CLIMA 2022
Eye on 2030 | Towards digitalized, healthy, circular and energy efficient HVAC

REHVA 14th HVAC World Congress
22nd – 25th May, Rotterdam, The Netherlands

Mine water geothermal energy - abandoned mines as a green energy source

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Abstract. Abandoned mines offer an opportunity to provide renewable energy. Due to almost constant temperatures all year round and the large rock surfacing as heat-transferring surfaces, mine water is ideal for heating and cooling. At sites where water still has to be pumped upwards after mining has ended this water can still be used for heating or cooling supply of industry or districts e.g. in the German Ruhr area. This offers a positive additional effect of the eternal task for old mining areas. In North America and Europe in particular, a number of pilot plants have already been commissioned. These existing and planned mine water geothermal plants worldwide were studied as part of a literature search. The five largest ones have a maximum heating load of about 0.9 to 11 MW. The construction of further plants often stumbles due to the fact that mine water competes with fossil fuels e.g. natural gas or fuel oil. This is compared under economic and ecological criteria within this paper. As a result, mine water geothermal energy is cheaper to operate than fossil fuels such as oil or gas and labour costs below 6ct/kWh are possible. From an ecological point of view, CO2 emissions are reduced by at least 56 % compared to fossil fuels. One important technical risk for mine water plants is the fouling which must be taken into account: impurities in the mine water can reduce the heat transfer in the heat exchanger, which reduces the efficiency of the plant.

Keywords. mine water, geothermal energy, heat pump, district heating cooling.
DOI: https://doi.org/10.34641/clima.2022.55

1. Introduction

Mining has shaped humanity for thousands of years. The first metal ores were mined on the surface in Germany as early as 1000 BC[1]. Over the centuries, mining changed, and from the 10th to the 12th century in particular, more and more silver and copper deposits were developed in Europe. The countries with the largest mine production are currently China, Australia and Indonesia [1 - 4]. Nevertheless the individual deposits are also finite; when the resources are exhausted, the abandoned mines are usually flooded and this offers considerable potential: use as a regenerative energy source. Depending on the location, mine water with temperatures between 15 and 40 °C is available and can be used for heating and cooling applications.

2. Technology

Fig. 1 shows a simplified version of the most frequently used functional principle of mine water geothermal energy. First, the mine water is extracted (a). There are various possibilities depending on the available extraction points. At some locations, e.g. in the Ruhr area, the mine water has to be pumped out permanently so as not to endanger the groundwater. These pumped-out waters can be used directly. At other sites, the former mines are drained via galleries, so that the extraction of mine water is possible there. Further extraction possibilities are listed in Fig. 1. After the mine water has been extracted, the heat is transferred in a heat exchanger (b) to a closed intermediate circuit (c) and from there to the consumer or, if the temperature level needs to be increased, to a heat pump. The cooled / heated mine water is discharged after the heat exchanger, e.g. into surface waters or back into the drainage gallery. Other systems for geothermal use of mine water are described in [5, 6]. The possible consumers also listed in Fig. 1 require different temperature levels, so that different users result based on the general conditions of a former mine site. This is also one of the limitations of mine water geothermal energy: only consumers near abandoned mines can be used. Transporting the heat over longer distances is often not economised.

