

REVIEW

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# Possibilities for using mine waters in the context of the construction of heat energy clusters in Poland

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## Abstract

**Background:** Non-renewable energy continues to remain the main link in energy production in Poland. At the end of 2016, fossil fuels (hard coal and lignite) accounted for around 82% of gross domestic energy production. Reducing the share of fossil fuels in renewable energy sources in the overall energy mix is a long-term process. An example of solutions for the use of renewable energy sources as one of the key elements of sustainable development, ensuring rational, economical, ecological and social effects is the application of heat from mine waters for the production of thermal energy. The work estimates the current national energy balance in the country and describes the role of fossil fuels in the context of the issue of low emissions. Political transformation and accession to the European Union (EU) have contributed to greater care for natural environment. Poland, while being obliged to comply with the European guidelines, monitors the state of atmospheric air pollution and takes measures to improve its condition. Research issues presented in the article are addressed in the socio-environmental context.

**Methods:** The method of reviewing scientific articles on the subject was used in the course of research task implementation (leading to the creation of a sustainable energy node or the idea of use of mine water). In addition, an analysis was carried out of the existing energy clusters in order to catch up with the standards of the European Union.

**Results:** The analysis of world and national literature shows potential of using energy from the mining waters of active and closed mining plants. The authors propose the introduction of a precise term regarding mining potential as a thermal energy cluster. The opportunity to change the image of mines as polluters consists in using their potential beyond their main activity profile. Furthermore, the use of the hidden potential of mines signifies prolonging the life of an enterprise and thus, as its consequence, sustaining jobs and developing the region.

**Conclusions:** The analyses presented in the article indicate the possibility of thermal energy production from mine waters not as an alternative but as an addition to the existing solutions, especially for the local needs.

**Keywords:** Mine waters, Abandoned mines, Energy cluster, Sustainable development, Poland

## Introduction

Non-renewable energy is still the main link in energy production in Poland. Domestic fossil fuels (hard coal and lignite) accounted for around 82% of gross domestic energy production at the end of 2016 (including 50.02% thermal power plants for hard coal and 31.49% for brown coal). The balance is supplemented by industrial power plants (6.23%), hydropower plants (1.47%), wind farms and other

renewable energy plants (7.24%). Year by year, the process of decarbonisation of the country's economy has been observed through a decreasing share of fossil fuels in energy production (93% in 2000) [1].

However, this process is a long-term operation in which coal will continue to be the main strategic fuel. On the one hand, this demonstrates Poland's energy security and fuel independence; on the other hand, it is a problem to catch up with the tightening emission standards and a 15% share of renewable energy in total energy consumption in 2020. The Environmental Agenda stresses the need to shift energy sources towards less emissive ones, such as

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natural gas, nuclear energy and renewable energy. In the case of natural gas, the Russian Federation can be considered as the main supplier of this fuel to Poland, which means that the strategy would undermine the country's energy security [2]. There are no nuclear power plants functioning in Poland, and there is also no social acceptance for their construction (opinion polls showed that 52% of respondents would object to the construction of such a power plant and 70% would object if a power plant were to be built near their place of residence [3]).

Thus, the development and support of renewable sources is indicated to increase energy security. Although renewable energy sources are currently of lesser significance for Poland's energy security, their use improves energy security on a local scale and contributes to the improvement of the energy supply, especially in areas with poorly developed energy structure [4]. The use of renewable energy sources is one of the key elements of sustainable development, providing rational, economic, ecological and social effects. Developed countries recognise the need to reduce emissions from the combustion of fossil fuels and the need to look for alternative energy sources.

Support for the development of the use of renewable energy sources has become a very important goal in the European Union [5]. Poland is currently under special supervision of the European Court of Auditors because in the current accounting period in place continuing until 2020 has been experiencing significant problems with the disbursement of EU structural and investment funds on RES. It is related, amongst others, to the indolence of territorial self-government units and the lack of low-emission economic programmes (non-compulsory action), whose conditions for the commencement of actions are related to applying for EU funds.

