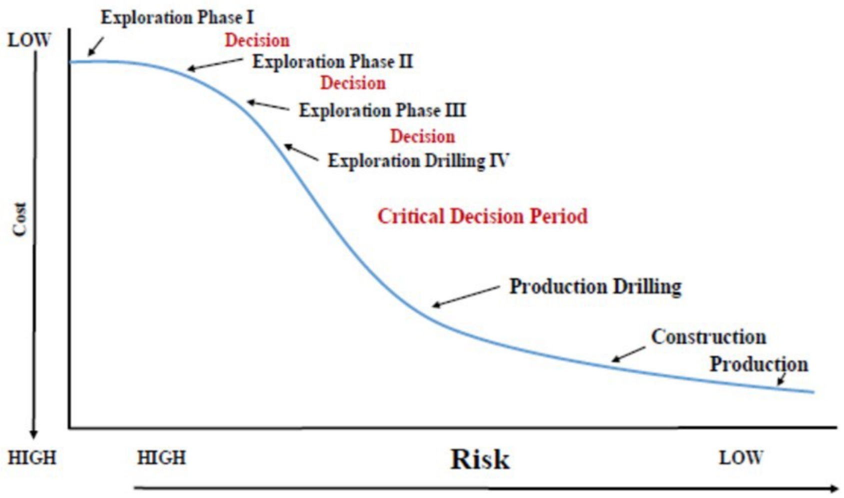

Figure 18 Variation of risks at different phases of a geothermal project (Source: Klingel, 2019[105])

Addressing geological uncertainty is critical to the success of geothermal developments at almost every step of the planning and development process. Publicly available, high-quality subsurface data should be collected and disseminated through a national geothermal database containing maps, tools and best practise guidelines for developers and installers. This would achieve the following broad aims:

- Provide free access to information that can de-risk geothermal developments;
- Increase the reliability of available data through standardised collection and quality control;
- Identify areas for further research and investigation (avoid doubling-up of research);
- Provide reliable initial estimates of geothermal resources;
- Encourage the development of a geothermal industry and skilled labour force;
- Raise public awareness of Ireland's geothermal energy potential and how it is used and
- Allow appropriate subsurface management of resources

Any national geothermal database should aim to provide free access to reliable information to inform policy and planning, de-risk investment, and promote awareness and understanding of geothermal energy has played a vital role in geothermal development, as evidenced by the rapid uptake of geothermal heat in the Netherlands in the past decade. Best practice suggests databases should include geological and technical information on the subsurface, data on the location and nature of all existing geothermal installations, guidance on how to navigate the regulatory environment, and a full spectrum of information for professional, educational and individual consumers and stakeholders.

GEOLOGICAL AND SURFACE STUDIES	GEOCHEMICAL SURVEYS	GEOPHYSICAL SURVEYS
• Mapping surface geology (Puente and De La Peña, 1979) • Locating and mapping active geothermal surface features • Structural geological interpretation • Earthquake locations and focal mechanisms	• Collect samples from all thermal features for analysis • Geothermometry (water and gases) (Ellis, 1979; Giggenbach and Goguel, 1989) • pH + electrical conductivity • Flow rate and temperature of fluids discharging from active thermal features • Soil sampling and gas flux (Harvey et al., 2011)	• Remote sensing • Heat flow survey of fluid discharge sites (Fisher, 1964) • Gravity and magnetics (Pálmason, 1975) • Electrical resistivity • Magnetotellurics (Anderson et al., 2000) • Passive seismic monitoring • 2D and 3D seismic reflection • Temperature gradient and conductive heat flow

Figure 19 Examples of the types of geological information required at exploration stage. (Source: ETIP-DG, 2019[106])

6.2 Building an Irish geothermal database

Geological Survey Ireland has initiated identified gaps in the current national databases including: Temperature at depth; thermal conductivity; heat flow; deep borehole logs; porosity/permeability data; deep groundwater chemistry, and geophysical surveys. By collating existing data and collecting new geothermal data we can close our knowledge gaps in such a way that will 1) ensure accurate assessment and communication of the potential national resource; 2) reduce risk and cost for geothermal developers and system designers in the exploratory and design phases of a project, and 3) assist with successful operation and maintenance of geothermal plants.

Deep subsurface geology

Basic geological and lithological information from depths in excess of 1,000 m is sparse in Ireland (and particularly so in the south and west) due to a lack of historical onshore hydrocarbon and mineral exploration at these depths. This means that the lower limits of potential geothermal targets such as sedimentary basins or radiogenic rock formations are unknown or poorly constrained. This uncertainty prohibits accurate calculation of the geothermal resource and increases the risk to any potential geothermal development. Although recent research has sought to address this knowledge gap using geophysics to sense the extents of some geothermal targets (e.g., IRETHERM project; GeoUrban project), deep drilling is now needed to verify the geophysical models. The acquisition of deep drillhole data and dense seismic geophysical surveys are standard for commercial geothermal (and hydrocarbon) exploration projects, but have been outside of the budgetary scope of Irish research projects to date. In order to reduce geological uncertainty there is now a need for national high-quality seismic geophysical surveys over key Irish geothermal targets to be followed by targeted drillholes.

Deep hydrogeology

The hydrogeological properties of deep Irish bedrock (i.e., movement and interaction of water in the subsurface) are largely unknown. Certain mining areas, such as Navan, Co. Meath, may have bodies of privately held legacy data and records of deep hydrogeological parameters, e.g., groundwater strikes, flow rates and chemistry. This information is critical in evaluating hydrothermal resources and predicting how a resource will behave over time. Systematic collection of hydrogeological data from new or existing boreholes should include, e.g.: groundwater levels, strikes and inflows; groundwater temperature and chemistry; estimates of hydraulic conductivity and transmissivity from aquifer tests.

Subsurface temperatures

It is clear that known temperature data from the deep (>500m) subsurface is very limited in Ireland, comes from a variety of sources and is of variable quality (for example, temperature data from just 75 boreholes between 300 m and 2,300 m depth were available for the thermal models produced by CSA in 2004[55]). The distribution of data points is biased towards Carboniferous geology as this is where most historical exploration has been focussed. As a result, subsurface temperatures outside of the Carboniferous Irish Midlands are relatively unknown. Deep temperature data is needed in the northwest, west, southwest and southeast to balance the knowledge of the thermal regime in Ireland and to improve the accuracy of existing thermal models of the Irish crust. Continuous downhole temperature measurements are preferable to bottom-hole-temperature measurements to provide an accurate picture of the thermal regime in the subsurface[70]. GSI is currently undertaking work through both the MUSE and Hotlime projects that will improve our understanding of these areas supported by other GSI-funded external research projects.

Bedrock thermal conductivity

Thermal conductivity is an important geothermal parameter[107,] which, alongside temperature, permeability and rock heat production rates allows the heat flow from the Earth's interior to be calculated, and the heat potential of prospective geothermal reservoirs to be estimated. Previous studies have compiled a total of over 300 thermal conductivity measurements from Irish bedrock focussed mainly on limestone [108]. A further twenty-one thermal conductivity measurements undertaken recently by the Go.THERM3D project reported thermal conductivities that were much lower than historical averages for Irish bedrock[109], which implies that geothermal gradients may be higher than previously anticipated. It is now necessary to systematically reassess and add to our measurements of bedrock thermal conductivities to build a 3-D picture of thermal properties, and enable more accurate assessment of geothermal resources.