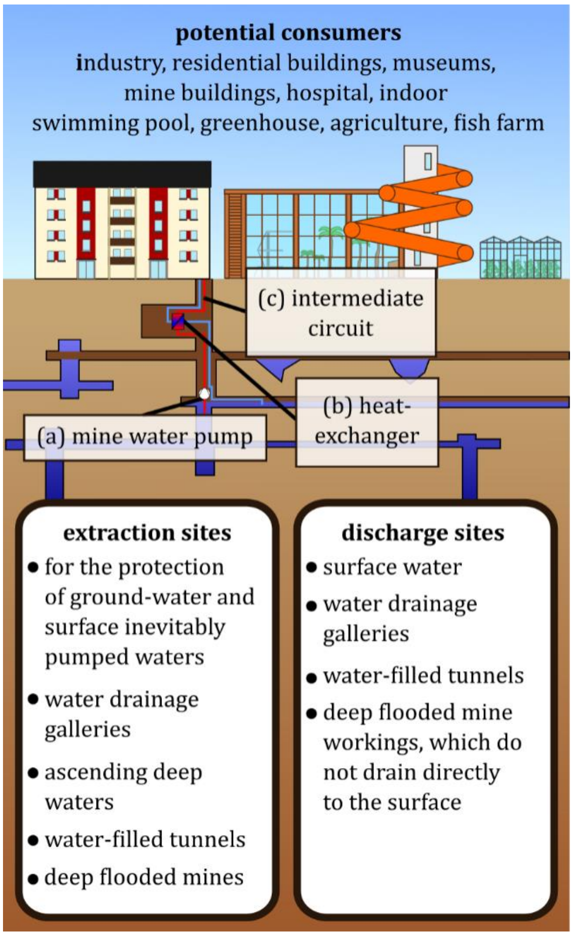


Fig. 1 Basic principle of mine water geothermal energy plant and extraction and discharge sites as well as possible potential users, according to [7]

3. Status quo

Within the framework of literature research, a total of 44 active mine water geothermal plants could currently be researched worldwide. Most of them are located in Germany, Great Britain and the USA [7]. In addition, there are eight decommissioned plants and a large number of planned plants, plants under construction and studies. These are mainly concentrated in Europe and North America. For South America, Africa and Oceania, for example, there is no information on existing or planned plants. Table 1 lists the characteristic values of the five largest plants worldwide.

Tab. 1 –Characteristic values of the currently five largest active mine water geothermal plants worldwide

Novoshakhtinsk	
Location	Novoshakhtinsk, Rostov Region (RU)
Raw Material	coal
Heating power in kW	10.900
Literaturesource	[8]
Zhang-shuanglouCoal Mine	
Location	Xuzhou City (CN)
Raw Material	coal
Heating power in kW	4.750
Literaturesource	[9]
HUNOSA's minesin Cuenca Central	
Location	Mieres, Asturien (ES)
Raw Material	coal
Heating power in kW	3.856
Literature source	[10 bis 13]
Wismut-Schacht 302	
Location	Marienberg (DE)
Raw Material	uranium
Heating power in kW	1.700
Literaturesource	[14, 15]
RothschönbergerStolln	
Location	Freiberg (DE)
Raw Material	silver
Heating power in kW	860
Literaturesource	[16, 17]

One of the first plants in Europe was a plant in Essen, which was opened in 1984. It was used to heat a retirement home [15, 18]. Fig. 2 gives an overview of the number of plants commissioned and shut down per year. The oil price is also shown. It can be seen that there is certain dependence between the rising oil price and the increased commissioning of mine water geothermal plants. A rising oil price also means that the price level for fossil resources rises in general, making the use of alternative energy sources with predictable prices more attractive. Moreover, it must also be taken into account that the reduction of CO_2 emissions is now more important in politics, society and therefore. The expansion of renewable energy sources is to be pushed forward.

Of the currently 18 active plants in Germany, 10 are located in the Ore Mountains in the east of the country. At the moment, for example, energy utilisation concepts are being developed in the MareEn project for the former coal mining area of Lugau/Oelsnitz (Saxony), in which mine water geothermal energy can be used as the main energy source. For historical reasons, structural change is already more advanced in the Ore Mountains. Currently, however, many plants are also being planned and built in the Ruhr area [7]. For example, in the area of the former mine "Haus Aden", an urban district is to be built on an area of 54 ha, which will be supplied to a large extent with mine water geothermal energy. [19]