Linking the coal economy with numerous mines in the country, with the guidelines of decarbonisation and the development of renewable energy, is a difficult task to reconcile. This occurs all the more when the results of some researches related to the development of economy based on non-renewable sources raise doubts. Analysis carried out by [6] suggests that renewable energy has not contributed to economic growth, while non-renewable energy has and this should be included in the definition of energy strategies. Various correlations between energy consumption from renewable sources and economic growth can be found in the literature; positive correlation was noted by [7], while lack of any sort of relationship was presented by [8].

The literature review conducted here thus allows us to see an additional source of renewable energy in domestic conditions, which can include (as in the case of global projects) the mine waters. The article constitutes a set of global solutions in this regard, referring to the current state of knowledge and national initiatives implemented

in Silesia, as well as indicating the post-mining area with potential energy capacity in Lower Silesia. This solution has been placed in the context of the circular economy concept, so having in mind the second life of mines and development of energy clusters in accordance with sustainable development at the local level (distributed energy).

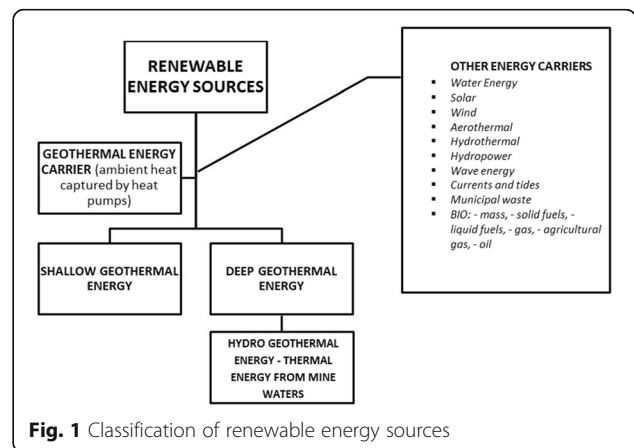
**Mine waters as a source of energy**

Mining waters are treated as an additional RES source in creating new (heat) energy clusters at the local level. For this purpose, the classification of renewable energy sources specifying mine waters as a carrier of geothermal energy has been proposed (Fig. 1).

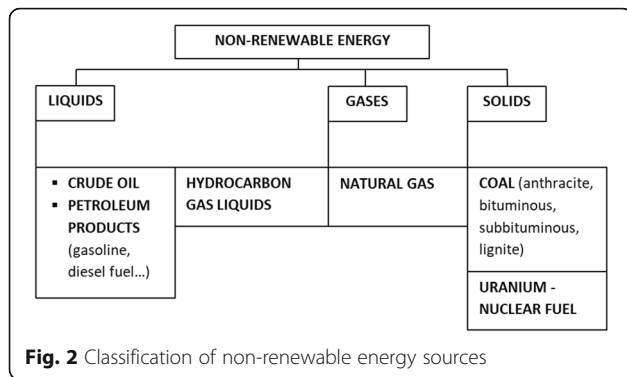
Bearing in mind the importance and the predominant role of non-renewable energy sources at work, an additional classification scheme for these sources is provided (Fig. 2).

In the publication [10], it was demonstrated that mine water is an attractive source of energy due to the fact that stored water and its stream in mine excavations constitute a reservoir of heat from renewable sources, along with the ability to change the brand potentially polluting the environment as a "green" source of energy or the development of many mines as commercial/industrial parks. In addition, the use of mine water finds its economic use justified on the example of Scotland, Canada, Norway, the USA, Great Britain and the Netherlands [11].

In the work of [12], we find a description of global documented examples of geothermal systems using energy from mines. Among the 13 examples presented (status as of 2011), 7 concerned the acquisition of energy from underground coal mines. Moreover, the uranium, molybdenum, tin, silver or flooded quarry were all listed as an energy source. In the more recent work from 2016, [13] enumerates 28 such systems, of which 57% are coal mines. Significant theoretical and academic studies were carried out to estimate the thermal potential of mine water in flooded coal mines [14–17]. In their studies [18], they carried out an analysis of the efficiency of using mine water



**Fig. 1** Classification of renewable energy sources



from an abandoned coal mine for heating buildings using the Ground Source Heat Pumps (GSHP) system.