To support our geoscience research community and enable innovation, a suite of national scientific observation boreholes in key localities should be drilled to collect the most accurate, highest quality data in strategic locations. This data may then be used as quality control for the existing and legacy data, and to improve database maps and products.

Environmental risks

Environmental risks are site specific and initial investigations must be carried out on each proposed site. However, the standard environmental risks to be considered include: the possibility of induced seismicity during drilling or production; contamination of groundwater and/or soils; the presence of naturally-occurring radioactive fluids; the possibility of finding fluids under pressure; water consumption; noise; and visual impacts[110,111]. These risks can all be mitigated with a better understanding of the subsurface and appropriate (and implemented) regulation. In general. most risks are already considered under existing legislation (e.g., water management).

Risk	Description	Mitigation measure
Geological risks inherent in the drilling project	Insufficient information for engineers, planners, investors, decision makers	National database for geological, geophysical and temperature data hosted by GSI. This will include existing data and maps, but will be expanded to include geophysical, structural and borehole data for Ireland. As with current GSI data, it will be open access to all interested parties.

Insufficient heat produced	This could result from lower than expected temperature and/or low flow rates in open systems	Detailed geological studies (including test drilling, temperature testing and geophysics) and continued investment in subsurface research and exploration techniques
Sustaining a long term resource	Geothermal resources can deplete over time if overused or poorly managed	Full temperature assessments and monitoring with appropriate management plan for resources extraction. This must include subsurface management of nearby resources (e.g., heat and water)
Release of radiogenic gases	Radiogenic gases naturally occur in some types of rocks	Radiogenic gases can be managed at the extraction point at the surface.
Induced seismicity	There have been cases where deep (i.e., > 1 km) geothermal wells have caused seismic events. These range from microseismicity of <1 magnitude up to events of 3-4 magnitude. These can be caused by (a) reactivation of an existing fault zone or (b) changes in stress and pressure from abstraction/injection of fluids or during drilling.	Pre-project baseline studies and high resolution (spatial and temporal) monitoring throughout all development and operational stages. The Irish National Seismic Network, maintained by the Dublin Institute for Advanced Studies, has been adapted for very low level detection (<mag. 1). DIAS have also been developing adaptive real time monitoring techniques as part of an international project. It is recommended that parallel seismic monitoring is carried out through a government organisation and not be the sole responsibility of the private developers.
Poor groundwater resource management	Over-abstraction or contamination of groundwater resources or release of warm/contaminated waters to the aquifer	Careful monitoring and modelling through GSI's Groundwater programme, and/or monitoring by the appropriate agency depending on location. Enforcement of relevant legislation.
Inappropriate resource (heat) management	Ensuring the heat extracted is at a rate consistent with maintaining a sustainable resource	Allowing the system to equilibrate and continuous temperature measurements to ensure minimal impact on the resource. This would require monitoring, modelling, guidance and best practice, underpinned by legislation
Negative audio-visual impacts	The physical surface infrastructure and plant may not be acceptable (though this is a larger issue for geothermal electricity production than for heat production). Installation of the boreholes (drilling) may be noisy, but this is temporary.	Surface infrastructure is generally not a problem for small-medium scale geothermal plants, however all infrastructure will be in line with planning regulations. Noise disturbances can be reduced during drilling by using, e.g., baffles

		around the drill rig. Noise during production is minimal.

6.3 The economy and jobs

As indicated previously, the economic risk is generally associated with the initial exploration and is due to geological unknowns. This usually impacts a company's ability to raise funds. This can be addressed by the recommendations in the section above. The other identifiable economic risk is the lack of end users for the energy. It is recommended that geothermal district heating in Ireland is developed in collaboration with local authorities and potential commercial users from the beginning to ensure economic feasibility.

Financial supports, incentives and insurance

Geothermal energy projects must be able to demonstrate a strong case for economic viability if they are to attract private-sector investment. Projects must deliver a stable return on investment with the lowest possible risks[111]. Experience in Scotland, which is at a broadly similar stage of developing geothermal energy as Ireland, shows that project developers and investors tend to be risk-averse and it has proven difficult to find investors willing to take on the up-front risks[86].

Access to finance is a major barrier for geothermal projects worldwide. Government-backed incentives and risk mitigation programmes for geothermal energy are used widely to support the development of geothermal energy but they are complex instruments that must be tailored to specific market maturity and conditions[94] and designed to achieve known policy goals[112].

Government support schemes: There are three major categories of support schemes that address different challenges and produce different outcomes:

- Direct investment supports in the form of grants and repayable loans provide funding to projects that have a high degree of uncertainty.
- Damage mitigation supports in the form of insurance and risk mitigation funds are appropriate for projects where the risk is clear, quantifiable, and predictable.
- Market stimulation in the form of feed-in tariffs and subsidies increase income once a project is in production[113].

Geothermal-specific incentives: The structure of incentives that are designed for other sources of renewable energy may not be ideal for the geothermal sector. Geothermal energy has high capital costs and initial project risk, it supplies heat, and it provides a constant baseload supply of energy. In contrast, wind and solar energy have lower project risk and initial costs because they are at the surface where wind and solar radiation can be accurately measured and the installations are readily accessible, but they are both intermittent sources of energy. One form of incentive is unlikely to be appropriate for all renewable energy sources.

Establish demand: The market for heat is demand-driven and location-specific. The supply of geothermal energy must mesh physically, economically, and administratively with the consumer network. European experience shows that it may be more straightforward to focus initially on developing demand for district heating in public or commercial buildings rather than starting with the more complex consumer situation in housing stock.

Public-private collaboration: The Dutch government has worked closely with the horticulture sector and with coalitions that include industry, research bodies, the finance sector, and a range of other stakeholders including communities and workers to develop consensus-based and collaborative approaches to developing geothermal energy, including creating a roadmap that outlines contributions from both government and industry.

Education, Training and skills

Professional awareness*:* The development of geothermal energy sector in Ireland provides an opportunity to use new energy resources. However, as with all new technologies, its application and potential will need to be promoted. Useful information must be provided to all relevant professional sectors such as architects, engineers, planners, energy consultants and the construction industry. This will require engagement with professional bodies and trades and should be done in a coordinated way with clear information and supported by agencies and government departments.

Education and training: In collaboration with the professional bodies, continuous professional development courses can be established to up-skill those in the relevant sectors and to train new entrants. Educational and training programmes (e.g., through third level institutes, FETAC etc.) in the area of geothermal energy development and infrastructure maintenance can be established to support the sector. New geothermal components can be added to existing energy-related training programmes.

Standards: Best practice guidelines, professional accreditation (e.g., geodrilling apprenticeship, geothermal plant operators), and standards are important in promoting the adoption of unfamiliar technologies and giving the public confidence in geothermal energy as a source of heat for district heating. The Heat Pump Association of Ireland has published installation guidelines as part of a heat pumps code of practice[114]. The Geothermal Association of Ireland has developed technical best practices for the installation of shallow geothermal energy collectors**[Error! Bookmark not defined.]**. The National Standards Authority of Ireland adopted the European standard EN 17628:2015 on determining the thermal conductivity of soil and rock using a borehole heat exchanger in 2015[115]. While this progress is welcome, more comprehensive standards and enforcement mechanisms for larger geothermal district heating networks are needed.

