With the growing need for new low-carbon energy sources, harnessing heat from flooded coal mines appears to be a very attractive solution. In the UK, 37% of the energy consumption is used for residential heating, largely contributing to the carbon emissions of the country. Fortunately, most of the territory has been extensively mined for coal, and despite all the underground mines are today closed, the resource that once contributed to the overall air pollution is now home to another valuable and easily accessible resource: hot mine-water. Using ground-source heat pump (GSHP) systems, heat energy can be extracted from this water and potentially be used for space heating. Mine-water based GSHP schemes have already been implemented worldwide and one of the most successful projects is located at Herleen in the Netherlands. In Scotland, such system has been used since 2006 in Shettleston to provide heat to 16 dwellings. Earlier this year, the Coal Authority has inaugurated the first large scale mine-energy district heating scheme in the UK in South Seaham, where 18-20°C mine water is used to provide heat to the 1500 residents of the new Garden Village.

*A great opportunity, but what its potential?*

Mines have great assets compared to conventional geothermal reservoirs. First, the existence of deep shafts offers a direct access to the mine-water without needing to drill new boreholes, which tend to reduce considerably investments costs. In addition, the risk to tap in an inexistent resource is small, and there is no need to transport this energy far away as the consumers are there, just above the mining fields. Not only could the local population directly benefit from it, but The Coal Authority also sees there a great opportunity to finance the operation costs of the water pumping and treatment schemes already implemented, by selling the heat that naturally comes with it. A great opportunity then! So why are we still questioning it? Because we would like to avoid repeating the same mistakes. Even if the resource is here and might be extensive, we don’t want to deplete it too fast. There is a great challenge in finding the right balance between the geological, technical and economic aspects - between what we need and what the Earth can really offer. To make the heat extraction sustainable, we need to assess the full extent of its potential, and understand how fast the energy we take from the mine-water to heat our houses will be replenished within the mine system, and this is the purpose of my PhD. *Where does the heat come from?*

My research project is about trying to understand what the heat sources in mines are, their contribution to the total heat generation, and the heat recharge mechanisms that controls the mine-water temperature over time. During the operation of a geothermal production system (i.e. mine-water extraction), groundwater might enter the mine reservoir at a colder temperature, if not directly re-injected from the GSHP into the mined strata. The biggest issue would be that this water reaches the production well before warming up. Unfortunately, such “short-circuiting” effect is very likely in mines, where the interconnection of shafts, tunnels and galleries tends to enhance the reservoir permeability at very large scale, connecting hydrological systems that would have been naturally separated. If the inflowing water is hotter than the rock, the recharge potential of the mine might be guaranteed, but if it is colder, then the water might deplete the rock from its heat to fulfil our need. The key question will be to assess if yes or no, a sustainable heat extraction rate can be maintained over the long-term without mining the rock of all its energy.

*Mines, a complex geothermal system.*

Unfortunately, mine reservoirs are not simples. Their complex geometry, that result from a long mining history, make it difficult to predict the mine-water flow path. And to cap it all, no matter how detailed mine plans can be (and they really are!), the amount of collapse that occurred after the mine closure and the current state of the galleries is quite uncertain. As a result, we don’t exactly know the volume and the shape of the residual voids, and thus the volume of accessible water. But more importantly, this might also indirectly affect our capacity to predict the nature of the heat fluxes in the mine, and thus its heat recharge potential. But actually, how important is it?

One of the main points of my study will be to find a way to deal with those uncertainties, by assessing what parameter or geometrical feature does really matter when it comes to understand the key heat transfer processes controlling the temperature distribution at the scale of the mine.

*Look at the past to understand the present and predict the future.*

Mines are complex in space, but in time too. During mining activities, pumping and ventilation were implemented in deep galleries to ensure good working conditions for the miners. Such prolonged periods of cooling in the underground might have induced long-term, if not permanent perturbations of the thermal state of the mine and yet, a few studies aiming at assessing the geothermal potential of flooded mines worldwide considered this possibility. Surely, this is not the kind of anomaly we generally need to consider when evaluating the potential of conventional geothermal systems, but it might be inherent to such “anthropogenically enhanced reservoir” (XXX). Looking back on the history of the mine might therefore be necessary to understand the initial temperature distribution in the mine and the thermal fluxes, and this will be another line of investigation of my PhD.

Who owns heat - Can Science answer the question?

To answer those questions, this project will mostly involve the development of numerical models, calibrated and validated using temperature data acquired from mine shafts by the Coal Authority, who partly fund this research. As no “best” mine modelling approach has emerged yet, developing a tool that could be used in the future to evaluate the full extent of the heat available over the long term would be a valuable outcome of this study. First, it could help optimize the architecture and dimensioning of GSHP systems, for long-term usage. In addition, it would help defining the footprint area of heat extraction, provide a scientific support to guide the licensing of heat. Because when we can’t match geographical boundaries on geological processes, can we set up best practice instead? Indeed, even if delineating hydrological system can be possible and allow predicting the extent of the water resource used, this is not as simple for heat. Heat can go through rocks. So how can we know that we are not stealing heat from the neighbour?

*Cyclical production and mine stability*

Not only could mine systems be seen as an energy source, but also as a storage system, where heat could be injected either seasonally by reversing the GSHP system, or from local buildings or infrastructures in need (i.e. data centres, incinerators), in order to be used later in the year (i.e. winter time). Seasonal production/injection of heat and cold has been proven to increase the efficiency and the sustainability of GSHP system, by ensuring the artificial recharge of heat into the underground. However, the impact of such cooling-warming cycles on the stability of coal pillars that resisted until now to the flooding of the mines is uncertain. If pillars collapse, subsidence of the ground, that generally occurred during or shortly after mining, could be resumed. This would have both a negative impact for the underground by reducing the rock permeability, but also for all houses located at the surface.

Here again, the opportunity turns into a challenge. But luckily, this challenge has been accepted by Fiona Todd, who started her PhD at the University of Edinburgh in XXX. Her project, which consists in evaluating the risk of pillar collapse through a full hydro-thermo-mechanical study of cyclical mine-water heat production, already showed that…

*To conclude…*

Recycling old coal mines into a renewable energy source could highly contribute to the decarbonization of residential heat targeted by the UK to reach Net Zero emissions. Hopefully, Fiona’s study and mine will show optimistic results with respect to the geothermal potential of coal mines in the UK, up to our expectations. Diversifying the energy sources is the key to a reduction of our impact on the environment, and it is legitimate to put mine-water heat on the table. But for that, we need to find the right balance, think in terms of what is available rather than what we need, and for that, we need to get a vision of its potential over the long term. A *Final word? Be smart.* Antoine Lavoisier said “nothing is lost, nothing is created, everything is transformed”. What if we could make it true at the scale of our energy consumption? A giant interconnected loop, where all energy created is recycled, all waste is converted into usable energy source. Let’s think big. And the more brains involved, the more possible it can become.