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Mine Water Utilisation for Climate-Friendly Heat Supply in Residential and Commercial Buildings with Ultra-Low Temperature Heating Networks#

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ABSTRACT

Decarbonising the heating sector is highly relevant and challenging. Heat pumps are promising technologies with strong dependencies on heat source temperatures. Using heat sources with higher temperatures lead to better efficiencies of heat pumps. One heat source that is available in regions worldwide where mining used to be a part of economic activities is water from coal mining. This article investigates the possibility of reusing the abandoned mining areas in the Ruhr area, Germany, in particular the possibility of using the heat from mine water to distribute it to heating networks. The former mine operator needs to pump mine water to the surface for eternity. For the analysis of the mining infrastructure, all existing and relevant data of the shaft locations were analysed. In the process, 7,800 documented shafts were identified. The totality of shafts was reduced by exclusion criteria in the first analysis to 119 potentially usable sites in the Ruhr area. Based on this, a categorised evaluation of the remaining sites was carried out with regard to their technically developable utilisation potential. This evaluation is based on the conditions of the shaft locations, supplemented by the underground main flow paths and volume flows of the mine water. Results show, that 150,000 households can be supplied with heat from mine water. The findings are generally transferable to other areas with former coal mining activities, e.g. in the UK and other regions worldwide.

Keywords: renewable energy resources, exceed heat, ultra-low heating networks, geothermal mine water utilisation, decentralised heat pumps, abandoned mine infrastructure

NOMENCLATURE

Abbreviations	
CHP	Combined heat and power
GIS	Geoinformation system
GSHP	Ground source heat pump
HP	Heat Pump
LANUV	State Agency for Nature, Environment and Consumer Protection
RAG AG	RAG Aktiengesellschaft (stock company)

1. INTRODUCTION

1.1 Motivation

To stay on the path of reducing greenhouse gas emission by 80-95% by 2050 compared to 1990 fixed in the Paris Agreement [1], it is crucial to transform the way we convert and use energy. The challenges for transforming the energy system span all sectors. With a final energy consumption of 50% for heating and cooling purposes in the EU27, it is the sector with the highest energy demand. Moreover, almost 75% of the fuel consumed within this sector comes from fossil sources [2]. Nowadays these fossil fuels are mostly oil and gas, but in the past, it was widespread to use coal for heating purposes.

Coal mining was the engine of European economic development for decades. In several regions, such as the Ruhr area in North Rhine-Westphalia, Germany, the massive coal deposits attracted industry settlements along with numerous jobs. With increasing globalisation, the displacement of domestic mining began in the 1950s with the first coal crisis in 1958. The phase-out of coal mining was decided in 2007 with the Coal Financing Act [3]. As a result, the last hard coal production at the Prosper-Haniel mine in Bottrop came to an end at the end of 2018. In addition to the historical legacy, mining leaves behind an enormous task for the post-mining era in the form of mine water drainage. The lifting of mine water is one of the eternal tasks of RAG AG. The RAG AG is the mine operator in the western part of Germany and is responsible for all eternity tasks around post-mining. In total 95 Mio. m^3/a of warm mine water needs to be pumped, historically so the mine workers wouldn't drown and nowadays so the mine water doesn't mix with

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the groundwater. 99% goes into nearby rivers and isn't used. [4] Mine water can contribute to a sustainable heat supply. Temperatures similar to the use of near-surface geothermal energy can be reached, varying from 20 to 30 °C depending on the location. By harnessing the heat of mine water, concepts for heating and cooling supply are possible. Examples of mine water usage can be found in Heerlen/Netherlands [5]. Mine water drainage as a perpetual task of RAG serves as a starting point for the consideration of different heat utilisation concepts. The potential of heat utilisation with a focus on the Ruhr area are discussed in the following and are based on the research project "Mine Water Ruhr" (dt. Grubenwasser-Ruhr)[1].

1.2 Scope of work

The scope of this work is the conceptual development, planning and economically feasible implementation of a heat utilisation concept using the existing mining infrastructure in the Ruhr area. To this end, heat from mine water is to be made usable in the long term at various locations in the Ruhr region to supply residential and commercial consumers. Many pieces of research in mine water in Germany focus on geochemical questions around mine water [6-8]. This research aims to identify possible uses of the heat potential of mine water and to show practical examples that will serve as multipliers for further implementations. Therefore, different methods to extract geothermal heat from mine water need to be evaluated and, based on this, distribution concepts for heating purposes need to be designed.