Risk	**Description**	**Mitigation measure**
Insufficient financial supports & incentives	Sufficient financial supports and incentives must be in place for private investors and developers to invest in projects	National geoscience programme to provide subsurface information and test well drilling to reduce initial costs/risks. Establish national financial programmes for developers to access. Increase

		awareness among financial policy specialists.
Insufficient uptake	Geothermal energy production will be demand driven	Identify key urban/industrial areas that will ensure uptake of the resource. Promotion among key groups e.g., planners, architects, educators
Lack of risk insurance schemes	It is difficult to secure insurance for private developers as geothermal plants have a particularly high Capex and are considered high risk (i.e. potentially expensive outlay with possible technical or geological problems that result in a failed project)	National insurance programmes (these have been developed in a number of countries, sometimes including a government agency on a project board to ensure value to the State) evolving to a standard insurance market over time. This will be assisted by building geological knowledge.
Insufficient training opportunities and skills training	The development of a geothermal sector will require further development of existing and new apprenticeships and CPD courses	Key agencies and training centres will need to collaborate to develop the appropriate (re)training programmes, e.g., geo-drilling apprenticeship

6.4 Policy and society

The development of geothermal district heating will require political and societal support. In the context of the Just Transition and eradicating fuel (energy) poverty, geothermal district heating can offer a solution to socio-economic disadvantaged areas and municipal buildings such as Deis schools. However, as with the development of any natural resource, this will require full engagement and transparent information systems from all stakeholders.

Definition of terms: Terminology is often used rather loosely in the geothermal sector. The EU definition of geothermal energy ("energy stored in the form of heat beneath the surface of solid earth[116]") includes heat that is stored very close to the surface of the solid earth. Other definitions of geothermal energy exclude this heat source because at least some of the heat originated from the sun rather than being generated from within the Earth[117]. One consequence is that statistics for geothermal energy resources and installations may not be comparable across jurisdictions. The terms "shallow" and "deep" are often used in regulating geothermal systems but in some cases without any rigorous definition or a clear rationale for the separation[118]. The loose use of terminology is confusing within the industry and is likely to be even more confusing for the public, which may have implications for public understanding and acceptance.

Integrated subsurface planning: Geothermal energy is one component of the subsurface system. Countries are increasingly recognising the need for integrated subsurface planning in order to optimise use of all subsurface resources and to prevent and mitigate unintended consequences on the environment. Effective subsurface planning will require greatly improved datasets, analysis, and understanding of the complex dynamics of the subsurface environment and the appropriate expertise.

Align diverse policies and regulations: Policies and regulations from local to national levels, including those for planning and land-use, water management, procurement, and district heating, should facilitate the co-development of geothermal energy and district heating and should avoid administrative barriers to development.

Geothermal-specific legislation: In the initial stages of development, geothermal legislation in countries has often been based on existing models particularly those for oil and gas exploration and production (e.g., the Netherlands, South Australia). As the differences between heat and other natural resources become more apparent, countries are developing geothermal-specific legislation and regulations as shown by the current revision of Dutch geothermal policies.

Legal opinions vary on whether heat can be subject to ownership but studies show that state ownership of heat resources provides more security and stability for the sector than when the surface land owner controls the resource[88]. An analysis of the Dutch licencing system concluded that issuing licences on a "first-come, first-served" basis leads to sub-optimal use of geothermal resources and that alternative licencing systems that are integrated with regionally coordinated masterplans for geothermal energy should be examined[119].

Integrating regulations for shallow and deep geothermal resources: There is a need for specific and detailed legal frameworks for shallow geothermal development, which is often regulated through existing planning and environmental regulations[118], in addition to the need for geothermal-specific legislation and regulation for deeper developments. Many jurisdictions have different legislation and regulations for shallow and deep geothermal regimes but this may cause an artificial regulatory barrier within the continuum of the natural geothermal system (depth is a somewhat crude determinant of the characteristics of a geothermal resource and advances in technologies such as drilling, pumping, and heat systems may reduce the significance of particular depths).

As geothermal development increases, countries such as the Netherlands are examining the implications of the separation between shallow and deep geothermal regulation. The French model includes all geothermal resources under the same legislation but with different regulations for categories based on a combination of temperature, depth, and heat output (see Appendix 1 for futher detail).

Streamlined regulatory requirements: Aspects of geothermal energy come under the jurisdiction of many agencies in most countries, which can lead to a complex permitting and reporting situation. This time-consuming and sometimes duplicative system is seen as a barrier, especially for smaller developers who do not have the knowledge or resources of major companies. The Netherlands is in the process of streamlining its environmental and planning structures and Scotland has prepared comprehensive guidance to explain the regulations related to geothermal energy to developers.

Public Awareness: People need to be aware of geothermal energy before they will choose to use it. Geothermal energy is, however, easy to overlook. The U.S. Department of Energy recognised this challenge in their *Geovision* report, "... because of their subsurface nature, all geothermal resources share one key non-technical barrier: lack of awareness and acceptance. … the public is generally unaware that geothermal resources exist and could be used for a wide array of applications"[120]. In addition, "Awareness and acceptance [of geothermal energy] can influence policies, incentives, land access, and other features crucial to geothermal development".
Two studies indicate that public awareness of geothermal energy in Ireland is relatively low. In a 2018 online survey of 1,208 nationally representative Irish households, 37% were aware of ground source heat pumps, the most common form of geothermal heating in Ireland[121]. In an earlier study, Gibbons found that 35% of 105 respondents to a survey in Co. Donegal were aware of geothermal energy as a source of renewable energy[122]. These figures are in line with the findings of a 2011 Eurobarometer survey which found that 47% of respondents had heard of geothermal energy but with a wide variation between the countries surveyed, ranging from 94% familiarity in Finland to 27% in the Czech Republic (Ireland was not included in the survey)[123].

Public acceptance: Assessing public acceptance of geothermal energy is more complex than measuring public awareness. Once people are aware of geothermal energy, they may then choose to embrace or reject it at either a personal or a community level and an array of social dimensions may affect that decision. A nationwide sample of 724 respondents, found that geothermal energy is generally acceptable to the Irish public and is thought to provide low risk to the environment, society, and the economy[124]. The authors note, however, that this may not necessarily translate into acceptance of specific projects and they recommend that communities should be involved in geothermal energy development.

In a study of heat pumps for residential use, that did not differentiate between geothermal, air, and water heat pumps[125], approximately 60% of respondents to a national survey had a positive attitude to heat pumps, with about 17% against and 22% neutral towards heat pumps[121]. The authors note that Irish responses indicate a higher willingness to pay for heat pumps than is found in France and Finland, which have longer experience with the technology. However, they caution that, "When survey participants have little experience of the technology involved, they may overstate their appreciation of features such as environmental sustainability or bill savings"[121].

Studies show that geothermal energy may intersect with strongly held cultural and historic values[126], and reactions may vary depending on whether people emphasise their local, national, or global attachments[127] or their commitment to environmental values[128]. Open access to information and public trust in those involved in developing and regulating geothermal energy can also play a key role in determining public responses[129, 130]. Perceived environmental risks may also influence public acceptance.

Stakeholder dialogue: A broad consortium of Dutch geothermal interests, including the government, regional bodies, industry, financial companies, and diverse stakeholders have developed a *Master Plan for Geothermal Energy in the Netherlands* in which they describe a need for national dialogue on the energy transition and more focused discussions with stakeholders about geothermal development[131]. Geothermal energy may provide an opportunity to develop dialogue with multiple participants in the context of a just and sustainable energy transition.