Flooded coal mines in the UK are a potential source of energy (with low temperature) due to their availability throughout the UK. Water from the flooded coal mines is ideal for use for heating, which can greatly help in achieving the goal of acquiring 12% RES for the country (for 2016, it was about 1%) [13].

Good examples of the use of mine infrastructure to utilise water from underground hard coal mines for geothermal purposes are presented by [14]. The advantages of the activities include, among others, reducing energy costs or creating new jobs. The quality of mine water plays a crucial role. The operators of the installation in the first years of mining water extraction gained extensive experience, which helped to solve many problems with heat exchangers and filtering systems.

The Heerlen (Netherlands) programme is worth attention because it shows how, when struggling with the social and economic crisis after the mine had been closed, the city managed to be successfully transformed. Using the heating and cooling system of the mine with the support of public and private investors, a sustainable energy node was created [11]. The Heerlen project is a good example of implementing a policy of socially responsible mining, associated on the one hand with closing mines, and simultaneously giving them a second life with the involvement and acceptance of the local community.

It is also advisable to determine the geothermal potential of abandoned underground mines. The procedure was developed by [19] additionally specifying the level of reduction of CO<sub>2</sub> emissions related to the use of mines instead of conventional heating technologies.

Initial investment costs and annual operating costs of heat pumps are too high for a single recipient. According to the source [Greenmatch.co.uk](http://Greenmatch.co.uk), the initial cost is about £ 12.5–22,000, annual running costs amount to £ 975–1200 with a payback period of about 4–5 years. The proposal of the authors of this work is the implementation of this type of investment by the energy cluster at the local level, with the participation of the local government units and the

support of i.e. EU funds, especially in places where there is a large problem with low emissions.

As practice shows, energy clusters are perceived as a priority by the Polish Ministry of Energy as a mechanism for stabilising the share of renewable energy sources (RES) in the energy system (implementation of the project “Energy clusters in Poland and the possibilities of their financing under OPI&E (Operational Program Infrastructure & Environment) 2014–2020—energy sector”). They are perceived in the category of ensuring energy security, taking into account local resources and the potential of domestic energy. They are to contribute to improving the local natural environment and increasing the competitiveness and economic efficiency of the local economy (innovation and building social capital).

**The idea of energy clusters and circular economy on the background of the RES and low emission balance**

The draft Renewable Energy Directive regulates in detail the functioning of prosumers and energy cooperatives on the energy market [20]. In Poland, national legal conditions will be implemented, amongst others, by energy clusters [21]. This term was introduced into the Polish legal order in the Journal of Laws of 22 June 2016, amending the act on renewable energy sources alongside some other acts. It introduces into law item 925 as a “civil law agreement, which may include natural persons, legal persons, scientific units, research institutes or local government units, concerning the generation and balancing of demand, distribution or trade in energy from renewable energy sources or from other sources or fuels, as part of distribution network with a rated voltage lower than 110 kV, in the area of operation of this cluster not exceeding the limits of one poviat or 5 communes”.

The concept of a cluster in general and energy cluster is found in various scientific papers, including among others [22–26]. The concept of clusters is a significant element of the EU’s economic policy, Europe 2020: A Strategy for Smart, Sustainable and Inclusive Growth, Commission Communication, European Commission, Brussels 2010. The cluster inventory conducted at the end of 2015 [27] shows that typical energy clusters in the energy and renewable energy sector constitute 12% of all clusters created in the country.

The inventoried 134 clusters represent a wide range of industries, from traditional to high-tech. The largest number of clusters analysed operate in the ICT sector—information and communication technologies (14%), construction (9%) and medical and tourism industries (7.5%), while other industries have a smaller share. At the end of 2017, a clear revival in energy clusters was visible, as several letters of intent concerning the

cooperation of local governments in the field of renewable energy were then signed, including in the Podlasie, Podkarpackie and Śląskie voivodships (cluster associated with mining—methane, mine waters), Dolnośląskie, Małopolskie and Kujawsko-Pomorskie, which are one of the ways of using funds under the Operational Programme “Infrastructure and Environment”.

