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Abandoned mines as a source of heat and cold

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Abstract

Mining has influenced and shaped the development of humankind for many thousands of years. After closure, these mines are often flooded and then offer a very high potential as a regenerative energy source for heating and cooling. Due to the almost constant temperature between about 10 to 30 °C throughout the year, an independent source of energy is permanently available, which can be brought to the necessary temperature level with heat pumps. In total 116 existing, planned and decommissioned systems were found worldwide. The observation of monitoring results of an example mine ("Reiche Zeche" in Freiberg/Germany) and a comparison to three other locations shows that the parallel use of mine water for heating and cooling can achieve coefficients of performance of the overall system of up to 10. Even with high electricity prices, operation costs for geothermal mine water energy of between 5 and 10 ct/kWh$_{heat}$ are possible. Compared to fossil fuels, at least 50 % CO_2 emissions are saved.

Keywords: mine water, geothermal energy, heat pump monitoring, district heating cooling

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1. Introduction

Mining is changing worldwide, e.g. in Germany the last hard coal mine was closed in 2018, brown coal is to be mined until 2035 at the latest [1]. In the Czech Republic, coal mining is planned to be finished in 2033 [2], similar to the situation of Canada, where coal mining is to end in 2030 [3]. The closure of the mines will inevitably lead to structural changes in the affected regions. Jobs in the mining sector will disappear and former mine sites will be renaturalized.

But these abandoned mines also offer potential: they can be used as a regenerative, geothermal energy source to provide heating and cooling. In most cases, abandoned mines are flooded and thus function as huge heat reservoirs. Depending on the location, the water temperatures are usually between 10 and 30°C. By using heat pumps, the temperature level necessary for the consumers can be provided. In the following, the basic structure of a typical geothermal mine water plant is presented and the current worldwide status quo is reviewed. Subsequently, the monitoring results of one plant in Germany are examined in more detail and compared to other plants located in Germany, the USA and Great Britain. Finally, the ecology and economy as well as identified problems are discussed.

2. Technological basics

The principle structure and possible extraction and return points of geothermal mine water systems are shown in figure 1. Firstly, the mine water is pumped to a heat exchanger (a) where heat is extracted (heating case) or supplied (cooling case) to a second fluid cycle. Afterwards, the heat will be transported in that intermediate circuit (b) to the heat pump (c), whereby the necessary temperature level is provided. If the temperature level is suitable for direct use as a heat sink for cooling, no heat pump is necessary. After heat is

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extracted (heating case) from the mine water or supplied to it (cooling case), it is returned to the mine building. Depending on the location, other plant designs are also possible. [4, 5]:

- At pumping stations where mine water has to be pumped continuously, e.g. to protect groundwater level, and is discharged into surface waters, the pumped water can be used directly above ground, which is then transferred to surface waters. The same principle can be applied to active opencast mines where sump water is discharged.
- In the past, drainage galleries were built to transport the mine water out of the mines. Energetic utilisation is then also possible at the mouth holes, which avoids additional expenditures, e.g. for drilling.
- If there is enough space, it is also possible to install a closed loop system in the mine water, e.g. pipe bundles which are submerged in the mine water

