The Fortissat Minewater Geothermal District Heating Project: A Case Study

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Abstract

This paper summarises the findings of a feasibility assessment for a potential minewater geothermal energy system in the vicinity of the James Hutton Institute's Hartwood Home Farm, North Lanarkshire in Scotland's Central Belt.

The study aimed to assess the potential for Scotland's first minewater geothermal scheme in a rural area with social deprivation. While focused on the specifics of the location, the project is conceived as a readily replicable and fully operational mine-water geothermal district heating system demonstrator project that would act as proof of concept for duplication elsewhere.

The study concluded that the scheme is technically and financially viable, breaking even or better with a network scenario covering the 'representative' communities of Allanton and Hartwood. As expected, there are considerable economies of scale, with the scheme becoming commercially viable when the network is extended to the town of Shotts.

Keywords: Geothermal heat, abandoned mine, mine water, district heating

Background and Study Area

The Fortissat project was one of four projects awarded funding from the Scottish Government's Geothermal Energy Challenge Fund (GECF), for the 'Catalyst Stage', which covers initial strategy development and feasibility work[1]. These projects have been funded to explore the potential of Scotland's geothermal resource to meet the energy needs of local communities.

The study area for the Fortissat project lies in the Midland Valley of Scotland, some 27 ESE of Glasgow and 43 km WSW of Edinburgh. The study area extends 5 km from Hartwood Home Farm (3.8388°W, 55.8129°N), which is roughly equivalent to the Fortissat ward of North Lanarkshire, and includes the settlements of Hartwood, Allanton, Shotts and Salsburgh. Although the feasibility study also addressed the complex technical and stakeholder management issues associated with development of a community district heating system within a varied portfolio of existing accommodation held under mixed tenure rather than a new build housing scenario, these issues are not described here.