In 2016, the President of the Polish Energy Regulatory Office (PERO) granted 150 license promises for the production of electricity from RES, while as of 31 December 2016, there were 393 valid pledges, including a significant share of wind and sun (225 installations using wind energy, 155 ones using solar energy), alongside individual installations for biomass, biogas, hydropower, thermal transformation of waste or geothermal energy [9]. Offshore wind farms with a planned capacity of  $2 \times 600$  MW (start of construction 2020–2023, commissioning date 2022–2026) are in the development phase. In Poland, the share of RES in thermal energy production at the end of 2016 was at a 7.6% level [28]. The percentage share of generation from coal fuels for heat production has a downward trend (–6.7 percentage points). In 2016, it amounted to 75% compared to 81.7% in the base year 2002. The share of gaseous fuels increased in the years 2002–2016 from 3.0% to 7.2%, and the share of heating oil decreased over the 14 years analysed from 7.8% to 5.6%. In 2016, the share of RES fuels, and in particular biomass, amounted to 7.6% (increasing by 4.7 percentage points).

We can hear the most about coal Poland in public broadcasts during the heating season or during the settlements of CO<sub>2</sub> emissivity. It is unjust to assign exclusive emissivity (smog) to the largest issuers (coal-fired power plants). Our analysis of articles, reports [29–31] and observations clearly indicates that this low emission contributes the most to direct air pollution, forcing the restriction of outdoor activity. Surface emissions (so-called low) come from individual heating systems, including home furnaces. Linear emissions come from the car, railway or river communication sequences in which the source of emission is close to the surface of the earth.

One major problem in recent times has been the attention to the problem of low emission, described *inter alia* in works for selected areas of Poland [32, 33]. In many regions of Poland, the utilisation of municipal waste is practiced in domestic solid fuel stoves, unsuitable for this purpose (in 2015, about 49% of households' heated premises with heating appliances for solid fuels) [34]. Coal combustion and solid municipal waste is a social phenomenon that is a major source of harmful emissions to air [35]. About 38% of particulates emitted directly into the atmosphere originate from this source. It is unjust to assign exclusive emissivity of dusts to power plants and other industrial units.

Household furnaces do not have exhaust gas cleaning technology, and they are responsible for the emission of 20% sulphur oxides (SO<sub>x</sub>), 43% particulate matter (PM<sub>10</sub>), 51% carbon monoxide (CO) and 76% benzo(a)pyrene (BaP) (one of PAH polycyclic aromatic hydrocarbons). This is confirmed by sector emission results for EU-28 countries. The group of individual issuers, i.e. the vast majority of commercial, institutional and households, corresponds to the emissivity of dust, i.e. 57% for PM 2.5 emission and 42% PM<sub>10</sub>, whereas the energy production and distribution sector at 5% (PM<sub>10</sub> and PM<sub>2.5</sub>) (controlled emissions). For gases, they are SO<sub>x</sub> proportions: 59% energy production and distribution and 13% households. Nitrogen oxides (NO<sub>x</sub>) are 19% for energy production and 14% for farms [29].

Coal burning in households is the main contributor to the emission of particulate matter during the heating season of buildings [24]. The fuel quality is not verified in any way and the purchase incentive is the low price. The problem is so extensive that it more often affects the less industrialised regions of the country. Moreover, numerous spas that charge the clean air climate fee are not in fact so clean (exceeding the admissible levels or target substances in the air, mainly PM<sub>2.5</sub>, 10 and benzo(a)pyrene) [30]. Instead, good practices can be found in the emerging so-called anti-smog resolutions approved by the local parliaments of the Małopolskie, Śląskie, Opolskie, Mazowieckie and Łódź Voivodships (5 out of 16) and low-emission economy plans (LEEP), which are a key element in applying for EU funds in 2014–2020.

Other noteworthy national practices aimed at improving air quality include, among others, the first urban electric car rental in Poland in Wrocław or the development of public transport using trolleybuses in Gdynia. These are important initiatives given the fact that sustainable mobility and the introduction of electric vehicles on roads is a necessity from the point of view of ecology, which will gradually lead to a reduction of dependence on oil. An electric vehicle is the optimal solution for urban mobility because it does not emit fumes. In cities and unfavourable climatic conditions, emissions generated by traffic reduce the air quality to a level that poses a threat to the health of the population. By respecting the natural environment, electric vehicles give access to historical city centres and contribute to the reduction of air pollution and noise pollution [36].