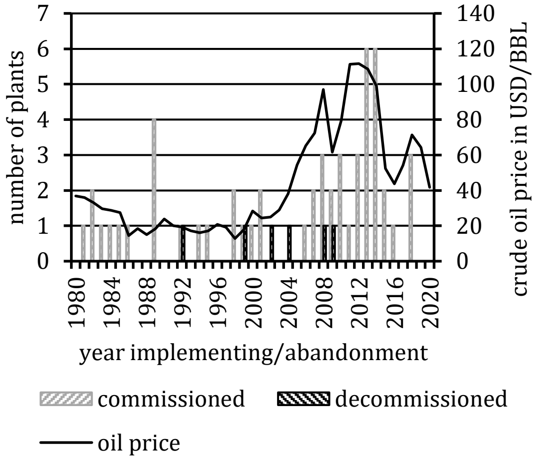


Fig. 2 Comparison of commissioned and decommissioned mine water geothermal plants per year compared to the oil price (according to [7], oilprice: [20])

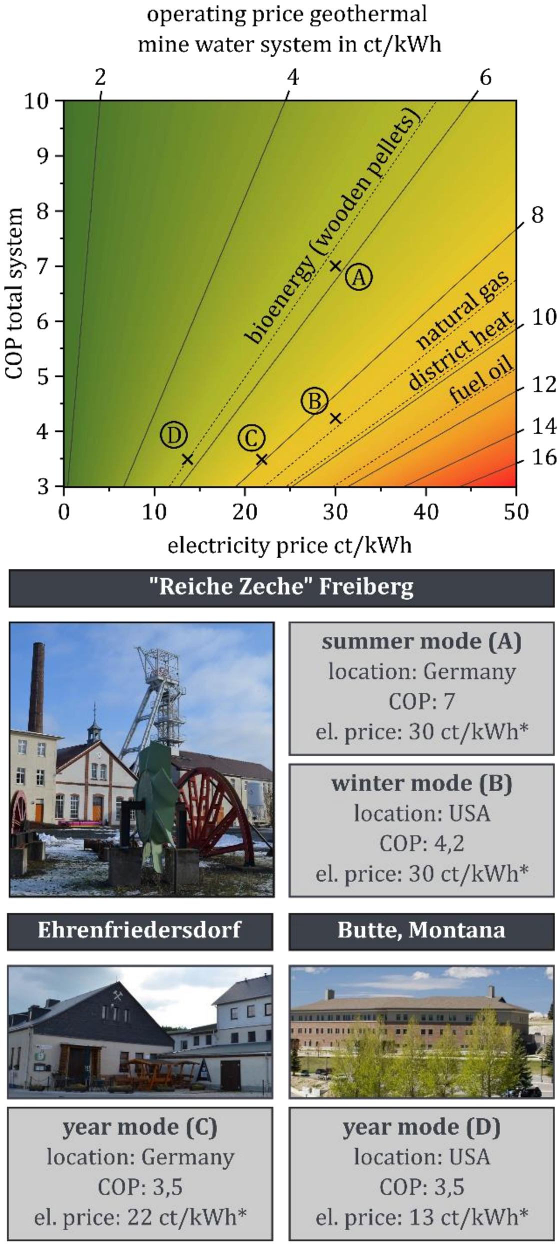
4. Economic advantages

As a renewable energy source, mine water geothermal energy competes with other renewable and fossil energy sources. The labour costs of the plants depend on various factors. The economic efficiency of the system is subject to various influencing factors:

- Purchase price for electrical power to supply the heat pump, circulation pump, etc.
- Coefficient of performance (COP) of the overall system, depending on e.g.: Temperature range, volumetric flow of mine water, effectiveness of heat exchanger, transport path of the heat, etc.

Figure 3 shows the COP of the overall mine water system and the electricity price in euro cents. From the intersection of these two influencing factors, the labour price for one kWh of heat or cold of the mine water geothermal system can be read. In comparison, the labour costs for a kWh of heat from bioenergy (wood pellets), district heating, natural gas and fuel oil are shown. This is based on the framework conditions and costs of the German market.

As an example, the labour costs are entered for three different plants and scenarios. These are based on monitoring results and electricity prices customary in the respective countries. It becomes clear that at very high work rates (e.g. summer mode at the Reiche Zeche), labour costs for mine water geothermal energy of less than 6 ct/kWh are achieved even at electricity prices > 30 ct/kWh. This makes the energy source competitive with fossil fuels such as gas. The great advantage of this plant is the combined use of mine water for heating and cooling.