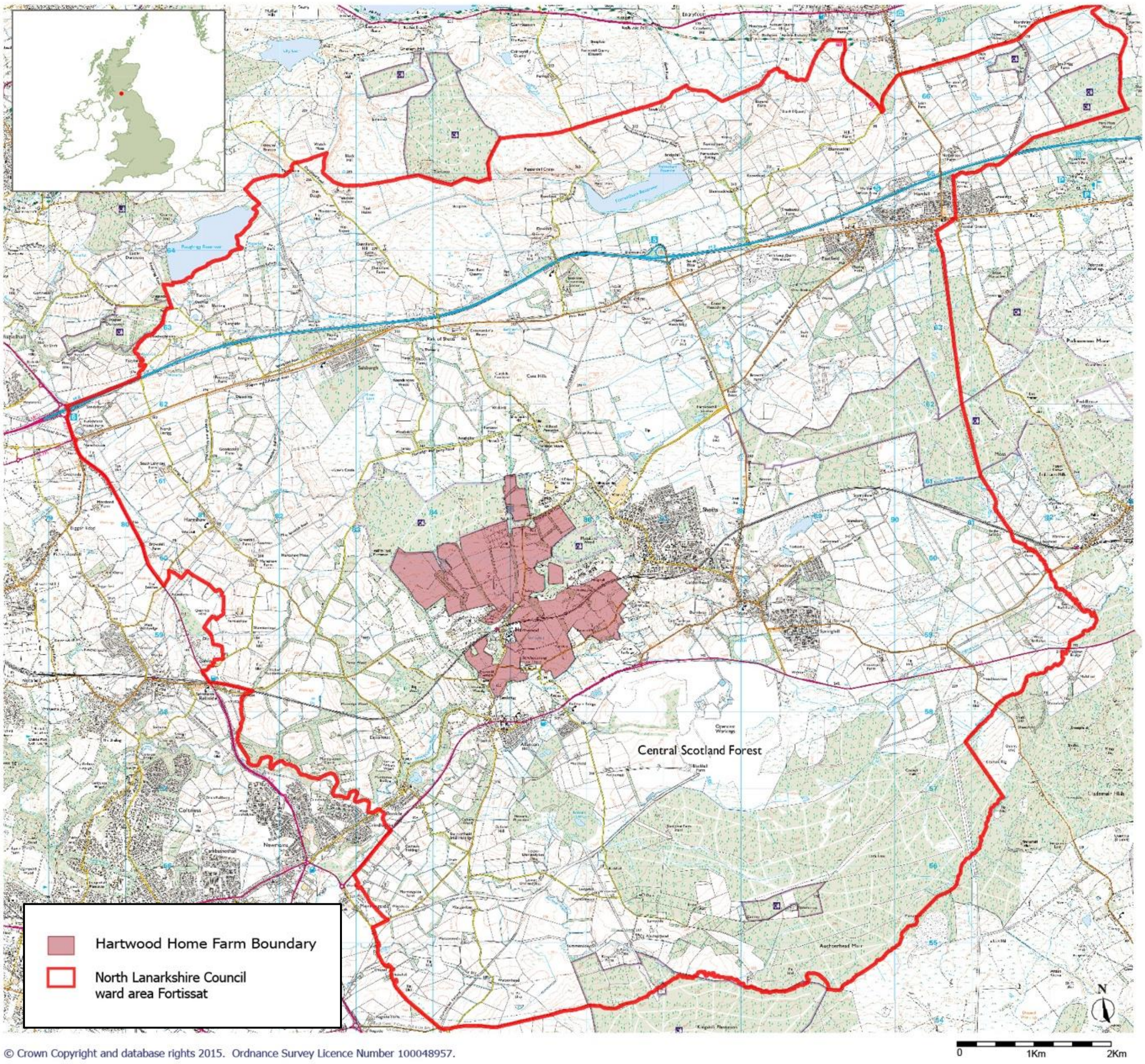


Figure 1: Map of study location.

Geothermal Supply

The geothermal resources targeted in the study are low enthalpy (temperatures in the region of 10–20 °C, depending on depth), requiring the use of heat pump technology to provide space heating. Abandoned mine workings have previously been used successfully as geothermal sources in Scotland and elsewhere in the UK[2,3,4,5]. The minewater mapping of the Fortissat study area has identified the worked coal seams of the Kingshill Colliery as by far the most significant low temperature geothermal resource in the area of interest and has been the main focus of this study, following a geothermal systems option appraisal which considered the various mine systems in the study area. Kingshill Colliery is one of Scotland's largest historical mine systems and the mine seams (primarily comprising the Wilsontown Main (WNMA) and Woodmuir Smithy (WRSM) seams) partly underlie the southern area of the Hartwood Home Farm, and extend southwards under the village of Allanton. Kingshill Colliery[6,7] was abandoned in 1975 and allowed to flood. By 1985, minewater levels had reached surface and started to discharge in vicinity of Allanton and the Kingshill No. 1 shafts[8,9,10]. The former Kingshill Colliery No. 1 shaft site lies to the south of Allanton, and is in the ownership of North Lanarkshire Council, and drainage maintenance presents an ongoing financial burden to the Council, with minewater resurgence issues allegedly continuing to affect homes in Allanton. The estimates of the geothermal potential in the WRSM and WNMA, subject to the uncertainties implicit in a desk-based assessment, represent 258 years of heat extraction at a rate of 0.63 MW, or 71 years of heat extraction at a rate of 2.3 MW[1].

Two preferred options have been identified for the geothermal supply in two locations, and with alternative methods for discharging the minewater - both involve drilling to workings in excess of 300 m deep. The 'preferred' option (Fig. 2) locates the production well at or in the vicinity of the Kingshill No.1 shaft to the south of Allanton, and proposes a passive treatment system to treat the minewater at surface prior to discharge to an existing watercourse. This option is preferred due to its potential to regionally lower minewater levels and thus to mitigate existing minewater resurgence issues affecting the village of Allanton, whilst properly treating the minewater. The ‘alternative’ option (Fig. 3) proposes a more traditional geothermal doublet system, with a widely-spaced production well and injection well(s) located on Hartwood Home Farm (note, one option would be to drill more than one injection well, given the typically lower specific capacity of injection wells relative to production wells[11] and the potential down time required for maintenance and backwashing).

District Heating Network

In parallel with the geothermal system options appraisal, an appraisal of potential district heating network (DHN) design options (Table 1) and associated heat market has been undertaken. The initial focus for assessing the energy needs of local communities in the area encompassed the town of Shotts, the villages of Hartwood, Allanton and Salsburgh, and residential and non-residential development within the area, roughly equivalent to the Fortissat Ward of North Lanarkshire. The feasibility study identified constraints and opportunities in relation to using the available geothermal energy to provide heat in this area, to inform the identification of potentially viable heat networks. Balancing the risks and opportunities, a medium term potential has been identified which connects Allanton and Hartwood to a DHN (design option C). This DHN is scaled to enable the primary heat source for the energy centre to come from the geothermal minewater, pumped from a single production well.