Risk	**Description**	**Mitigation Measure**
Insufficient political support	Development of geothermal district heating will require support from local and national government	Promotion of the opportunities to Local Authorities and Government Departments. Information on the GSI website for all policy makers and planners.
Delays due to planning and legislation	Feedback from private industry developers has been that the lack of clear legislation has had a negative effect and investors are not willing to go ahead with outline projects.	Appropriate, clear planning and licensing system in place with associated legislation as early as possible to lower the perceived risk for investors and insurance schemes.
Lack of public awareness/ support of geothermal energy for district heating	As the both the public (through district heating systems) and commercial industry are potential users of this technology and resource, they need to be fully informed.	Clear, transparent and objective information provided by trusted sources describing how geothermal energy works, advantages and disadvantages, risks and mitigation measures.

6.5 Pilot Projects

Participants in the GSI stakeholders workshop 2018 indicated that investors may remain hesitant until there are some successful pilot projects that prove the concept of geothermal energy for district heating in a local context. Successful pilot projects, where information is openly shared, are important in developing technical, organisational, and administrative experience. They also give commercial, municipal and individual consumers the opportunity to become familiar with geothermal energy and district heating without being exposed to the full risk of the project. Government investment in pioneering projects in the Netherlands and Flanders has helped to lay the foundations for subsequent developments. Data from similar projects in Ireland would reduce uncertainty and enable project managers and potential investors to develop technical and economic models based on Irish data that they could use as a basis for decision making.

7 Conclusions

It is evident from research to date that Ireland has significant geothermal energy resources that are underutilised. Geothermal heat has the potential to contribute to the decarbonisation of Ireland's heat sector and offers unique benefits compared to other renewable options in terms of baseload provision (energy stability) and security of supply. Ireland's higher-temperature geothermal resources (obtained by drilling deeper into the crust) could also ultimately help decarbonise domestic electricity production in the future.

The development of Irish geothermal resources is particularly hampered by high capital costs and associated risks where the resource is poorly characterised. The high cost of drilling makes geothermal developments unattractive for potential private developers, particularly in the absence of financial assistance and/or insurance. There are currently a significant number of international projects addressing the costs of drilling for geothermal energy by developing new technologies and methods, however, nationally it is critical that we reduce the geological uncertainty surrounding Irish geothermal resources. The reduction in subsurface uncertainty will reduce upfront costs resulting in increasingly competitive prices for geothermal energy.

To further support the sector national legislation and regulation will be needed along with early and meaningful engagement with all stakeholder groups. Effective demonstration of the technology through local pilot studies will help increase public awareness and understanding of the resource and highlight its benefits to society.

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APPENDIX 1 – International comparisons: France, the Netherlands, Belgium and Scotland

FRANCE

France has a long history of using geothermal energy for heating. The world's first known district heating system was installed in the village of Chaudes-Aigues in the volcanic region of Auvergne in the Massif Central in the 14th century. Water from Europe's hottest (up to 82°C) springs, which are located above the village, was piped through a series of wooden pipes to heat a network of houses[1]. France now ranks sixth in the world in geothermal direct heat usage, mainly due to growth in the sector in the 1980s and since the mid-2000s[2].

In mainland France, the oil shocks of the 1970s, which increased the cost of fossil fuel energy, drove the development of geothermal energy and led to the installation of some 30 geothermal plants in the Paris Basin and Aquitaine between 1980 and 1985[3]. The government supported this development by creating the world's first risk guarantee mechanism for geothermal energy[2]. More recently, EU and national climate policies have provided the main impetus for the adoption of renewable energy sources, including geothermal. The government's energy objectives and priority actions for the period 2019- 2029 are defined in the Programmation Pluriannuelle de l'Energie (Multiannual Energy Plan). Goals in the recent draft plan include increasing the consumption of renewable heat by 25% by 2023 and by between 40% and 60% by 2028 compared to 2016 levels[4].

Near-surface geothermal resources, suitable for use with a heat pump for individual houses, are available throughout most of France but the installation rate has dropped significantly since 2010 due to competition from natural gas and air system heat pumps[5]. Brittany in the west and the Auvergne-Rhone-Alpes region in the east show the most interest in geothermal installations for individual houses. In 2018, geothermal heat pumps comprised only 0.5% of the heat pump market and 0.2% of all domestic heating installations[5].

In contrast, the use of deeper hot sedimentary aquifer resources to provide direct heat for collective housing (community housing, offices, hospitals, municipal buildings), offices, and district heating networks is well established in some regions. This sector grew rapidly in the early 1980s mainly in the Paris Basin with additional activity in the Aquitaine region of SW France. More than 70 geothermal district heating systems were installed in the Paris area[6] and a majority of the original operations are still in use[Error! Bookmark not defined.]. There was a hiatus in geothermal drilling between 1986 and 2007 but the number of installations has risen since the government increased its support for renewable energy. In 2016, the Dogger aquifer in the Paris Basin provided heating to approximately 200,000 buildings or about 650,000 people[7]. The main aquifer in the Paris Basin, the Middle Jurassic Dogger carbonate sequence, covers an area of approximately 150,000 km^2 at depths of 1,600–1,800m with temperatures varying from 56°C to 85°C. Some more recent installations exploit younger Early Cretaceous aquifers for heating and cooling using large heat pumps[5].

France also has hotter geothermal resources from hot sedimentary aquifers, crystalline basement, and volcanic sequences. These resources are mainly focused on the Rhine

Graben area in the northeast of the country and in French volcanic islands such as Réunion and Guadeloupe, with additional potential in the Massif Central and the southwest of the country. The hotter resources are targeted for both heat and electricity production using enhanced geothermal systems and several projects are in production or development[Error! Bookmark not defined.].

The Bureau de Recherches Géologiques et Minières (BRGM), the French geological survey, began examining geothermal energy in the 1960s. Initially, the goal was to identify indigenous energy sources for some of the overseas French islands but later work focused on low-temperature resources for district heating. As a public industrial and commercial organisation, BRGM has a complex role. In addition to the traditional role of a geological survey to conduct research, provide information and data, and advise government, BRGM may carry out commercial, industrial, and financial operations that are compatible with its mission, including creating subsidiaries, taking stakes in organisations and companies, and providing loans[8]. BRGM has a wholly-owned subsidiary, CFG, which is a service and engineering company specialising in geothermal energy[9]. This means that BRGM, other national agencies, local and regional governments, and various actors in the private sector can be involved in a variety of arrangements to advance mutual goals in the geothermal sector.

Geological data, research, and development projects

Information: BRGM is the main source of geological information through its geological mapping and modelling programme and an online database of subsurface information, including information submitted under Mining Code regulations[10]. In 2001, BRGM set up the Dogger databank to gather information on the main aquifer used for geothermal extraction in the Paris Basin. The database includes all available geological, hydrodynamic, thermal, and geochemical data, plus operational monitoring data from geothermal plants. The database is used by operators, developers, consultants, and regulators and BRGM have received requests to extend similar coverage to other geothermal resources[11]. Based on this dataset, BRGM have developed a 3-D model of the Dogger deposits to better understand the aquifer and its potential for CO_2 storage[12].

BRGM also provides information on geothermal energy for the general public and decision makers by producing newsletters for specialists and public authorities, technical guides on heat pumps for professionals and the general public, and participating in public and technical events. BRGM launched a new website in January 2020[13], Géothermies.fr, which includes regional and local-scale maps of geothermal resources, information on existing facilities, and guidance on the regulatory requirements and standards for developing geothermal energy[14].

Research: BRGM works closely with ADEME (French Environment and Energy Management Agency) which manages the main part of the national R&D budget for geothermal energy. BRGM is mapping the potential for shallow geothermal energy throughout France, in addition developing improved geothermal technologies and an active geothermal research programme.