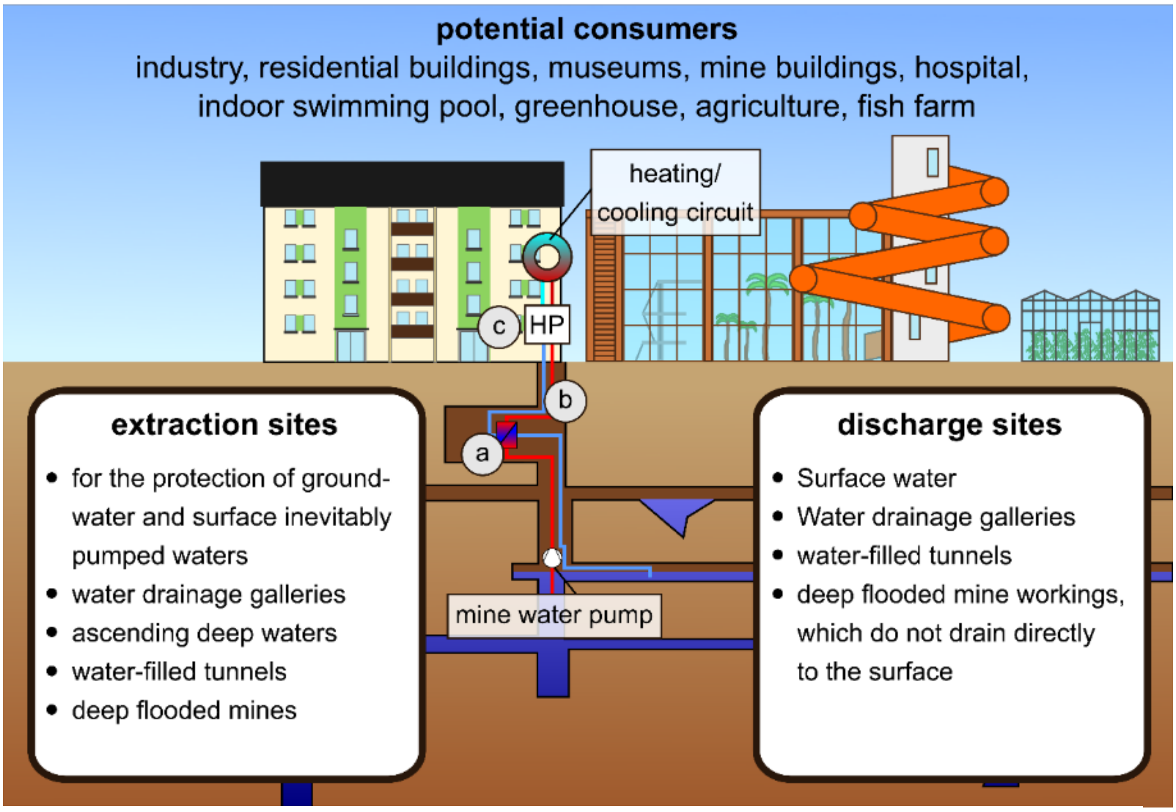

Fig. 1 Schematic structure of the geothermal mine water system as well as possible extraction and discharge sites and possible consumers (according to [4,6])

3. Current overview of geothermal mine water systems worldwide

In order to get an overview of the worldwide status quo of mine water geothermal systems, systems were searched in English and German literature, and a total of 42 active plants were founded worldwide. There are studies and construction plans for many more plants; a total of 116 plants could be found worldwide. Figure 2 gives an overview of the plants in Europe (up) and North America (down). It is clear that most plants are located in old mining areas in Germany, Great Britain, the USA and Canada. Outside these regions, only plants in China could still be found. However, there is also potential in other locations in South America and South Africa. Possible reasons for the lack of studies and planning for example could be a lack of investors or other, better available or cheaper renewable energy resources.