*Electricity price assumed/estimated | conversion from national currency

Fig 3. Labour costs of a mine water geothermal plant as a function of COP and electricity price, comparison of different scenarios and to costs of other energy sources (dotted lines) (data, figure Butte: [21])

For cooling, the temperature level of the mine water can be used directly at this location (around 14 °C in summer); no additional effort is required for a secondary system as e.g. a heat pump. Cooling thus represents a large additional benefit, with only little additional effort due to the circulation pumps. For a detailed consideration of the monitoring results of the “ReicheZeche” plant, please refer to Oppelt et al. 2021 [7]. However, even older systems like the one in Ehrenfriedersdorf/Saxony (year of installation: 1994), which achieve coefficients of performance between 3 and 4, can operate economically if they run effectively and, for example, a more favourable heat pump tariff for electricity supply is possible. The operational costs such as maintenance and servicing along with the consumption-related costs are referred by the energy prices shown in the diagram.

It becomes clear that all the scenarios considered are cheaper than the supply costs for fossil energy sources such as fuel oil, natural gas or the German district heating mix. Only a supply via wood pellets (and thus also renewable) can be cheaper in the scenarios considered. However, heating with pellets does not allow for parallel cooling and large heating capacities are usually not possible or require a great deal of effort to have enough pellets available.

It is also clear that the price of electricity has a decisive influence; with lower coefficients of performance, the system can still be economical. This can be seen in the plant from Butte (D) listed in Figure 3. Due to the lower electricity price in the USA, the plant would even be cheaper under the German framework conditions than a supply with bioenergy.

The CO_2 tax could be an important factor in the future. If additional costs are incurred for the resulting emissions, e.g. for a kWh of gas, this fossil energy source becomes more expensive. We will take a closer look at this in the following section in order to be able to classify the energy source of mine water geothermal energy ecologically.

5. Ecological advantages

For the mine water geothermal plant in Ehrenfriedersdorf (see Figure 3), a life cycle assessment according to DIN EN ISO 14040/44 was carried out as an example. The entire life cycle was considered. Figure 4 shows the result for the following five impact categories:

- Global Warming Potential (GWP)
- Acidification potential (AP)
- Eutrophication potential (EP)
- Ozone Depletion Potential (ODP)
- Photochemical Ozone Creation Potential (POCP)

It is clear that 88 to 96 % of the environmental impacts of the impact categories arise from the operational phase. The reason for this is the electricity mix used as a basis in Germany. Increased use of renewable energy sources in the German electricity mix would enable further reductions here. Only in the case of ozone depletion potential are most of the effects in the construction phase, the cause being the refrigerant. However, it should be noted that this only has a negative impact in the event of leakage or improper disposal. In summary, it is also clear that the disposal of the system usually accounts for less than 1 % of the total impact and thus causes only minor environmental effects.

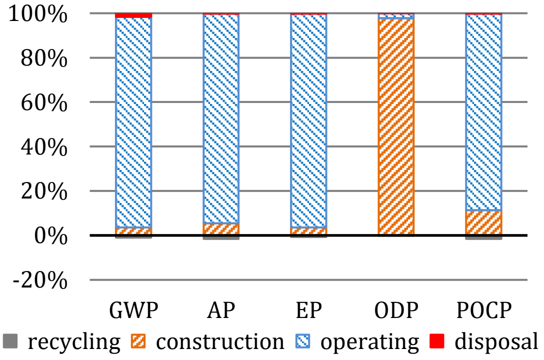
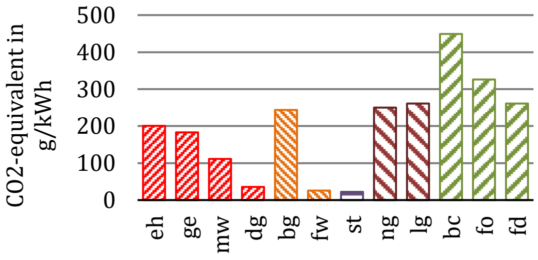


Fig 4 Percentage shares of the life cycle phases in the total impact per impact category

Figure 5 shows a comparison of the energy source mine water geothermal energy to other energy sources based on the CO_2 equivalent. The basis for the calculation for mine water geothermal energy is the analysis of the plant in Ehrenfriedersdorf.