Table 1: District Heating Network Options.

DHN design option	Description
A	700 kW heat pump capacity, 173 council houses and 155 private houses, low temperature DHN (Allanton only)
B	1 MW heat pump capacity, 197 council houses, 240 private houses, low temperature DHN, 1 school (Allanton only)
C	2 MW heat pump capacity, 201 council houses, 415 private houses, low temperature DHN, 1 school (Allanton and Hartwood)

The estimated minewater temperature of 18 °C necessitates a heat pump based system. Heat is extracted from the minewater using a heat pump and upgraded to the required network flow temperature. The heat pump model has been developed to take account of the diversified demand profile, with a gas boiler providing system top-up and back-up.

To evaluate the optimal supply and return temperature, the financial sensitivity test for different supply and return temperatures was conducted[12]. The financial sensitivity tests 75/45, 65/35 and 55/25°C design options, all with a 2 MW heat pump total capacity.

Table 2: COP and Flow Rate at different network flow temperatures[12].

T_{supply} / T_{return} (°C)	55 / 25 °C	65 / 35 °C	75 / 45 °C
COP	5.90	4.40	3.58
Flow rate (kg/s)	49.62	46.17	43.06

On the basis of the sensitivity analysis, a low temperature district heating network system with 75/45°C supply and return temperatures is proposed, which is deemed sufficient to meet end user's space heating and domestic hot water needs[13].

The higher capital costs of the low temperature system are offset by the lower operating costs [13,14,15] and crucially, eligibility for the Renewable Heat Incentive (RHI) that follows from a Co-efficient of Performance (COP) above 2.9.

As regards the "parasitic" power potentially consumed by the submersible pump used to extract water from the mine workings, it should be remembered that, while the workings may be at >300 m depth, the static water head in the mine is very close to ground level (and in some locations, potentially artesian). Although, the act of pumping would draw down the head somewhat (to a degree that cannot be reliably predicted until a trial borehole has been drilled and test-pumped), there are grounds to be optimistic that the pumping head would be modest. The power (P) required by the submersible pump to overcome the pumping head (h) can be estimated by[11,16]:

$$P = Q \times h \times \rho \times g / \eta \qquad \text{(eq.1)}$$

where Q = pumping rate (L/s), h = pumping head (m), ρ = water density = c. 1 kg/L, g = 9.81 m/s^2 and η = pump efficiency (0.6 to 0.7, say).

Thus, pumping 30 L/s up a height of (for example) 80 m would imply a parasitic power of 30 x 80 x 1 x 9.81 / 0.65 = 36 kW, whereas the water could have a potential heat yield of over 30 L/s x 4200 J/L/K x 5 K = 630 kW. If we assume a heat pump COP of around 5 (Table 2), this level of parasitic power would reduce the effective COP to around 4.1.

Development Options

The development options integrate the geothermal system design options appraisal and district heating network (DHN) design options appraisal. Two alternative design options are selected, taking into account all subsurface and surface factors considered. Option 1 (Fig. 2) consists of a single production well and passive minewater treatment facility. The identified location for the production well is south of Allanton near or even at the Kingshill Colliery Shaft No.1. Pumping minewater in this vicinity offers the highest potential for lowering the local minewater levels and reducing or preventing the minewater resurgence issues which affect this area and the nearby village of Allanton. It also allows the polishing wetlands to be located in an area already containing sedimentation lagoons, and contribute to the objectives of the Local Nature Reserve and Site of Importance for Nature Conservation. Minewater would be pumped from the WRSM seam at a depth of c. 340 m below surface level.