2. CASE STUDY AND DATA

The overall method to investigate the potential for the utilisation of mine water in a specific area is presented in the following sections. Based on the results, the development of suitable energy systems is shown.

2.1 Research Questions

Due to the industrial change in several regions of the world, one of the world's process-leading metropolitan areas offers many opportunities to explore possibilities of an environmentally friendly transition. In former coal regions, questions arise on many levels. Coal mines have closed down, but the abandoned spaces are still there. This paper tries to find answers on how these areas can be used after the end of coal burning. In particular, energy-related questions are answered:

- Can we develop concepts to continue using these very long-lasting structures?
- Is it possible to implement heat utilisation structures to heat houses around these areas?

This paper offers a guideline for the development of technical concepts and gives insights into the barriers to the realisation of such concepts. The study area is located in North-Rhine Westphalia, Germany, in one of the largest metropolitan regions of the Ruhr area, Fig 1. From the 15th century until 2018, this area was dominated by mining with 400,000 jobs in this sector at peak times.

The study is limited by its investigation area. Especially the high population density of the study area has to be considered when transferring the results to other mining regions.

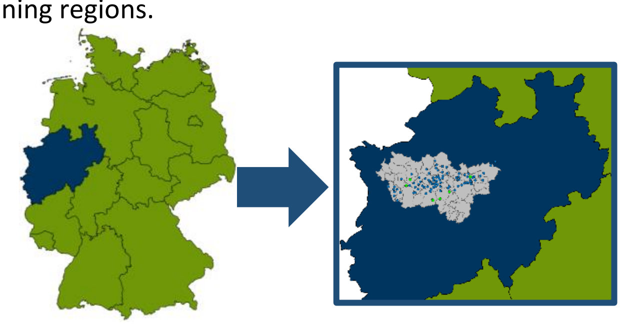

Fig. 1 Location of the analysed mine area

3. MATERIAL AND METHODS

The methods used to answer the research questions focus on finding implementation options for mine water utilisation plants. Focusing on the Ruhr area, a GIS-based analysis of existing mine shafts is required to identify potential heat sources. Based on shaft location data from RAG AG, the Ruhr area is scanned and a categorisation of different shaft types is undertaken. Four categories of different shaft types are identified. Shafts with the highest thermal potential are in category one and shafts with the lowest potential are in category four, compare Fig 2. Criteria for the categorisation are the thermal potential, the type of shaft, the accessibility and the proximity to buildings of any kind.

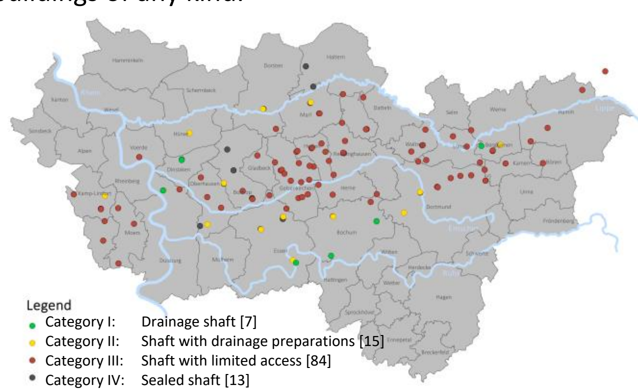

Fig. 2 Categorisation of shaft types

[1] Project Mine Water Ruhr, Development of innovative and efficient heat utilisation concepts considering the mining infrastructure in the Ruhr area, Bochum, 2020.

Of the approximately 7,800 shafts from the last centuries, a total of 119 shafts with different potentials for heating purposes could be identified.

Based on the evaluation of the mine water potentials, locations with the highest implementation confidence were selected for further investigations. Of particular interest are the drainage shafts. At these sites, RAG AG has to pump mine water from a depth around 600 m below the surface eternally. With temperatures of about 20 °C, the heat cannot be used directly.

After identifying potential heat sources, it is also necessary to find sufficient heat sinks near the shafts. A quantitative screening of the area one kilometre around the shafts was carried out. Data from LANUV (State Agency for Nature, Environment and Consumer Protection NRW) on heat demand was used.

For category I shafts, a qualitative analysis through site visits and stakeholder dialogues was carried out afterwards. Shafts in category II and III were further investigated through internet research and following telephone calls to potential stakeholders in the vicinity.