Poland can boast of local energy self-sufficiency in a small rural commune of Kisielice in the Warmian-Masurian Voivodship (over 6.5 thousand inhabitants) (heat and electricity from wind, biomass, biogas plant) or in Uniejów, where the first national geothermal heating plant operates using only renewable energy sources (geothermal waters and biomass). The report [38] informs on all current Polish geothermal heat plants, while the possibilities of using

domestic geothermal resources (both petro and hydro-geothermal) have been discussed in this research [37].

Ad hoc operations involve numerous checks on the quality of the fuel burned, for example, in Katowice, where it is supported by a specialised drone for smog patrols serviced by the municipal police. A Smog-Free Tower has been introduced in Kraków to purify local air.

Other changes have been introduced in the direction of clean air, such as the regulation on boilers from 7 January 2017, which prohibits the sale of boilers for solid fuels with an emission class lower than V. However, there are still no guidelines regarding the quality of the fuel burned in households.

The development of local RES installations within energy clusters has been described by [39], focusing on the problem of estimating renewable energy resources in Poland for emerging local initiatives—energy clusters. In particular, the small and medium enterprise sector has been taken into account, as pro-effective and prosumer activities can significantly contribute to improving energy security at the local level and increase the share of renewable energy in the country's energy balance. The implementation of infrastructural investments in renewable energy while still maintaining the requirements of environmental protection is consistent with the principle of sustainable development in relation to the idea of a circular economy (circular economy CE). The goal is to “close the loop”, that is, to turn the output product into the input product for further transformations.

One of the European Commission documents related to the issue of circular economy CE is “Towards a circular economy zero waste program for Europe”, according to which the circular economy is a strategy of economic growth (without increasing consumption) in a closed structure, presenting a fresh approach to the flow of resources. As the authors note [40], CE focuses mainly on research into waste generation, resource use and environmental impact, neglecting economic perspectives somewhat. Focusing on three perspectives ensures simultaneous and equal visibility of the constraints on natural resources, environmental issues and individual business needs (involvement of decision makers, government bodies and industry). Here, the final goal is to achieve a fully regenerating economy and natural environment in the proposed areas of support: legislation and policy, support infrastructure, social awareness, common business models, product design, supply chains and information and communication technologies (ICT).

Polish mining companies have also taken actions in line with the circular economy considerations as a priority. Among others, KGHM Polska Miedź SA (a company dealing with the exploitation and processing of polymetallic ores) has developed the Closed Circuit Economy program, thus moving away from the linear economy towards

closing the material flow [41]. The PGE Capital Group (a capital group whose activity includes, among others, PGE GiEK SA lignite mining, electricity and heat production) intends to prioritise CE by maximising the use of by-products of the electricity and heat production process, achieving the objective will be possible thanks to cooperation with start-ups [42]; LW Bogdanka (engaged in hard coal mining) implements the CE concept by increasing the economic use of waste mine water (underground) and waste rock [43]. The initiatives of the above companies are related to the issues of corporate social responsibility (CSR) discussed in other studies by the authors [44, 45].

In the context of the issues analysed here, the authors point to the possibility of considering (classifying) the possibilities of using mine water in the context of a circular economy in terms of energy cluster for the needs of local development.

### **Mine waters in Poland—the potential for creating clusters**

The analysis of world and national literature shows the potential of using energy from the mining waters of active and closed mining plants. The authors propose the introduction of a precise term regarding mining potential as a thermal energy cluster, similar to the above quoted sustainable energy hub in the Netherlands (former mining town). Programmes for constructing energy clusters exist, including in the Czech Republic [46] or in Germany [47], but they do not include solutions in the field of “second life of the mine.”

The opportunity to change the image of mines as polluters is to use their potential beyond their main (basic) activity profile. The search for green energy within the mining industry leads to the testing and application of solutions using energy sources, for which there was no use for many years, i.e. mine water. Bottom water can be used both by operating plants and those in which production has been discontinued.