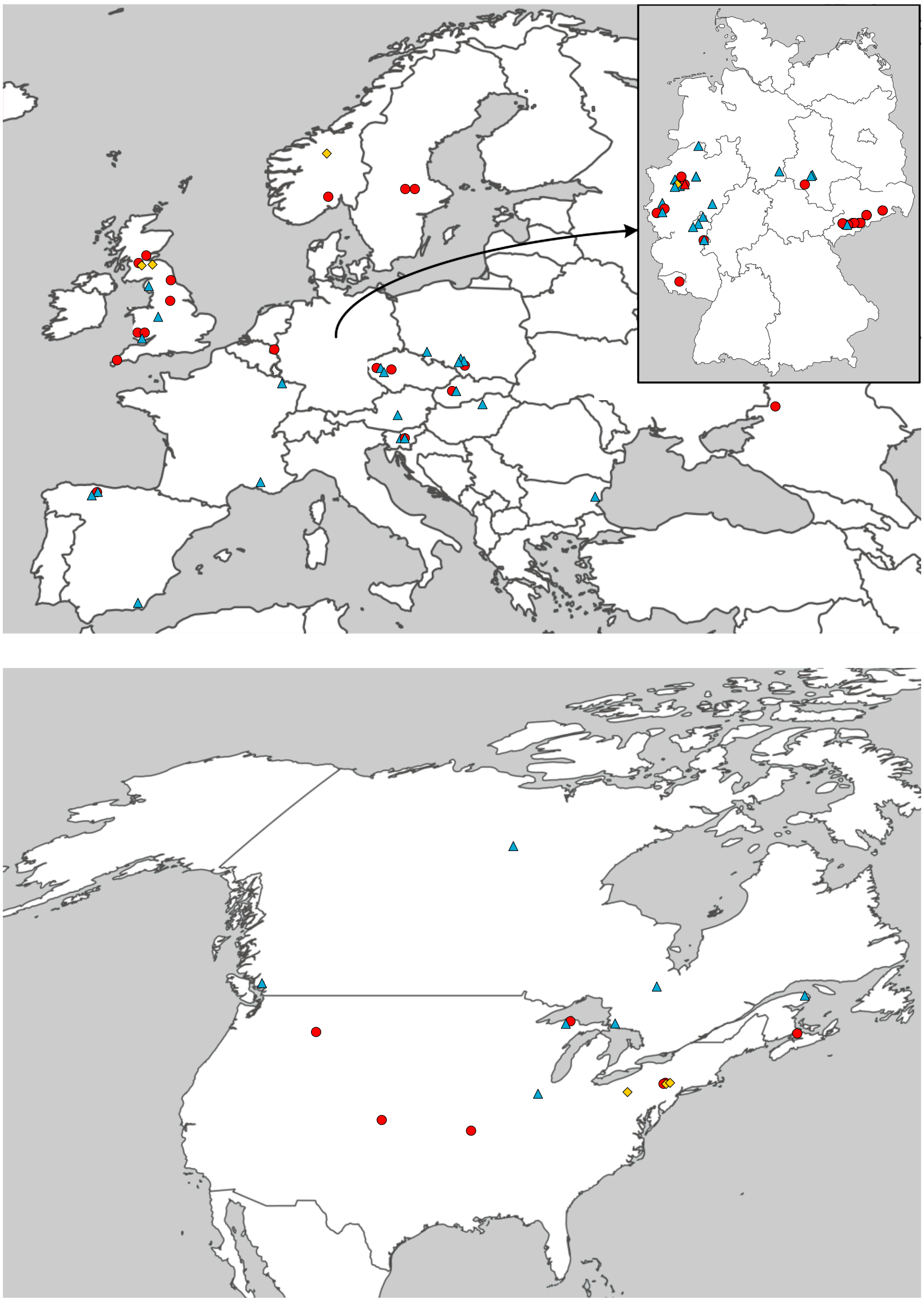

Fig. 2 Overview of current geothermal mine water plants in Germany/Europe (left) and North America (right) (o in operation, Δ planned/under construction/study, ◊ decommissioned, according to [5])

In order to give an overview of the amount of energy that is available through the geothermal energy of mine water, figure 3 shows the number of geothermal mine water plants built, planned and closed, summarized into freely chosen power classes. It can be seen from this that many existing plants worldwide are in smaller output ranges (below 200 kW), but new plants are more likely to be planned for larger output classes (over 500-1000 kW), or studies are being prepared for this. This is also evident in the projects currently planned and implemented in Europe:

- In Mieres in Spain, a large geothermal mine water plant is already in operation. There, mine water with a temperature of 23°C is used to supply various buildings, e.g. an university, with heat. The mine water is cooled down about 5 K, thus a heating power of about 4 MW is currently available after the heat pumps. In a further expansion stage, it is planned to increase it up to 6 MW. [7]
- Another big mine water project is also being planned in Germany: at the "Haus Aden" water extraction site (mine water must be pumped out permanently to protect the groundwater level) in Bergkamen in the Ruhr region, a new urban district is to be built on the former mine site and supplied proportionally with geothermal mine water energy. A mine water volume flow of about 1000 m³/h at about 20 °C is continuously available. This means that there is a theoretical potential of 30.6 MW, which will be exploited to set an example of how to safely supply renewable heat energy by mine water to urban districts. [8 bis 10]

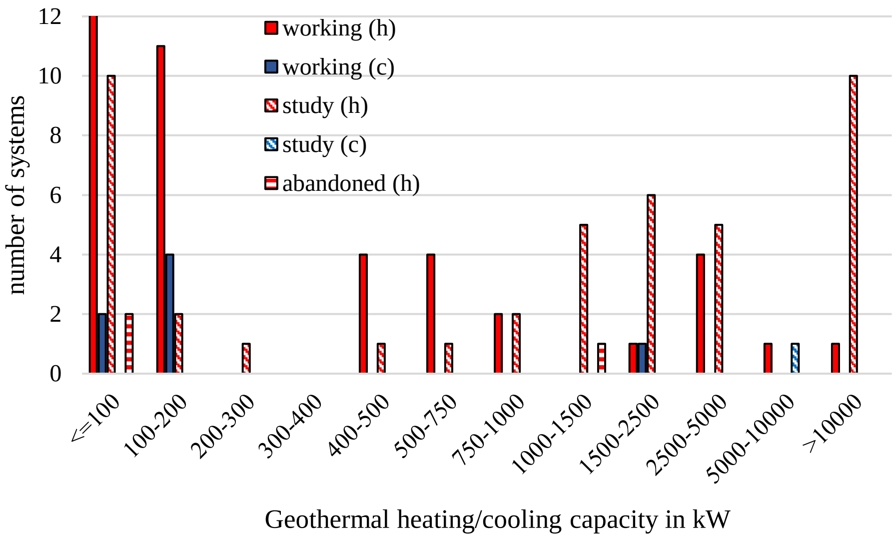

Fig. 3 Overview of the number of geothermal mine water plants in the different performance classes

4. Monitoring results

In 2013, a geothermal mine water system was put into operation at the former silver mine "Reiche Zeche" in Freiberg, Germany. In the current expansion stage, with a heating capacity of 175 kW and a cooling capacity of 100 kW it can supply several buildings at the university (offices, class rooms, laboratories, server rooms). The basic system design is shown in figure 4. The special feature here is that there are the three options for providing heating and/or cooling:

- Variant A (“Rothschönberger Stolln”): The mine water here is taken from the main drainage gallery of the Freiberg mining district, the “Rothschönberger Stolln”. This has a water temperature of about 14 °C.
  → Variant A is used when there is a predominant demand for cooling.
- Variant B (Shaft “Reiche Zeche”): Alternatively, the mine water can also be taken from the “Reiche Zeche” shaft, where the mine water has a temperature of about 19 °C due to rising deep water.
  → Variant B is used when there is a predominant demand for heating.
- Variant C (intermediate circuit): Only the fluid in the intermediate circuit between the heat exchanger at a depth of 228 m and the heat pumps on the surface is circulated. In the case of low heating or cooling requirements, the heat from the rock (Gneiss) that surrounds the intermediate circuit can be sufficient for heating and cooling.
  → Variant C is used when there is a low heating or cooling demand.