3.1 How to extract mine water heat from different sites

There are several ways to extract heat from the mine water. Either there is a drainage shaft at which the warm mine water is pumped through an open-loop system to the surface, or there is a location where there is no active pumping of mine water and the mine water heat needs to be exploited through a closed-loop system. At these shafts, it is necessary to transport the heat to the surface. These shafts have a very good expansion within the excavated shafts. This is because they are retained as so-called safety sites. Nevertheless, in the unanticipated case of a mine water raise in a specific region, it is still possible to insert a pump at these sites and balance the mine water level. A probe as one possibility of a closed loop system can be inserted into the shaft to extract heat from the mine water in the depth.

Active pumping is done by submersible pumps that are suspended in the shaft at a depth of around 600 m below the earth's surface. To utilise the geothermal heat of former mines without active pumping, probes must be installed in a similar way to the pumps. They can be hung in the shafts to harness heat from the depth. With this method, significantly less heat from the depth can be utilised, but almost no energy is needed for circulating water through the closed system, compared to very high energy expenses for the submersible pumps. A schematic illustration of these two systems is given in Fig. 3.

For heating purposes with an open looped system and ground source heat pumps (GSHP), research in the UK show, that mine water usage can be an effective mean of reducing carbon emission [9].

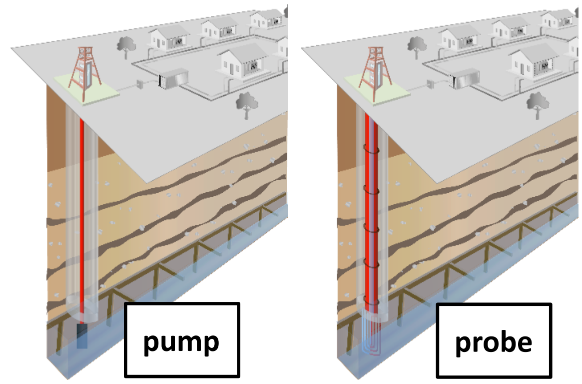

Fig. 3 Open-loop system (left) and closed-loop system (right)

3.2 Energy concepts

Based on the identified heat sources and their temperature level, different energy concepts can be defined. Depending on the framework conditions, a few concepts related to mine water heat can be identified. The results of the energy conception are laid out in this chapter.

In the development of energy concepts, a distinction can be made between two types of supply. Either a network-based supply system can be installed or a decentral system with many individual heating units. For the use of mine water heat, a network-based supply system for heating applications is necessary. Based on this decision, another one must be made. Either a central district heating network on a high-temperature level (Fig. 4) or a decentralised district heating network (Fig. 5) can be applied.

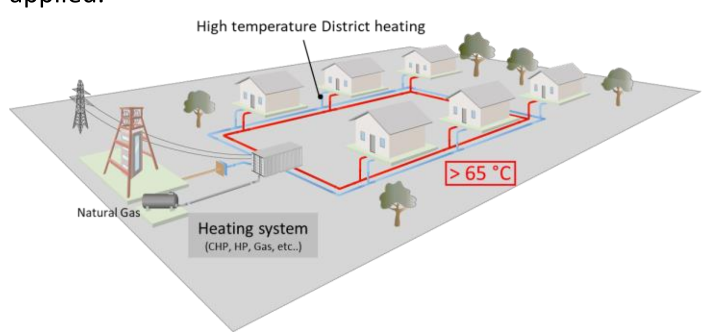

Fig. 4 Central heating system

The central high-temperature network is characterised by temperatures above 65 °C, insulated pipes, and relatively high heat losses due to recirculation. Different heating networks divided into networks of different generations are described in Werner et al. [10] and a further description of low-temperature networks with supply temperatures between 50 and 70 °C can be found in Lund et al. [11].

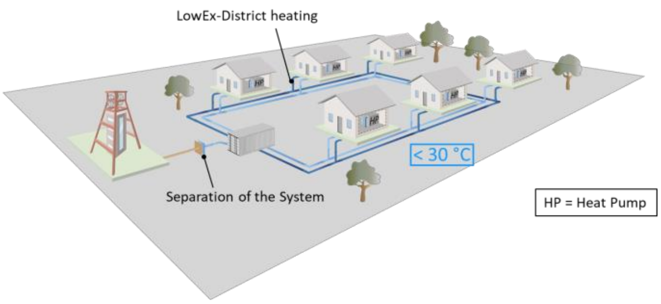

Fig. 5 Decentralised heating system based on heat pumps

The characteristics of a decentral concept based on a heating network are: ultra-low temperatures below 30 °C, uninsulated pipes, and decentral heat pumps for a demand-driven increase of temperature.