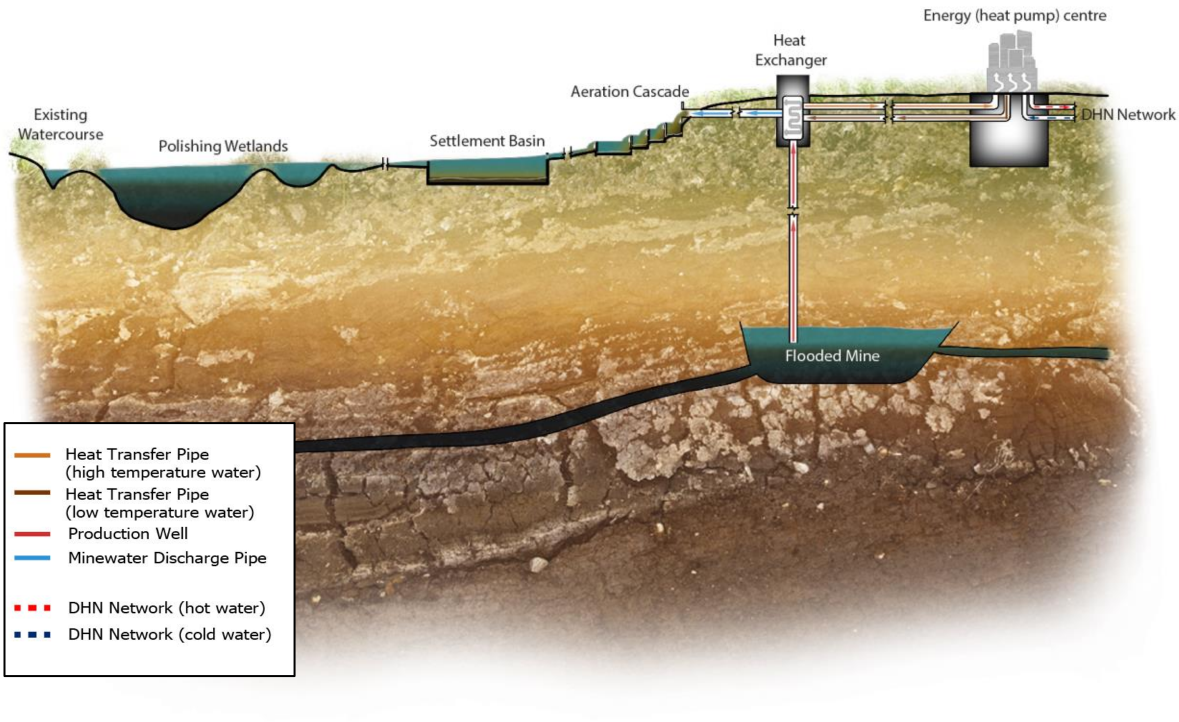


Figure 2: Illustrative diagram of passive minewater treatment facility. The depiction of the mine workings as an underground reservoir is, of course, a highly simplified version of the subsurface mine geometry.

Option 2 (Fig. 3) consists of a production well and two injection wells, with no passive minewater treatment. The geothermal system and heat centre components of this option are contained entirely within the JHI Hartwood Home Farm land boundary. This option produces and injects minewater from the WRSM seam at a depth of ca. 380 m below surface level. The heat centre in this option is situated between Allanton and Hartwood.