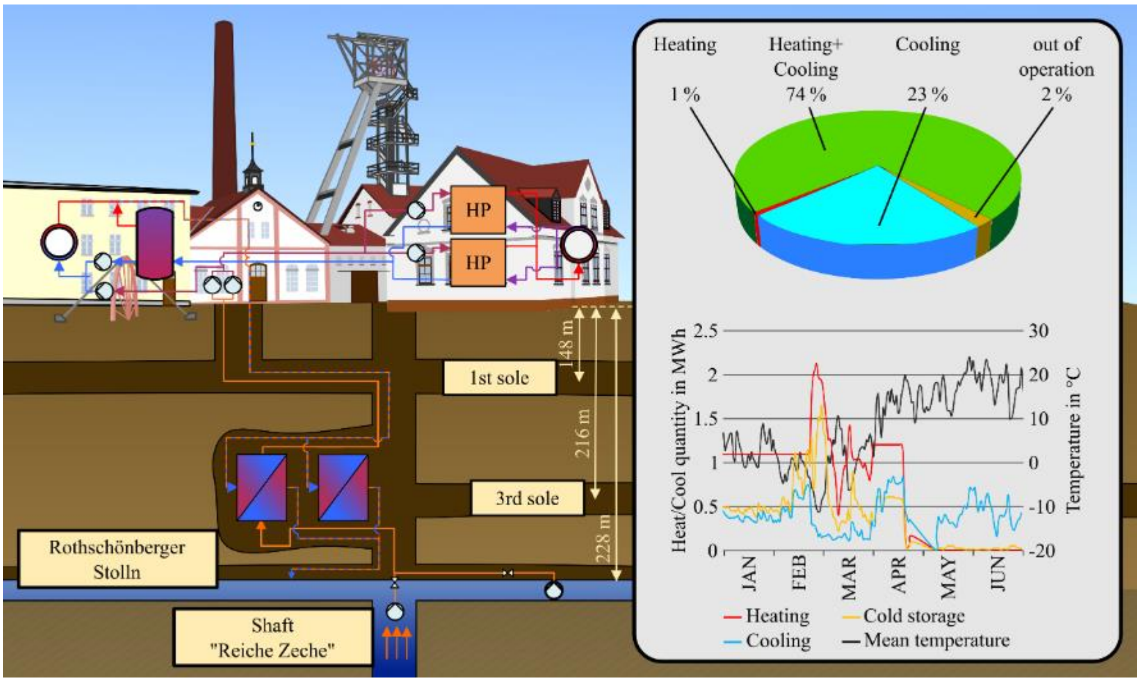

Fig. 4 Schematic structure of the "Reiche Zeche" mine water system and proportions of the operating modes over three years (top right) and heating and cooling quantities over half a year (bottom right)

This results in a total of 10 possible operating modes: for each of the three extraction options heating only, cooling only or combined heating and cooling can be selected. The 10th operating mode is "out of operation", e.g. because the system is being serviced. The diagram in figure 4 on the right top shows the proportions of the operating modes over an observation period of 3 years. Heating and cooling are used simultaneously for the most part; heating alone was only recorded in 1 % of the observation period. The reason for this is the basic cooling load that is necessary at the site for cooling the server and laboratory rooms. In most cases, there is also a need for cooling in the winter. Only on a few very cold winter days there is no cooling necessary for individual hours. Otherwise, cooling-only mode was only required in about a quarter of the period under review, and this was mainly the case during the warm summer months. This is also shown in the diagram of the amount of heat and cold shown in figure 4, bottom right. Until middle of April, the heat quantity is significantly higher than the amount for cooling. Afterwards the amount of cooling gets into the predominant position. In addition to direct heating and cooling operation, a cold storage tank is integrated in the system whereby the return flows from the heating circuit can be used for cooling. The cold flow from the cold storage tank is also mainly used until mid-April, as the storage tank is then no longer “loaded” due to the low heating requirements.

The almost continuous cooling demand has a significant influence on the efficiency of the overall system see figure 5. A representative summer and winter week is shown. As expected, the heating demand is predominant in winter, with overall system performance factor per hour (HPF_{HC4}) of about 3.5 to 4.5 (notation according to [11]). This also takes into account the expenditure for electricity of mine water pumps, pipeline pumps and the measurement equipment of the monitoring system. In comparison, significantly higher HPF_{HC4}s are achieved in summer. As can be seen in Figure 5, where the minimum HPF_{HC4} ranges between 5 and 6 but can also amount up to 10 in a representative summer week.

The reason for these HPF_{HC4}s is the predominant cooling demand. The mine water can be used directly as a heat sink and the electricity demand for the heat pump is omitted most of the time, unless there is a heat demand for hot water. The consideration of these two example weeks shows clearly that cooling can significantly increase the efficiency of geothermal mine water plants and thus make economic operation possible in the long term and in a stable manner. This issue is discussed in more detail in section 5.