It can be seen that mine water geothermal energy can significantly reduce CO_2 emissions compared to all fossil energy sources. For example, compared to the use of lignite, CO_2 emissions are reduced by around 75%, and by at least 56% compared to natural gas. Here, too, a further reduction is possible if the electricity required for the mine water geothermal system is provided from renewable energy sources.



eh	environmentalheat
ge	geothermalenergy (nearsurface)
mw	mine water geothermalenergy
dg	deep geothermalenergy
bg	biogas
fw	firewood
st	solar thermalenergy
ng	natural gas
lg	liquid gas
bc	brown coal
fo	fuel oil
fd	fossil district heat

Fig. 5 Ecological comparison of mine water geothermal energy with other energy sources via CO_2 equivalent for the plant in Ehrenfriedersdorf

6. Technical risk - fouling

Fouling can have a significant impact on the mine water system. Depending on the location, the mine water carries various dissolved/undissolved substances, particles, bacteria, etc. with it. If heat is extracted (heating) or supplied (cooling) in the heat exchanger, this can lead to precipitation in the tubes, filters and in the heat exchanger. An example is shown in figure 6. These deposits cause a reduction in the amount of heat transferred and an increase in pressure loss. As a result, the system works inefficiently: less heat can be extracted from the mine water and other, e.g. fossil, alternative systems have to be used additionally. In addition, the necessary cleaning of the heat exchanger results in downtimes and additional costs. Even with a biofilm of 250 µm, the amount of heat transferred is reduced up to 50 %. [22] In real terms, there are deposits of more than one millimeter.

Currently, the TU Bergakademie Freiberg is investigating possible materials and coatings for the heat exchanger with the goal to reduce the deposits or at least enable complete cleaning. Initial results show that a reduction in heat transfer losses of up to 80 % is possible. It should be noted that the mine water has different characteristics depending on the mine site and therefore site-dependent solutions must be checked and possibly developed.

Fig. 6 Fouling layer on a heatexchangerplate

7. Summary and outlook

Worldwide, the closure of mines offers opportunities to use them as a renewable energy source for heating and cooling. Depending on the site conditions, there are various possibilities to use the mine water, e.g. at sites where the mine water is pumped out to protect the groundwater or can be used directly without additional pumping. Since the 1980s geothermal mine water plants have been built all over the world, and in recent years the number of new plants has increased steadily. Reasons for this include rising energy prices and the political objectives of many countries against climate change. A mine water geothermal plant can compete with fossil energy sources if it is operated effectively (COP high) and at best can provide heating and cooling at constant, calculable energy prices. From an ecological point of view, a reduction in CO_2 emissions of at least 56% is also possible compared to fossil energy sources, depending on the boundary conditions. The limits of the technology are that consumers must always be available in the immediate vicinity of the source. Transporting low-temperature heat from mine water is usually not economical. Furthermore, the problem of fouling must be taken into account. The impurities carried in the mine water cause deposits in the heat exchanger and reduce the efficiency of the system. The TU Bergakademie Freiberg is investigating an innovative heat exchanger design to reduce fouling.

8. Acknowledgement

We would like to thank the European Union and the Free State of Saxony for the financial support of the VODAMIN II, GeoMAP and MareEn projects. In addition, we would like to thank all the technicians involved as well as J. Balski and R. Klink, who supported the project work as part of their practical student work.

The datasets generated during and/or analysed during the current study are not publicly available because they are part of the VODAMIN II project and the final version of the final report isn't published now but will be available when the finale report is published.

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