Furthermore, the use of the hidden potential of mines signifies prolonging the life of an enterprise and thus, as its consequence, sustaining jobs. Local societies react to changes cautiously, both when the matter in hand concerns making new investments and ceasing the existing ones, objecting to radical solutions through protection [48–52]. Prolonging the life of mines would enable a shift from mining activity of non-renewable energy sources to the functioning of mines as sources of renewable/geothermal energy. This concept is compliant with the climate policy, so limiting the emission of gases and dusts to the atmosphere (including, which is significant, greenhouse gases). Here, the continuing of economic activity where the liquidated mines are located would be compliant with the principles of environment protection, while remaining beneficial to the local community, forming at the same time part of the assumption of sustainable development.

The production of heat energy based on the water coming from the drainage of mine workings has its good and bad sides. Among the restrictions in conducting such activities one may indicate, among others:

1. An overly long transmission route: if there are no objects near the mines whose managers/owners would declare the need for their heating/cooling, then the heat losses of water at large distances will disqualify the use of low-temperature geothermal energy. It is recognised [53] that water can be spread over distances up to several kilometres in insulated pipelines. A good example is the use of water utilisation from active drainage of the Sobieski mine in Jaworzno (Śląskie Voivodship), belonging to the most water-bearing coal mines in Europe, where the underground water inflow is about 60 m<sup>3</sup>/min. The incoming waters come mainly from dynamic resources (infiltration of atmospheric precipitation and quaternary water) and from static resources (drainage of newly made parts of the deposit).

It is predicted that in the following years, with the provision of new deposits, the inflow of water to the mine will gradually increase [54, 55]. The temperature of mine water is nearly 20 °C. The heat pumps heat it up to 55 °C. Water is used for sanitary purposes in the baths belonging to the mining plant. It is made on a regular basis, as well as stored in trays with a total capacity of 63 m<sup>3</sup>. It is estimated that the return on the installation will occur after 6 years of use. The investment was carried out in 2015 [56] while implementation of the investment will allow the company to acquire property rights resulting from the energy efficiency certificate. They are a commodity and are traded on the Polish Power Exchange in Warsaw. The purchase of these rights is legally assigned to the trading companies and energy companies that sell energy to end users.

Another promising example is the proposal to use the Katowice mine located in the heart of the Silesian voivodeship. The mine was closed in 2001. Despite the fact that hard coal mining is no longer carried out in it, it should be dewatered to ensure the safety of other coal mines functioning in this area. The mines of the Upper Silesian Coal Basin form a hydraulic system, and completion of drainage of one of them would cause flooding of the remaining Bartosz II Shaft, in which water is pumped out, and which is located in the strict city centre. The distance from the future recipient (Silesian Museum) is about 150 m. The drainage is expected to last between several and a dozen or so of years. This is a sufficiently long time for the functioning and depreciation of this type of installation [57, 58].

The latest initiative to be implemented falls under the project “Clean Energy—Second Life of the Mine (LoCAL): Sustainable Use of Sunken Excavations after Exploiting Hard Coal as a Source of Thermal Energy”. The implementation of an international project in Poland involves the use of mine water in the Bytom Szombierka plant, which is now closed, for heating newly built houses. The last heating season was the first season when testing of the installation and heating of the building with an area of 130 m<sup>2</sup> took place. Now, the Bytom pilotage is the first attempt to use mine water in a commercial project [59, 60].

2. The need for infrastructure investments: in the case of a large-scale heating/cooling system, a significant infrastructure investment should be realised before the thermal resources can be used by local residents and companies. You can build a centralised machine for heat pumps, from which hot (for heating rooms) or cold (for air conditioning) fluids may be distributed to nearby users. Alternatively, mine water (or heat transfer fluid that is thermally coupled to mine water) can be distributed to users via flow and return pipes, while the heat pumps of individual users extract heat or reject heat to this fluid flow (distributed system). In both cases, the costs associated with the distribution/supply of mine water with heating and cooling pipes, especially in urban areas, may constitute the dominant investment cost. Additionally, in the case of modernising the heating of existing properties, it may be necessary to install modern, low-temperature radiators, underfloor heating, which works effectively with heat pumps [61]. It should also be remembered that dewatering itself generates costs and electricity costs can exceed even 90% of the total costs. The proper pump repair policy [62] supports the reduction of drainage costs. In the case of Polish liquidated mines, where drainage is still carried out due to the protection of mines active against water hazard, these costs are covered by the state budget [63]. The dehydration of liquidated and undergoing liquidation mines is concentrated in Spółka Restrukturyzacji Kopalń S.A., which is a State Treasury company. The estimated annual cost of drainage is in the case of regions planned as sources of geothermal energy of low temperatures: Szombierki 9 065 500 PLN, Katowice 7 778 900 PLN [64].
3. Re-collecting water through the mine: if the water whose thermal potential has been used is reintroduced into the mine, there is a risk that it will go back to the well. Cold water recovers heat from the surrounding rocks during the passage, but if the flow path is too short, cold water enters the