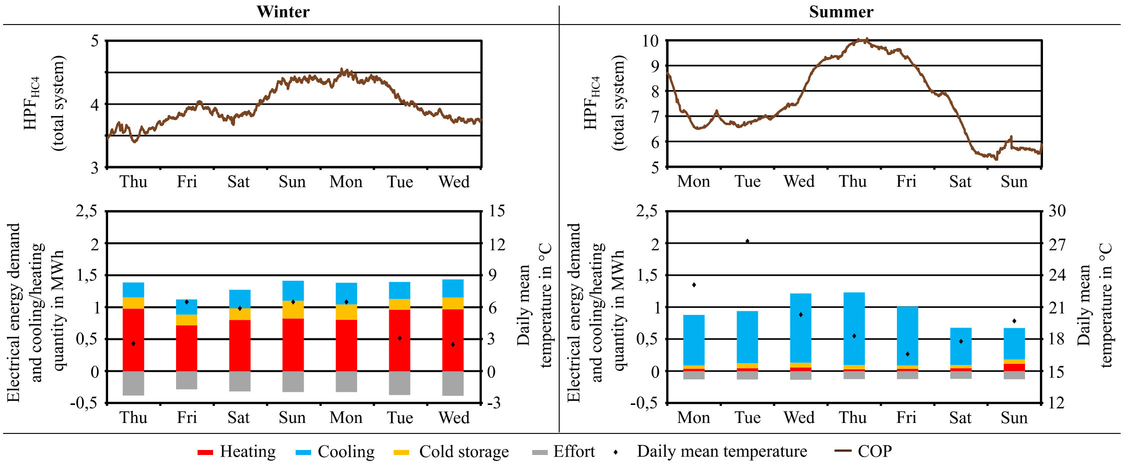

Fig. 5 Monitoring results of the geothermal mine water system "Reiche Zeche" in Germany of a representative winter week (left) and summer week (right)

In addition to the geothermal mine water system at the “Reiche Zeche”, other systems will be considered in the following:

- Since 2012, mine water from the former coal mine in Markham (Great Britain) has been used to heat company buildings. This system is an open system with mine water pumping to the surface. The mine water with an approximate temperature of 14 to 15 °C passes through the tubular heat exchanger within the mine water circuit, which heats the fluid in the intermediate circuit for a 20 kW heat pump. Due to the increased mine water level, the water extraction point was changed in 2015 so that water with a temperature between 13 and 14°C is now used. [12 bis 14]
- In Butte (Montana, USA), buildings at Montana Tech University are supplied with heating and cooling from mine water. The system uses water from the Orphan Boy shaft with a water level of 33.5 to 36.6 m below ground. The closed system includes a 175 kW heat pump that is connected to the building's heating or cooling loop, depending on the outdoor temperature. [15, 16]
- In Ehrenfriedersdorf in (Saxony, Germany) the buildings of the visitor mine are heated since 1992. The system has a total output of about 120 kW. The heat exchanger mine water–closed intermediate circuit is located at a depth of 110 m. Therefrom the heated fluid is pumped inside the intermediate cycle to the heat pump in the buildings [17]

Table 1 provides an overview of the seasonal performance factors (SPFs) of the presented individual systems and their operating modes. It is clear that for all systems, a SPF$_{H1}$ of the heat pump of over 3 is achieved. In addition, the comparison of the SPF$_{HC4}$ of the total system also shows except from location Markham for all other systems high SPF$_{HC4}$. Furthermore it’s obvious how worthwhile the combination of heating and cooling is (see “Reiche Zeche”), so that HPF$_{HC4}$s of over 5 can be achieved for the entire system over longer periods of time also in winter.

The coefficient of performance of the entire system in Markham is below 2. The main reason for this is probably the energy-intensive pumping of the mine water above ground in an open system. At the other sites, the mine water is pumped over lower altitudes and the heat is then transported in a closed system.

Table 1. Comparison of the performance factor of the selected geothermal plants (data: [12, 14, 15])

	Reiche Zeche Freiberg (GER)	Ehrenfriedersdorf (GER)	Markham (GRB)	Butte (USA)
Operating modes	Winter (more heating) /Summer (more cooling)	Heating	Heating	Heating
SPF$_{H1}$ (heat pump)	3,6/-	3,8	3,6	4
SPF$_{HC4}$ (total system)	4,2/7	3,6	1,6	3,5

5. Economic and ecological consideration

In addition to the investment costs, the operating costs during the operating period are a decisive factor in assessing the economic viability of geothermal mine water plants. Decisive influencing factors here are:

- Electricity price for the energy required for the heat pump, pumps, etc.
- SPF of the total system
- Costs for maintenance, servicing, etc.

Figure 6 shows the operating costs of a geothermal mine water system as a function of the electricity price in EURct/kWh and the SPF of the system. The operating costs can be read off from the sloping lines on the upper and right axes (in blue).