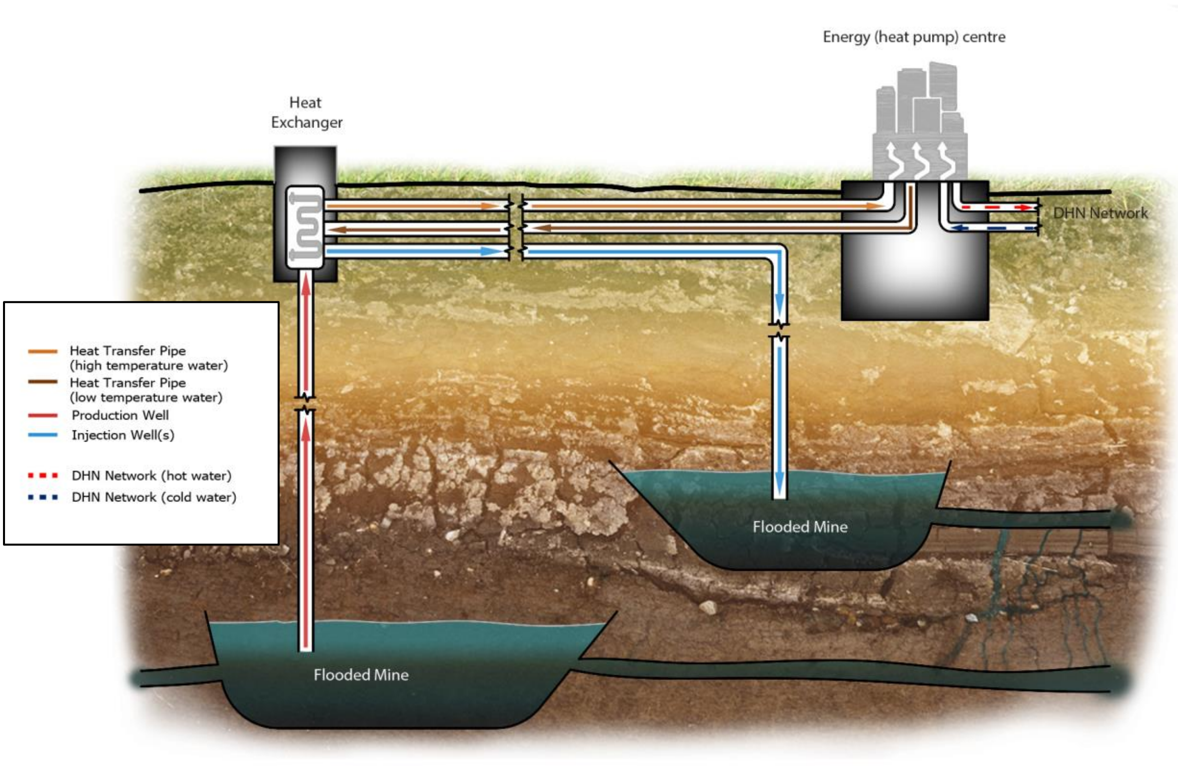
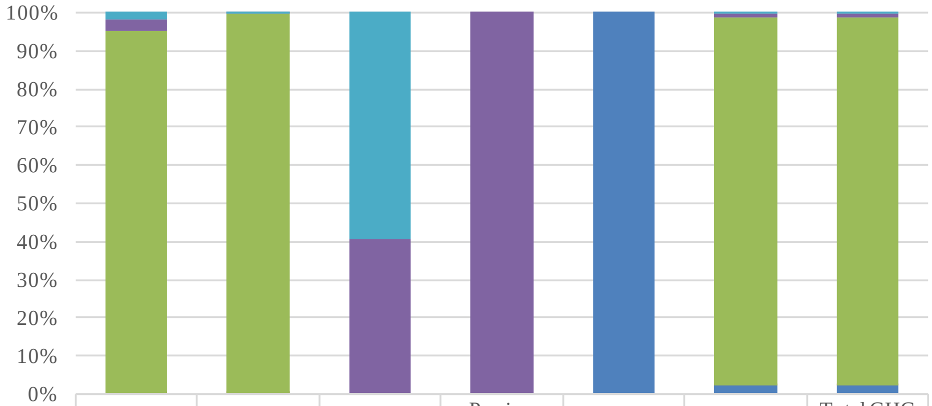


Figure 3: Illustrative diagram of doublet system with production and injection well(s). In reality, there will be subsurface hydraulic connectivity between the injection and production wells.

Life Cycle Carbon Analysis

Following a comprehensive life-cycle assessment[17] (Fig. 4), the proposed scheme has been calculated to offset 22 kilotonnes of greenhouse gases (GHG) over its projected lifetime compared with the (current) baseline in which end-users rely on a mix of electricity, oil, coal and gas.



	Production well (kgCO2e)	Heat Centre (kgCO2e)	Heat network (kgCO2e)	Passive Treatment System (kgCO2e)	System heat loss (kgCO2e)	Total GHG emissions (kgCO2e)	Total GHG emissions (gCO2e/kWh)
Material and energy prodution	23414	445	195542			219401	0.71
Construction	32896	18922	133380	48000		233198	0.76
Operation	1124828	42288438				43413265	141.47
Decommissioning	2146	37				2183	0.01
System heat loss					895226	895226	2.92

Figure 4: Full lifecycle GHG emissions of the Fortissat Geothermal Project[17]

Unsurprisingly, the operational element contributes most to GHG emissions (141.47 g CO_2e/kWh_{th}). Clearly, if the electricity used to power the heat pumps could be wholly or partially generated through low-carbon generation, the emissions offset of the scheme would be further improved. Options would include on-site CHP generator, with the exhaust heat being incorporated into the DHN, or the use of solar PV to power the heat pumps.