production well before it has a chance to regain the initial temperature and the cooling of the water will reduce the efficiency of the heating operation. It is therefore necessary to perform a detailed mapping of subsurface paths in combination with thermal modelling to prove the heat exchange capacity of the main flow paths [61].

4. Technical problems during the operation of the installation. The risk that iron or manganese hydroxides may precipitate in pumps, tubes, heat exchangers or injection wells can deter potential investors from heating/cooling systems based on mine water. It is a real risk for most mine waters [61]. Failure to maintain physicochemical parameters of groundwater used as a source of heat may lead to the disturbance of proper system operation due to erosion or corrosion of the evaporator and water supply pipes, shattering or clogging of the evaporator and water supply pipes or silting of the discharge well. If the water quality parameters deviate significantly from the permissible ones, then an indirect exchanger can be used on the downstream side, before the heat pump, which can be cleaned periodically of any deposits [65].

However, the benefits of using mine water as a low-temperature heat source include:

1. Economic benefits: they are related both to the omission of the geothermal exploration stage when we decide to use underground water and the use of mining shafts, and what is connected to it, the lack of necessity to make geothermal holes [59].
2. Ecological benefits: concern the reduction of emissions of compounds adversely affecting the local climate [59]. Here, it was estimated that the total amount of CO<sub>2</sub> discharged to the atmosphere owing to the installation being based on geothermal resources of the former Katowice mine is 76.8 Mg/year, while production of the same amount of heat and electricity using conventional sources results in CO<sub>2</sub> emission to the amount of 3686.7 Mg/year (48× more) [57]. Draining mines also provide protection against groundwater pollution. When water gradually fills up excavations and sidewalls of flooded inactive mines, sulphates and metals contained therein can get into aquifers [66]. In addition, water discharge results in changes in the chemical and physical properties of reservoirs. Warm underground water interferes with their ecosystem [67].
3. Social benefits: these concern heat consumers, who save on fees (reduction of energy costs) and changes the image of the mine from the

environmental pollutant to the responsible entity being the source of “green” energy [10].

It follows from the above that using the geothermal potential of mines is not only acceptable, but also advisable. Potential restrictions do not have to disqualify investments, while some of them can be counteracted.

In Poland, there are various possibilities of using the natural heat of the earth and water, especially in the area of the Upper Silesian Coal Basin (USCB). It is in the Śląskie voivodship that a project is being carried out, which is designated to produce mine water energy to meet the thermal needs of the mining bath in KWK Piast (mine). It is estimated that the average investment cost of a 0.5 MW installation is at the level of 0.8 million PLN, with the tendency increasing with the increasing power (prices of heat pumps and heat exchangers grow almost linearly with increasing power). The payback period of investment outlays is estimated at a maximum of 10 years. Fixed and variable costs of a functioning installation are estimated at approx. 300000 PLN/year. A reduction of the unit price of thermal energy production in relation to the current state (24.04 PLN/GJ) by about 2.5 PLN/GJ is planned [68].

Many works by [57, 58, 69] indicate the use of heat coming from mining excavations, primarily heat from mine water and heat contained in the ventilation air. While the pilot works are conducted in this region of Poland, a different post-mining area for conducting research on the use of renewable energy from the areas of the Lower Silesian Coal Basin (the Wałbrzych area) remains to be developed. Analysing the development strategy of this region, the bridge between the mining and renewable energy is the “Zielona Energia w Wałbrzychu” programme whose aim is to build energy foundations for Wałbrzych’s self-sufficiency based on renewable energy sources, including the use of heaps for the construction of photovoltaic farms [70]. Another opportunity for the region is the idea of using the water resources from mines [71].