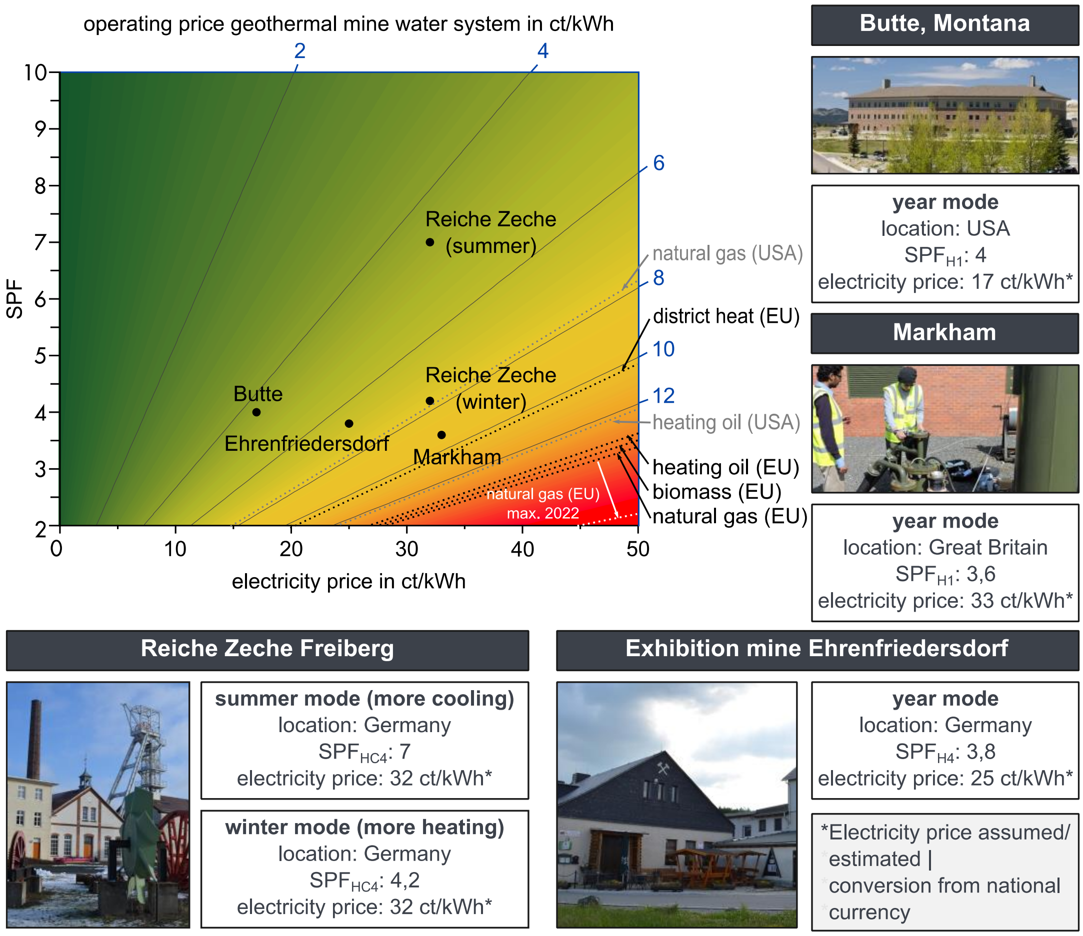

Fig. 6 Operating costs of a geothermal mine water system as a function of SPF_{HC4} and electricity price for various example plants compared to costs of other energy sources in the USA (grey dotted lines) and Europe (black dotted lines) data, pictures: [12, 14, 15]

The other costs, e.g. for maintenance, are included in the calculation as a percentage. The monitoring results presented in section 4 are integrated in figure 6, with country-specific electricity prices always converted to euros. It can be seen, that geothermal mine water energy is more economical than comparable fossil energy sources at all locations under the current framework conditions (as of November 2022). It can be seen that with high SPFs through combined heating and cooling, even with electricity prices above 30 EURct/kWh, working costs of the geothermal mine water system of about 5 EURct/kWh can be achieved. Favorable electricity prices, e.g. through special heat pump tariffs, as in the case of the plant in the Ehrenfriedersdorf visitor mine (Germany), then enable economic operation even with lower SPF_{H4}. The cost level of fossil fuels is always a decisive factor. The strong increase in the price of gas in Europe in 2022 is also shown in the diagram. With maximum gas prices of over 30 EURct/kWh, the energetic use of mine water is always more economical and might even present advantages in the short-term. In summary, at a current electricity price in Germany of 32 EURct/kWh, a working coefficient of the overall system of about 3 must be achieved in order to be cheaper than all comparable fossil energy sources. With an electricity price in the USA of the equivalent of 17 EURct/kWh, the systems are already more economical than fossil systems, also for e.g. gas prices in the USA. In a nutshell, the American plant in Butte must achieve a SPF_{H1} of at least 2.5 in order to be cheaper than fossil fuels on the American market. In addition, electricity costs can be further reduced through local combination with the yields of e.g. photovoltaic or wind power plants. It should be noted, however, that the above consideration refers only to the operating costs; the investment costs of the systems are not integrated in this consideration. Depending on kind of construction activities are necessary (e.g. drilling), these can amount to several million euros.