Several government-sponsored research centres and technological competitiveness hubs focus on geothermal energy. The G-Eau-Thermie Profonde Laboratory was set up at the University of Strasbourg in 2012 to study deep geothermal energy with initial funding of

€3 million over 8 years. Its annual funding is now about €2 million from government, European, and industry sources[Error! Bookmark not defined.]. The GEODEEP cluster provides a marketing platform for French geothermal companies and service providers. It also facilitates the GEODEEP risk mitigation fund which insures deep geothermal projects[15]. The Géodénergies public-private partnership was created in 2015 to study CO_2 storage, energy storage, and geothermal energy with initial funding of €15.9 million[16]. It combines 12 companies, seven public research institutions including BRGM, and two competitiveness clusters[17] to work on innovative projects to develop France's position in these market areas. The AVENIA hub

supports business development in all subsurface sectors. It has 194 members and funds research, development, and innovation projects and supports start-up enterprises[18].

Geothermal energy for buildings is one of five topic areas for the S2E2 Smart Electricity cluster[19].

Pilot projects: Pilot projects have played an important role in the development of geothermal energy in France. The Soultz-sous-Forêts deep geothermal pilot project in Alsace involved drilling three 5,000m wells in fractured granite combined with hydraulic and chemical stimulation at temperatures up to 200°C. The project began in 1985 and started production in 2010. It was taken over by Electricité de Strasbourg and moved to full industrial production in 2016, producing up to 12,000 MWh of electricity per year. This lengthy and successful pilot project spurred the installation of several deep geothermal power and heating plants throughout the Rhine Graben area in France, Germany, and Switzerland[20].

Research by BRGM in the early 2000s convinced ADEME and the Greater Paris regional authority to endorse and support geothermal development[21], which led to the rejuvenation of geothermal energy for district heating in the Paris region. Since 2009, BRGM has run an experimental laboratory at Orléans to test geothermal energy technologies such as heat exchangers, heat pumps, geothermal technologies for cooling, and technologies for underground heat storage. This work includes collaborative projects with businesses and local government agencies[22].

Legislation and regulation

Geothermal energy is state-owned and geothermal resources are regulated under the French Mining Code. Review of the Mining Code has been under consideration for more than a decade but apart from some administrative streamlining, there have been no major revisions so far[23]. Geothermal projects must also comply with environmental and other regulations.

Under the Mining Code, the geothermal system is subdivided based on a combination of depth, temperature of the geothermal fluid as measured at the surface during exploitation drilling tests[24], and energy output (Fig .1). Different regulations apply to each subset of the geothermal system:

- Installations at depths less than 10m are partly exempt from the Mining Code.
- Projects between 10 and 200m in depth with an installed power of less than 500 kWt go through a simplified application process.
- The procedural steps needed for low-temperature and high-temperature projects at depths greater than 200m are outlined in Table 1.

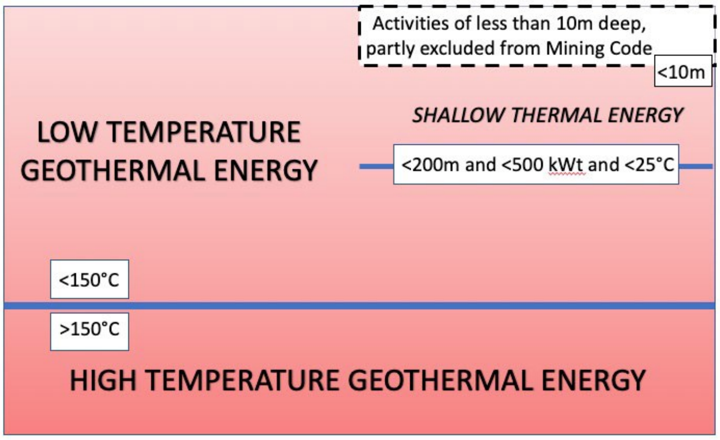

Figure 1. Summary of categories of geothermal energy resources under the French Mining Code. (Modified from Boissavy et al., 2019Error! Bookmark not defined..)

	Low-temperature project Drilling depth >200m Temperature <150°C	**High-temperature project Drilling depth >200m Temperature >150°C**
Application for an Exclusive licence to prospect	Administered by the prefecture Public inquiry	Administered by Ministry of Mines European competition Public consultation via web platform
Permit is issued	Prefectural decree, valid for 3 years	Ministerial decree, valid for 5 years
Authorization for exploration work	Administered by the prefecture Public inquiry	
Commissioning of plant	Administered by the prefecture Registry of public consultation	
Concession application	Administered by the prefecture Public inquiry Concessions are valid for 50 years, renewable for a period of 25 years	

Table 1. Main regulatory steps for low-temperature and high-temperature geothermal projects in France. (Chavot et al., 2019[3].)

Several levels of authorisation are required for exploration and production and the processes can be lengthy, especially for high-temperature projects. Two permits are needed for exploration: an exploration permit (Permis exclusive de recherche) that gives the exclusive right to explore, and an operations permit to allow exploration activities to take place. Two national ministries, the Ministry of the Economy and Finance and the Ministry of the Ecologic and Sustainable Transition (Ministry of the Environment), jointly administer exploration licences for high-temperature projects[25]; the local Prefect (Préfet), who is the national government's representative in an administrative region, decides on all other applications for exploration permits The Prefect also adjudicates on applications to carry out exploration work. Most exploration and extraction activities, including drilling, require an environmental impact assessment and a public inquiry[26]. A mining concession is required for production activities; this is administered by the Prefect.

Government support for geothermal energy

France was the first country to support low-temperature geothermal energy through a risk guarantee scheme, creating the Long Term Guarantee Fund to cover the operating life of geothermal works in 1981 and the Short Term Guarantee Fund to cover geological risks in 1982[2]. This innovation, combined with financial subsidies and repayable loans, is credited with establishing the low-temperature geothermal sector in France and it has been emulated by other countries, including the Netherlands. These programmes also provided value for money to the state. France paid €4.7 million to the Short Term Fund and for every

€1 paid by the state, €42 of investments were guaranteed. It paid €8.5 million to the Long Term Fund and for each €1, €33 of investments were covered. The original Short Term Guarantee Fund ended in 1996 and the original Long Term Guarantee Fund ended in 2013 when the last 25-year guarantee expired.

The risk guarantee funds have been reconfigured to encourage more investment in renewable energy. The current public-private geothermal risk guarantee fund, launched in 2008, applies to heat projects in deep low-temperature aquifers. It follows a similar model to the original scheme, providing cover for short term risk where a reservoir does not meet expectations and cover for long term risk such as a decrease in temperature or flow rate, or severe corrosion or scaling in wells. Companies pay 3.5–5% of the provisional cost of drilling to join the short term scheme and an annual premium for long term coverage. There is a 65% limit on the amount that can be claimed in compensation for full failure or a 20% cap for partial failure under short term coverage, with more complex calculations for long term guarantees[3]. The programme is administered by the French Environment and Energy Management Agency (ADEME) and managed by SAF-Environnement.

The AQUAPAC warranty is a separate fund administered by ADEME to mitigate risk associated with open loop geothermal drilling to depths of less than 200m with energy production of >30 kW involving heat pumps. This fund has been in operation since 1989. It covers the geological risk associated with a first borehole and production risks for the first 10 years of operation, up to a maximum of €140,000[27].