Delivery Model

The feasibility study has considered the potential business models and legal structures currently deployed for DHN in the UK, and potential Energy Services Company (ESCO) structures for the Fortissat Minewater Geothermal project, and how these might evolve over the lifetime of the development. A preliminary financial model has been prepared to assess the commercial viability of the development options. The financial model evaluates multiple scenarios based around a heating network that comprises:

- A minewater production well;
- A heat exchanger and clean source loop pipe to capture heat at the production wellhead;
- An energy centre that captures heat from the minewater;
- A back-up gas boiler;
- A district heating network comprising pipework and pumps;
- Housing stock upgrades comprising energy efficiency improvements and a domestic heat interface unit replacing gas boilers; and
- Two options for minewater disposal: either injection wells back into the mine; or a surface passive water treatment plant.

Construction is assumed to take 20 months, with the system becoming operational by 1 April 2021. Ongoing operating expenditure includes plant and well maintenance, electricity consumption, treatment of waste water and gas consumption for the back-up boiler.

The revenue is composed of two elements: heat sales to customers and income from the Renewable Heat Incentive. Appropriate governance structures need to be put in place for all heat customers to provide safeguards that the heat tariff is equivalent, if not discounted, against other forms of energy supply. The revenue for heat sales was modelled as 6 p/kWh which offers a 2% saving to Council tenants compared to a current price of heat from gas of approximately 6.13 p/kWh, and significantly higher savings to current users of oil or electricity for heating. Another factor which has the potential to affect the financial model relates to the cost savings to the Council arising from the new minewater treatment facility.

Table 3: Headline financial projections for development options 1 and 2.

Design Option	Description	20 year net cash (£m)	Project IRR (%)	CAPEX (£m)	COP**	Debt (%)
1*: 2 MW heat pump array, 75 °C	LT Allanton & Hartwood network + passive treatment	3.2	1.6	10.6	3.58	60
2: 2 MW heat pump array, 75 °C	LT Allanton & Hartwood network + doublet system	3.4	1.7	10.8	3.58	60

** This does not account for cost savings to the Council through implementation of a passive treatment facility.*

*** The COP here is for the heat pumps, and does not include the electricity consumed by the submersible pumps and network pumps.*

Both development options (passive treatment and doublet) have positive IRRs and positive aggregate net cash flows over the first 20 years. However, in neither case are the projected returns sufficient to attract commercial investors. This indicates that an appropriate delivery vehicle would be a not-for-profit ESCO which is 100% council-owned, at least at the outset.

Longer term financial modelling confirms that the removal of the RHI revenue after 20 years will have an adverse impact on the project value. There are, however, a number of ways in which this reduction in revenue could be addressed, including:

- The expansion of the network into Shotts would increase the linear heat density, revenue and profitability.

- Setting up a trading arm as a subsidiary, to connect non-Council off-takers on a commercial basis.
- DECC expects gas prices to increase in the future. This will drive up the costs of alternative sources of heating and allow higher tariffs to be used at Fortissat, while still offering customers a discount compared to the alternatives.
- Given the ambitious UK and Scottish targets for decarbonising heat, it is possible that new policies could be implemented to either (i) reform or extend the RHI, or (ii) replace the RHI with another support mechanism.
- Direct carbon taxes may become more prevalent. This would have the impact of increasing the price of gas and heating oil, which in turn would allow the Fortissat project to charge a higher tariff while still offering customers a discount.

There are also a number of factors which may in future reduce the project's operating costs. It is difficult to predict at this stage the likelihood of any of these occurring, or the impact that they may have on the project economics. These factors include:

- The project relies on electricity to power the heat pumps, electric submersible pump (ESP) and network pumps. It is possible that electricity cost will reduce over time as increased penetration of renewable energy in the UK lowers the marginal cost of generation.
- It may be possible in the future to install on-site electricity generation (e.g. solar PV) in order to lower the electricity cost for the project.
- A gradual improvement in minewater chemistry may reduce maintenance costs for the equipment and, possibly, treatment costs.
- Maintenance and infrastructure costs may decrease as heat networks supply chains become more established in the UK.

Conclusion

When viewed within the wider UK or European context, Scotland has (i) a relatively low gas-grid penetration rate; (ii) relatively high demand for heating as a proportion of total energy demand, which is only a small proportion is currently delivered through low-carbon sources; (iii) an anomalously high incidence of fuel poverty, particularly in rural areas; and (iv) an outstanding and virtually unexploited minewater geothermal resource base. In view of this, we believe the case for a demonstrator project in Fortissat – designed from the very outset with *replicability* and *scalability* in mind – merits serious consideration.

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