In addition to the economic advantages, the use of geothermal mine water energy can also offer an ecological advantage by reducing CO_2 emissions. Figure 8 shows a comparison of the CO_2 equivalent of geothermal mine water systems compared to other energy sources. It is obvious that compared to the use of fossil fuels like brown coal or natural gas, CO_2 emissions can be reduced by 75% and by at least 56%, respectively. This factor will play an even greater role for the climate and economically in the future if CO_2 taxes are introduced or increased. The emissions that occur during the construction and operation of a geothermal mine water plant were considered in more detail in [18]. In summary, it is clear that emissions from geothermal mine water plants are mainly due to the electricity purchased and the refrigerant used in the heat pump, which in the future both will fall in their emission impact due to the rise of renewable electricity generation and natural refrigerants. [18]

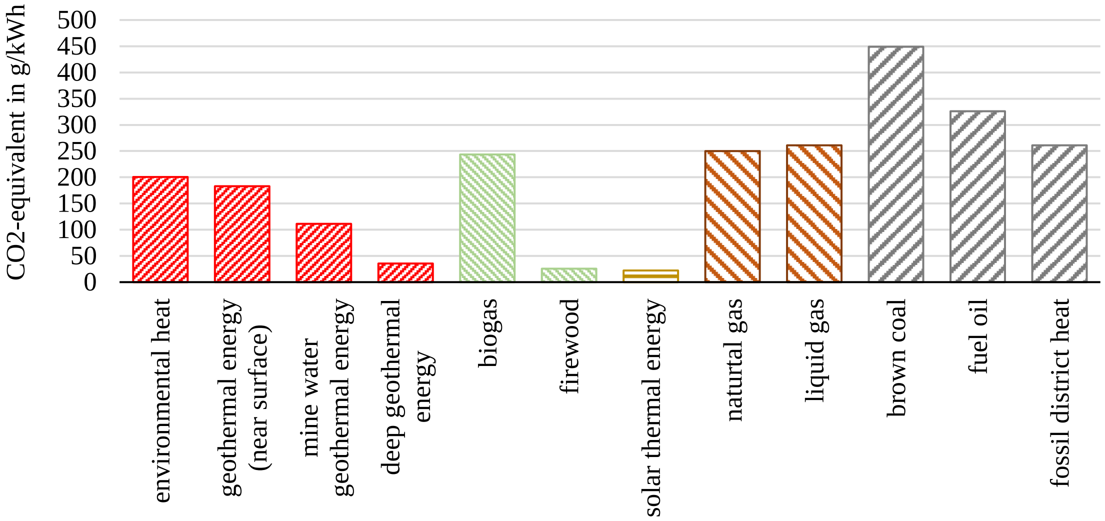

Fig. 7 Comparison of the CO_2 equivalent of geothermal mine water systems to other energy sources (data: [19], study for Germany)

6. Identified problems

One problem to be solved when using geothermal mine water energy is the formation of fouling/depositing in the heat exchanger or piplines. Depending on the site location, the mine water carries various loads, e.g. bacteria, dissolved and undissolved substances and other suspended matter. These substances can be deposited in the heat exchanger and thus significantly influence the plant efficiency. Even a biofilm of 250 µm can reduce the amount of heat transferred by 50 % [20]. In addition, the pressure loss across the heat exchanger increases, and the costs for maintenance also rise because cleaning is necessary. Furthermore, other sources of energy have to be used to compensate the resulting lack of heat. This also has a major impact on the SPF_{HC4}s of the plants, which can also be reduced by up to 50 % due to fouling. The TU Bergakademie Freiberg is currently researching optimized heat exchanger design to reduce fouling/depositing and increase the time between cleanings. [21]

In addition, there were problems in monitoring because the system at the “Reichen Zeche” was partially shut down due to technical defects and construction work in the mine, so that longer measurement periods could not be recorded.

Furthermore, depending on the system design, winter operation may be subject to low efficiencies. A possible solution for this could be the integration of a seasonal heat storage. Currently, only a cold storage facility is used in the “Reiche Zeche” system, but this already makes the potential visible. Seasonal storage in mine water, e.g. of heat dissipated for cooling purposes in summer which can be utilized in winter, would be desirable. Two current projects, WINZER (Funding reference number: 03G0912C) and MineATES (Funding reference number: 03G0910A) are investigating the seasonal storage of heat and cold in mine water.

7. Conclusion and outlook

An evaluation of 116 geothermal mine water sites worldwide with plants and studies on the energetic use of mine water shows that these are mainly concentrated on locations in North America and Europe. 42 currently active plants are findable (German/English). Most of them are in the power range below 200 kW; new plants are planned mainly in a higher power range above 1 MW. The results of monitoring data at the "Reiche Zeche" plant in Freiberg, Germany, show that the geothermal use of mine water by means of heat pumps is ecological and economical favorable. The combined use of mine water for heating and cooling regularly achieves high annual averaged coefficients of performance of over 7. A comparison with three other systems worldwide shows annual averaged SPF_{HC4} of at least 3.5 can also be achieved in pure heating mode. Under the current purchase prices for alternative energy sources, geothermal mine water energy is already cheaper for a SPF_{HC4} of 2 to 2.5, and with more favorable electricity prices, as in the USA, even more economical, also mode modeefor fossil fuel prices in the USA. However, the partly high investment costs for development of mine water resources are not included in the direct operating costs and must be considered during the pre-planning phase before investment decisions. From the ecological point of view, the energetic use of mine water can save CO_2 emissions between 56 % up to 75 % compared to natural gas heating. In future a task to be solved is the location-dependent formation of fouling in the heat exchangers and components in contact with water due to the chemical composition of the mine water and its (un-)dissolved substances. This reduces the usable heat output and thus decreases the efficiency of plants. Research into optimized heat exchangers and plant design must be intensified in the future and adapted to the respective locations. In addition, intelligent monitoring is recommended for the plants currently planned and under construction in order to be able to monitor the actual efficiency and to compare it to other running mine water systems.