In 2015, the government announced a new €30-million GEODEEP-SAS public-private fund to provide risk guarantees for deep geothermal wells producing waters at temperatures over 110°C for electricity and/or heat generation in mainland France. The European Commission gave approval for ADEME to contribute €16.1 million to GEODEEP in January 2020[28]27. The other funds are provided by industry and La Caisse des Depôts et Consignations, a public investment bank (Fig. 2). This risk mitigation fund is one of the main activities of the GEODEEP cluster, in addition to the group's marketing role. The fund will provide up to

€16.5 million if a well fails but the fund will close if its first two projects are total failures.

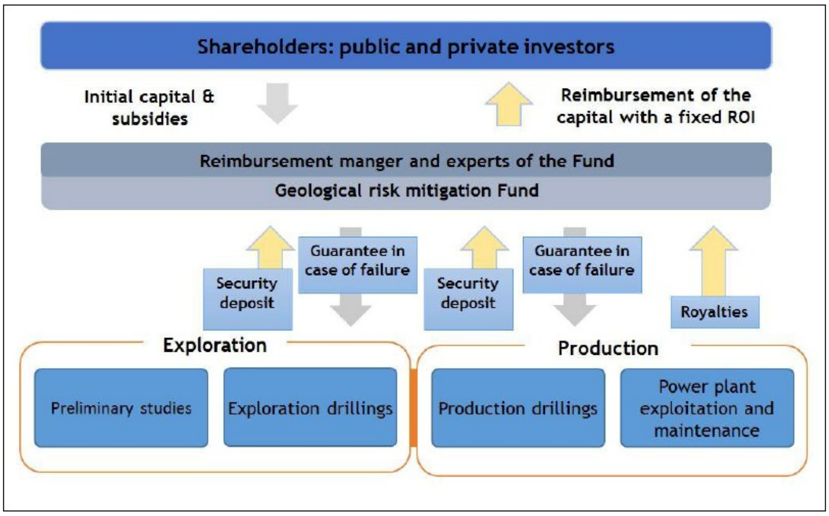

Fig. 2. Organisational structure of the GEODEEP risk mitigation fund for deep geothermal wells[2].

The Renewable Heat Fund is a different mechanism that has helped to revive investment in new geothermal installations and the renovation of existing facilities. It has also encouraged cities to incorporate geothermal energy in their local climate plans[3]. The Fund was created in 2009 to help renewable energy sources to compete with fossil fuels. The programme, which is administered by ADEME, provides a bonus based on the cost of geothermal heat compared to the cost from fossil fuel sources. Different subsidy rates apply to systems with and without heat pumps[29]. The Fund had supported 495 geothermal district heating and geothermal heat pump systems by the end of 2017 and had provided €141 million to new plants**Error! Bookmark not defined.**. There are concerns that the draft Multiannual Energy Plan does not guarantee a feed-in tariff for geothermal electricity going forward but this is still subject to discussion[28].

THE NETHERLANDS

Dutch government policies encourage the use of geothermal energy for heating and the Netherlands is regarded as a leader in this sector. Major impetus for both shallow and deep geothermal has come from pressure to meet national emissions goals and from the government's decision to end production of natural gas from Europe's largest gas field, Groningen, by 2022 following a series of earthquakes related to subsidence due to natural gas extraction. As of July 2018, newly built houses cannot be connected to the gas grid so interest in alternative affordable, reliable heat sources has increased.

Both shallow and deep geothermal sources are used to heat and cool buildings; geothermal energy is not used to generate electricity. Geothermal activities at depths greater than 500m are regulated under the Mining Act of the Netherlands so this depth is used to differentiate between shallow and deep geothermal projects.

Shallow geothermal energy has been used in the Netherlands since the mid-1980s. By 2015, it was the dominant heating and cooling technology for utility buildings and it was being used to heat individual houses and some residential areas with more than 1,000 houses[30]. Shallow systems include Ground Source Heat Pumps and two types of Underground Thermal Energy Storage (UTES): open-loop Aquifer Thermal Energy Storage (ATES) and closed-loop Borehole Thermal Energy Storage (BTES)[31]. The number of ATES systems more than doubled in 10 years, from less than 1,000 in 2008 to almost 2,500 in 2018, and UTES systems are considered a feasible alternative to gas-fired boilers. There is growing interested in high-temperature storage and hydrothermal energy, some of which would straddle the legislative boundary between shallow and deep geothermal energy.

After a rather unsuccessful start before 2000[30], geothermal energy production from depths over 500m has grown faster in the Netherlands over the past 10 years than in any other European country[32]. Nevertheless, geothermal still only contributes about 0.5% of the country's total heat production[33]. The horticulture sector has driven almost all of the growth by using geothermal energy to heat greenhouse complexes. This has helped to increase confidence among investors, government officials, and the public in geothermal energy[34].

Dutch deep geothermal production comes from hot sedimentary aquifers, primarily from Upper Jurassic–Lower Cretaceous and Permian[35] sandstones. In the West Netherlands Basin in the southwest of the country, the source of the majority of geothermal production to date, the primary targets are Lower Cretaceous fluvial sandstones at depths of 2,000 to 3,000 m[36]. At end 2019, there were 24 installed doublets in the Netherlands, of which 20 were in production. Heat production of 5.6 PJ (petajoules) in 2019 was 51% higher than in 2018[37]. Geothermal energy is not used to generate electricity in the Netherlands.

Geological data

TNO, the Netherlands Organisation for Applied Scientific Research, which includes the Geological Survey, hosts a very extensive, publicly available suite of databases on the subsurface, which is available through the NLOG (Netherlands Oil and Gas) portal[38]. "Nowhere in the world is there as much knowledge about the subsurface as in the Netherlands," according to Tirza van Dalen, Director of the Geological Survey[39]. The data come from work by TNO, academic researchers, and exploration and production companies which must share data with the Minister of Economic Affairs under the terms of the Mining Act[40]. Company data is made publicly available five years after acquisition[41].

There are, however, areas where there is scant information on the subsurface and some of these areas are considered to have good geothermal potential[42]. The TNO and EBN (Energiebeheer Nederland, a Dutch government entity involved in oil and gas activities on behalf of the state) started a three-year seismic programme, SCAN, in 2019 to acquire new data and reprocess existing seismic data to increase understanding of the subsurface and the potential for geothermal heat production.

The quantity and quality of Dutch subsurface data allows exploration companies and the government to calculate with 90% certainty (P90) the likely power output of a projected doublet. This degree of certainty enables the government to provide a risk insurance scheme and it helps companies to get up to 70% bank financing [43]but project financing can still be difficult.

Legislation and regulation

Deep (>500m) geothermal energy is regulated under the Mining Act of the Netherlands ("Mijnbouwwet")[44], which covers minerals at a depth of more than 100m, oil and gas, geothermal energy at depths of more than 500m, and subsurface storage including CO_2 storage. Geothermal energy laws and regulations are being revised; the current separation of policies on shallow (<500m) and deep (>500m) geothermal projects is under review[31].
Changes to the geothermal sections of the Mining Law are expected to come into force on January 1, 2021[37].

Operators must acquire a licence to prospect for or produce geothermal energy and they must share data with the government. The government may require geothermal producers to pay an annual fee to the state. Geothermal exploration and production activities must meet environmental and planning regulations. The Dutch government is in the process of
replacing 15 existing laws with a single, streamlined Environment and Planning Act, which is due to take effect in 2021[31].

Given the intense use of the subsurface in the Netherlands and the detailed knowledge available about much of the subsurface[45], the government is preparing a "Subsurface Policy Strategy" to support sustainable and responsible use of the subsurface[46]. Where there are numerous shallow geothermal systems, local authorities develop master plans to reduce interference between systems and to optimise use of the heat resource[47].