4. RESULTS AND DISCUSSION

The potential of mine water in the Ruhr area is very high. Especially for shafts in category 1, the amount of usable heat is immense. A summary of the incidental water volumes is shown in Tab. 1.

Tab. 1 Summary of predicted water volumes at shafts of category I

Mine water drainage	Location	Forecast water volumes
Friedlicher Nachbar Shaft 2	Bochum	8 Mio. m³/a
Walsum Shaft 2	Duisburg	8 Mio. m³/a
Robert Müser Shaft Arnold	Bochum	11 Mio. m³/a
Haus Aden Schacht 2	Bergkamen	13 Mio. m³/a
Heinrich Shaft 3	Essen	20 Mio. m³/a
Lohberg Shaft 1 + 2 (2035)	Dinslaken	35 Mio. m³/a
Σ	Ruhrgebiet	95 Mio. m³/a

To use the heat from category I shafts, the described energy concepts can be implemented. Both have their advantages. The investment costs (capex) for a central concept are slightly lower, but the operating cost (opex) are a little higher than for a decentral concept. This is due to the heat losses and the higher expenses for pump electricity because of constant circulation. Because of better average COPs in the decentral concept, most of the heat for covering the heat demand of buildings is extracted from the mine water. Depending on the COP, heat extraction rates of over 80% can be achieved.

Shafts of category II, 15 in total, also hold potential for geothermal heat utilisation. Because of the good shaft infrastructure, it is possible to hang a probe into the shafts (described in 2.3) and extract the heat through this closed-loop system at a depth of up to minus 1,000 m.

Shafts of category III and IV have limited access or are sealed in some way. Immense efforts need to be made to harness their potential.

After the identification of potential heat sources, a screening of heat sinks was done and three potential sites with a high probability of implementing one of the suggested concepts were identified. The first site is in Bergkamen, the former shaft "Haus Aden" in category I, where a new quarter is about to be built. The second quarter is in Bochum, the former mine "Robert Müser", with an active pumping site (category I) and the last identified site is in Essen, the former shaft "Amalie", in category II, where a new quarter "Essen 51" is planned. The three pilot sites are marked in Fig. 6.

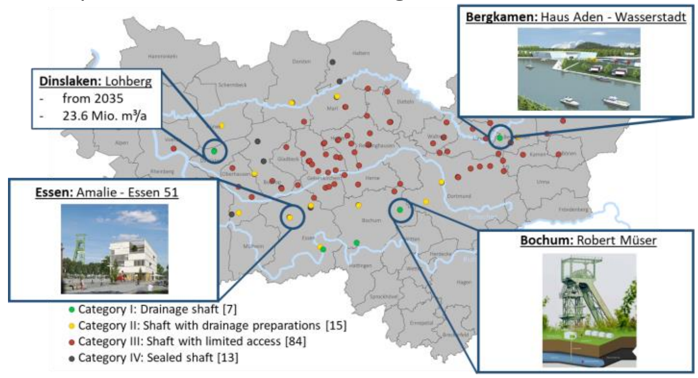

Fig. 6 Implementation plan and identified use case sites

5. CONCLUSIONS

There are many sites where it is possible to use mine water for heating purposes. There are a few technical challenges, but they can be overcome. Besides that, some other factors need to be considered when planning a mine water heat project. Even though there may be a potent heat source, it is not fixed, that the demand structure is in place. Newly transact gas contracts of a potential customer can be a barrier in bringing the source and the sink together. Another challenge is that former mines are not necessarily located in the middle of other buildings that might have a heat demand, so the heat demand density around abandoned shafts is not high enough to make the installation of a heating network economical. The fact that these former mines are being reused and upgraded for living and working purposes is a huge enabler for these projects. Completely new planned quarters are about to arise around these shafts so that the heat demand is brought to the source. The new building standard favours the relatively low temperatures of the heat source of about 20-30 °C.

There is a huge potential for mine water utilisation that needs to be raised. Every single project is unique and has to be looked at individually. But not use a source and an underground structure which our ancestors left us is quite a missed opportunity. The heat from mine water can cover the heating needs of a total of 150,000 households in the Ruhr area.

ACKNOWLEDGEMENT

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