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References

[1] Geinitz, C.: Kohleausstieg : Hart an einer Blamage vorbei. Frankfurter Allgemeine Zeitung (2020)
[2] Lazarová, D.: Coal mining in Czech Republic to be phased out by 2033. Radio Prague International (2022)
[3] Mihm, A.: Großbritannien und Kanada verkünden Kohleausstieg. Frankfurter Allgemeine Zeitung (2017)
[4] Oppelt, L., Grab, T., Pose, S., Storch, T. u. Fieback, T.: Mine water geothermal energy as a regenerative energy source - status quo and results from five years of monitoring. Oil Gas EUROPEAN MAGAZINE 47 (2021) 01/2021, S. 15–19
[5] Grab, T., Storch, T. u. Groß, U.: Energetische Nutzung von Grubenwasser aus gefluteten Bergwerken. In: Bauer, M., Freeden, W., Jacobi, H. u. Neu, T. (Hrsg.): Handbuch Oberflächennahe Geothermie. Berlin, Heidelberg: Springer Berlin Heidelberg (2018), S. 523–586
[6] Oppelt, L., Pose, S., Grab, T. u. Fieback, T.: Geothermische Nutzung von Grubenwasser zur regenerativen Energieversorgung. Geothermische Energie (2020) 95, S. 25–27
[7] "BARREDO COLLIERY" DISTRICT HEATING, HULLERAS DEL NORTE S.A., S.M.E., 2019
[8] Altieri, L., Wagner, H.-J., Gross, M. u. Reiners, T.: Kalte Nahwärmenetze mit Geothermischer Energie aus Grubenwasser. Der Geothermiekongress. Essen (2018)
[9] Kretschmann, J.: Sustainable Change of Coal-Mining Regions. Mining, Metallurgy & Exploration 37 (2020) 1, S. 167–178
[10] Potenzialstudie Warmes Grubenwasser. LANUV-Fachbericht 90, Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen, Recklinghausen (2018)
[11] IEA HPT Annex 53 - Long-term performance monitoring of GSHP systems for commercial, institutional, and multi-family buidlings. Subtask 3 report, Gehlin, S., Spitler, J., Witte, H., Andersson,

O., Berglöf, K., Davis, M., Javed, S., Bockelmann, F., Turner, J. u. Clauss, J., (2022)
[12] Banks, D., Athresh, A., Al-Habaibeh, A. u. Burnside, N.: Water from abandoned mines as a heat source: practical experiences of open- and closed-loop strategies, United Kingdom. Sustainable Water Resources Management 5 (2019) 1, S. 29–50
[13] Athresh, A. P., Al-Habaibeh, A. u. Parker, K.: The design and evaluation of an open loop ground source heat pump operating in an ochre-rich coal mine water environment. International Journal of Coal Geology 164 (2016), S. 69–76
[14] Burnside, N. M., Banks, D. u. Boyce, A. J.: Sustainability of thermal energy production at the flooded mine workings of the former Caphouse Colliery, Yorkshire, United Kingdom. International Journal of Coal Geology 164 (2016), S. 85–91
[15] Case Study of the ARRA-Funded GSHP Demonstration at the Natural Sources Building, Montana Tech, Malhotra, M., Liu, X. u. Walburger, A., (2014)
[16] Gammons, C. H., Metesh, J. J. u. Snyder, D. M.: A Survey of the Geochemistry of Flooded Mine Shaft Water in Butte, Montana. Mine Water and the Environment 25 (2006), S. 100–107
[17] Rottluff, F.: Neue Wärmepumpenanlage im Besucherbergwerk Zinngrube Ehrenfriedersdorf. Geothermische Energie - Mitteilungsblatt der Geothermischen Vereinigung e. V. 6 (1998) 21
[18] Oppelt, L., Grab, T., Wunderlich, T., Storch, T. u. Fieback, T.: Mine water geothermal energy - abandoned mines as a green energy source. CLIMA 2022 conference, 2022: CLIMA 2022 The 14th REHVA HVAC World Congress (2022)
[19] Emissionsbilanz erneuerbarer Energieträger, Memmler, M., Lauf, T. u. Sven, S., Dessau-Roßlau 2008
[20] Goodman, P. D.: Effect of chlorination on materials for sea water cooling systems: a review of chemical reactions. British Corrosion Journal 22 (1987) 1, S. 56–62
[21] Oppelt, L., Grab, T., Wunderlich, T., Pose, S., Storch, T. u. Fieback, T.: Innovative heat exchanger design to avoid fouling. European Geothermal Congress 2022 - Proceedings (2022)