Government support for geothermal energy

Shallow geothermal energy developed in the Netherlands with relatively little government support. There is a feed-in tariff scheme for sustainable energy, ISDE (Investeringssubsidie voor Duurzame Energie), that includes shallow geothermal energy and the government introduced a subsidy for heat pumps in 2016[31].

In addition to providing public access to subsurface data, the government has established several support schemes to encourage the development of deeper geothermal energy. In 2012, geothermal energy was included in the SDE+ (Stimulering Duurzame Energie) scheme which provides a subsidy for the production of renewable energy[48]. SDE+ is an operating (feed-in tariff) subsidy that compensates producers for the difference between the cost price of renewable energy and the market value of the energy supplied. The amount and duration of the subsidy depends on the technology used and the amount of energy produced. The 2020 SDE+ spring tender round for all types of renewable energy has a total budget of €4 billion. After spring 2020, the programme will be expanded to an incentive for sustainable energy transition (SDE++).

The Dutch government also established a risk mitigation fund that pays out 85% of well costs if the thermal power output is lower than expected, up to a maximum of €7.2 million. Participants pay a fee of 7% of the maximum support[41].

The government has partnered with the horticulture sector to reduce carbon dioxide emissions from greenhouses and to accelerate the use of geothermal energy in horticulture,

with a focus on targeted research and information sharing. The initial Knowledge Agenda programme lasted four years and a successor programme is being developed[3131].

Public-private sector cooperation and developing a Master Plan

The Dutch approach to policy involves consultation and collaboration between government bodies, trade unions, industry, and other groups. One of the main points of contact between the government and the geothermal sector is the Stichting Platform Geothermie (SPG), which was set up in 2002 to promote socially responsible development of deep geothermal energy through the dissemination of information and dialogue[49]. The SPG has approximately 85 members including governmental organisations at province, region, and municipality levels, academic and research institutions, and a wide range of companies with an interest in geothermal energy. The SPG, the Dutch Association of Geothermal Operators, the Stichting Warmtenetwerk (Heat Platform), and EBN (which is involved in oil and gas activities on behalf of the state) worked in collaboration with the Ministry of Economic Affairs and Climate, and the Ministry of the Interior and Kingdom Relations to produce a *Master Plan for Geothermal Energy in the Netherlands* in 2018[50].

The Master Plan sets out ambitious targets for the development of geothermal energy in the Netherlands, particularly for use in horticulture, urban heating (and cooling), and in industries that use low-medium temperature heat in their processes. A key goal is to develop 5-10 successful urban heating pilot projects and at least five successful industrial pilot projects to gain the knowledge needed to derisk further investment and development. The Master Plan identifies what the geothermal sector will provide and what the sector needs from others, including policy makers, in order to make progress in six areas: profitable projects; effective legislation and regulations, regulatory structure and policy; safe and effective operational activities; robust public support; innovation; and connecting to heat networks.

The Ultra-Deep Geothermal Energy Programme (UDP) is another example of cross-sectoral collaboration[51]. Ultra-deep is defined as greater than 4,000m. The programme started in 2017 and has been extended by its participants beyond its initial deadline of 2020 with the goal of starting a pilot project by 2022. Programme partners include the Ministry of Economic Affairs and Climate, which provides up to 50% of the funding for the Exploration Work programme part of the UDP, the EBN (state petroleum investment body) which provides expertise and coordinates the UDP, the TNO (state research body) which carries out research and makes data and information publicly available, and five consortia that fund at least 50% of the Exploration Work programme in their geographic area[52]. Much of the geological work is carried out within the SCAN research programme[53]. National-level studies are mainly done through the state bodies and the consortia then use the results of this work to carry out more out detailed regional and local studies and modelling[28]. In addition to the mainly geological Exploration Work programme, the Knowledge and Expertise programme addresses topics including communication and stakeholder engagement, business case analysis and financing, system optimisation, and project management.

BELGIUM

Geothermal energy usage has grown slowly in Belgium but investment is increasing and several larger scale projects are under development. The main geological target horizon in Belgium, Lower Carboniferous limestones and dolostones[54], would also be a major target in Ireland so the Belgian experience may provide useful guidance especially on geological, technical, and research issues.

Belgium is a federal state where regions and communities have considerable policy independence. The federal government is responsible for Belgian relations with the European Union and Belgium has published a draft Integrated National Energy and Climate Plan 2021-2030, that combines individual plans and goals developed by the regions[55]. The three regional governments – Flanders, Wallonia, and Brussels-Capital – have primary responsibility for geothermal policy through their roles in setting energy, environmental, business, and research policies[56]. Regional policies, which are summarised below, reflect the different geological, economic, and physical settings of the regions. The three communities– Flemish-, French-, and German-speaking – are responsible for health, education, and other topics that may impact the geothermal sector[57].

In the country as a whole, the shallow geothermal sector is expanding and there were approximately 25,000 ground source heat pumps in operation in 2018[58]. Energy efficiency regulations and moves towards passive construction (which has been mandatory in Brussels-Capital since 2015) are driving the expansion. Geothermal systems have the added advantage of providing both cooling and heating functions, which are needed in well- insulated buildings.

The most attractive deep geothermal targets are karstified Devonian-Lower Carboniferous carbonate rocks at depths of about 4,000m in the Campine Basin in Flanders. A pioneering deep geothermal project, Balmatt in Flanders, reached production briefly in 2019 but was

shut in pending investigation of induced seismicity[59]. Similar rocks in the Namur-Dinant Basin in Wallonia may also be of interest and some younger sediments may have potential[60]. Three heating networks in Wallonia are linked to deep geothermal wells and another should be onstream by 2022. Belgium generates no electricity from geothermal sources.

Geological data, research, and development projects

Research by the Geological Survey of Belgium (BGS) includes studies on the geothermal potential of Belgium, developing management and monitoring tools for a 3D (sub-) surface inventory of resources and activities, and modelling of multiple resources activities in the same area[61]. BGS also coordinates with geological bodies in the three regions that carry out their own research programmes[62].

Flanders: VITO, an independent Flemish research organisation specialising in cleantech and sustainable development, has developed Balmatt, a major deep geothermal heat and power pilot project in northern Belgium at a cost of about €45 million, of which approximately €40 million came from private sources and €4.15 million was provided by the Flemish government[63]. After a 10-year research programme, they successfully proved reservoir temperatures of 138°-142°C at depths of 3,000-3,600m in a fractured Lower

Carboniferous carbonate reservoir[64]. Balmatt came onstream in May 2019; production was stopped, however, after a 2.1M earthquake on 23 June 2019. Researchers are working to resolve the problems. In spite of this setback, a spin-off company plans to develop 10 additional geothermal plants in the region[65]. Balmatt is a key element in several research programmes including DGE-ROLLOUT, a transnational collaboration on geothermal energy by Germany, the Netherlands, Belgium, and France[66], GEOENVI, which assesses environmental impacts of deep geothermal energy[67], GeoSmart, which is investigating the ability of geothermal plants to respond to changes in demand[68], and HEATSTORE, an international study on the role of smart district heating network controllers[69].

Wallonia: Most deep geothermal activity in Wallonia is centred around the Mons area where Devonian-Lower Carboniferous carbonate reservoirs are already used to provide district heating. Research includes seismic and gravimetric surveys as part of the site investigation for a doublet to provide heat for a hospital[64]. Shallow geothermal systems are also being investigated because many cities in Wallonia are underlain by highly productive, shallow (~5-30m), alluvial aquifers that could act as aquifer thermal energy storage (ATES) systems for heating and cooling[70].

Brussels-Capital: The Region and the European Union funded the four-year (2016-2020) Brugeo programme, which focused on collecting, compiling, and sharing information on the subsurface to depths of approximately 250m to support the use of shallow closed and open loop systems linked to heat pumps[71].

Legislation and regulation

There are no national-level regulations on geothermal energy[72]. Shallow geothermal projects are dealt with under environmental and planning regulations. Flanders has the most developed deep geothermal policies, followed by Wallonia. Brussels-Capital focuses on relatively shallow geothermal projects for urban uses because it does not have deep geothermal potential.

Flanders: The Flemish government is developing a structural vision for the deep subsurface (defined as depths below 500m) to support planned and sustainable management of the subsurface[73]. A structural vision is an advisory document that sets out how the planning agency wants to see an area develop and provides guidance for decisions on competing uses of the area. The structural vision is implemented via land-use plans and project plans[74].

Flanders has chosen not to define ownership of geothermal heat, arguing that "geothermal heat is not a matter in itself, and one can only speak about property (rights) with regard to matters" [Google translation from the original Dutch][75]. The Region regulates exploration for and production of geothermal energy through a licensing system and through environmental regulations[76].

Wallonia: There is currently no single piece of legislation covering deep geothermal activities in Wallonia. Activities related to geothermal development come under the water, environmental, urbanism, and housing codes and require an Environmental Impact Assessment[77]. The government is expected to adopt a new decree on underground resource management that will include geothermal energy as a strategic resource and would define exploration and production protocols; the decree is still under development[64].

Brussels-Capital: The Region has no specific geothermal legislation but geothermal projects are subject to environmental and urban planning laws and regulations. For heat pump systems, the type of authorisation required depends on the rated electrical power of the compressor and the recirculation pump, combined with the amount of heat transfer fluid in the heat pump and its content of ozone-depleting substances[78].

Government support for geothermal energy

Flanders: Producers of geothermal heat do not have to pay a fee to the Flemish Region, unlike hydrocarbon producers[75]. Since 2018, the government has underwritten a guarantee scheme for geothermal heat projects to cover short-term geological risk associated with the initial drilling phase, including issues associated with the thickness of the aquifer, its permeability, depth, salinity and geothermal gradient[73]. The guarantee scheme does not cover technical issues, induced seismicity, or other risks. Developers must pay a premium of 7% of the maximum benefit amount; the maximum cover is €18.7 million, not exceeding 85% of eligible costs. There are different provisions for the first and second wells of a doublet. Separate finance programmes support investments in large (over 5MW), small (up to 5MW), and agricultural geothermal installations[79].

Wallonia: In 2019 Wallonia created a regional guarantee system to cover the geological risk associated with the initial drilling for a geothermal project[64]. Energy subsidies, investment assistance, and zero-percent interest loans are available to support the generation of heat from renewable sources[80]. The Walloon Region considers subsidies for deep geothermal projects on a case-by-case basis and some projects may qualify for European Regional Development Fund (ERDF) support.

Brussels-Capital: The Region provides energy subsidies and investment incentives to encourage the development of heating systems that use renewable energy sources and meet stringent energy efficiency standards[81].

SCOTLAND

Scottish geothermal policy and project development is at a broadly similar stage to Ireland. Scotland is focusing on geothermal development for heat production because the heat sector has been slower to decarbonise than the electricity sector. Heat policy is devolved to the Scottish government but some other aspects of energy policy, including electricity policy, are reserved to the UK Parliament at Westminster[82]. Scotland produced a Heat Policy Statement in 2015 that prioritises decarbonising heat, energy efficiency, and the development of district or communal heating projects.

Scotland has the potential to extract heat from water in abandoned coal mine workings in addition to thermal energy from hot sedimentary aquifers and hot dry rock sources. The British Geological Survey is constructing a major research facility near Glasgow, the Glasgow Geoenergy Observatory, to examine the heat potential of flooded coal mines[83].

The Scottish government has a full-time Geothermal Programme Manager in the Energy Industries Division of the Scottish Government Onshore and Subsurface System Policy Unit who leads policy development and implementation.

There are no projects currently producing heat for district heating[84]. Two small district heating projects using heat from mine waters operated for several years[85] but shut down in part due to the lack of broad maintenance support.

Geothermal legislation and regulation

Ownership of geothermal energy in the UK has not been resolved. The UK Department of Energy and Climate Change considers that “the heat which is the essence of geothermal energy is not itself capable of ownership” but that the medium that transfers the heat from underground to the surface (e.g., groundwater) is capable of ownership[82].

Scotland has no specific geothermal legislation. A Regulatory Review subgroup concluded in 2015 that “the regulatory framework for mine water and hot sedimentary aquifer geothermal projects is sufficient for the purposes of the current geothermal industry” but they could not determine whether additional legislation was needed for hot dry rock (enhanced geothermal systems) projects because there were no test projects on which to base a decision[86]. The legislative and regulatory situation will be reviewed if issues arise when projects are being developed; in the meantime, geothermal developments are regulated through existing planning, environmental, health and safety, and other regulations.

Geological and regulatory information

The Scotland Heat Map collates information on heat supply and demand in Scotland with layers providing geospatial data on heat demand, energy supply, geothermal, tenure, and district heating[87].

A comprehensive two-volume *Study into the Potential for Deep Geothermal Energy in Scotland,* (2013) examined the possibility of deep geothermal energy in Scotland. Volume 1, written by AECOM, includes details on ownership of geothermal energy; potential licensing options and regulatory regimes; an assessment of costs, financing and benefits; and recommended actions[82]. Volume 2, prepared by the British Geological Survey, reviews the geological aspects of geothermal energy in Scotland. For the purposes of the report, “deep” was defined as greater than 100m depth but, in considering a future potential licencing regime, "200m has been recommended as the nominal division between generally shallower GSHP [ground-source heat pump] developments and 'deeper' geothermal developments"[82].

A summary of government actions on geothermal is available on the Scottish government website on renewable and low carbon energy[88]. To help developers navigate the regulatory requirements, the Scottish government prepared a summary of the regulatory framework for exploring and exploiting Scotland's geothermal resources that lists the relevant legislation and regulations[89]. The Scottish Environment Protection Agency has published a guide to their requirements for activities related to geothermal energy, which is "broadly defined as energy from the interior of the earth used for heating or cooling"[90].

Government support for geothermal energy: In 2015, the government launched a £250,000 Geothermal Energy Challenge Fund[91] under the Low Carbon Infrastructure Transition Programme[92] with European Region Development Fund support for geothermal projects to meet the energy needs of local communities. Four projects were funded (five projects were selected but one project dropped out before receiving funds) at a total of £185,235 but none are in production yet. Other funding for geothermal heat projects may be available under the Community and Renewable Energy Scheme and the District Heating Loan Fund.

Under the Renewable Heat Incentive (RHI) scheme, which includes England, Scotland and Wales but not Northern Ireland, some domestic ground-source heat pumps may be eligible for quarterly cash payments over seven years. In the non-domestic RHI sector, different rates of subsidy are set for small water/ground-source heat pumps (<100 KWth), large water/ground-source heat pumps (≥ 100 KWth), and deep geothermal (defined as heat from depths of below 500 metres underground[93]). The rates favour deep geothermal over shallower sources and this may impact some mine water geothermal projects which are likely to be shallower than 500m.

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