The number of shafts located in the former Lower Silesian Coal Basin indicates the necessity of their inventory in the context of determining the potential and possibilities of constructing thermal energy clusters in their environment. Formal conditions related to the regional scope for the cluster would be met (geographical coverage of one powiat or five communes). The initiative of a thermal energy cluster is used in generating heat for prosumers in the immediate vicinity of the shaft. One of the important conditions for the construction of a thermal energy cluster using mine water energy is the condition for the effective use of heat pump must be relatively close to its source [10] (exclusion of transmission due to heat loss). In the context of the proposed energy cluster construction area, the authors indicate a potential recipient, the Stara Kopalnia Science and Art Centre in

Wałbrzych (public utility building), as the biggest attraction of post-industrial tourism in Poland, located on the site of the former Coal Mine "Julia ("Thorez") (Fig. 3).

According to the authors, there is a need for future assessment of the possibility of using mine water for this shaft and for the entire Wałbrzych region (new life of mines). The next stage will require carrying out a detailed inventory of the technical condition of the existing shafts in the Wałbrzych region along with their energy potential and local land use, including infrastructure on the surface.

**Discussion and conclusion**

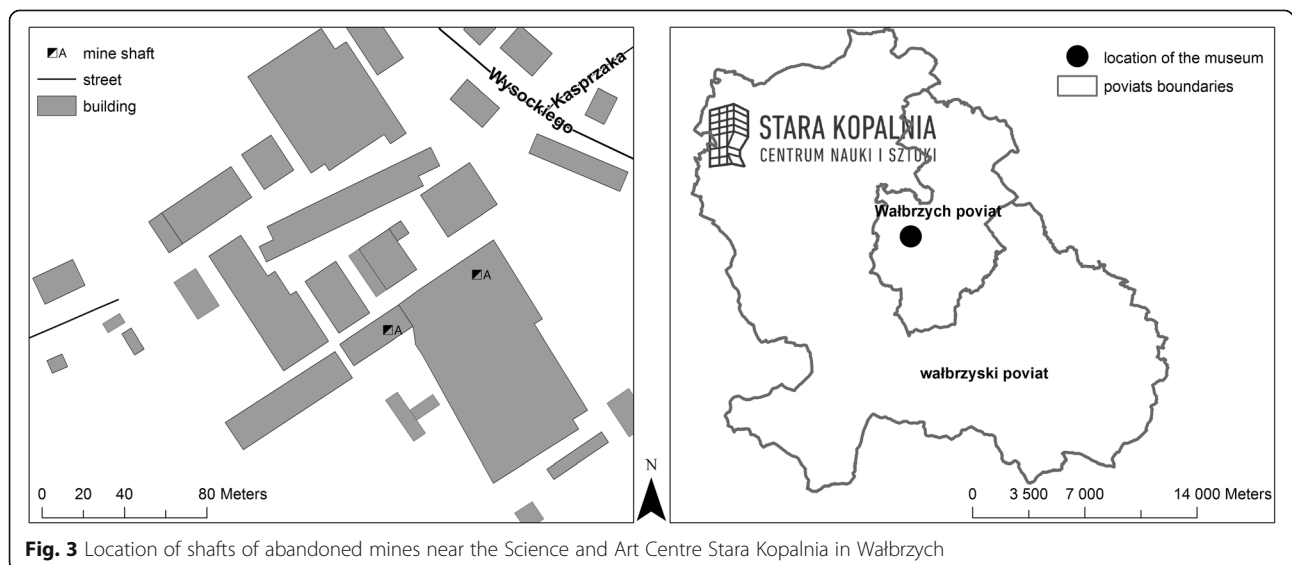
Poland is one of the countries (states) that for decades belonged to the "Eastern bloc", being politically isolated and falling behind in implementing any environmental policy. Together with part of SE Germany (former East Germany) and the Czech Republic (western part of former Czechoslovakia), SW Poland has formed an area known as the "black triangle". This amalgamation has involved the emission of pollutants subject to cross-border transfer. Air pollution is responsible for environmental threats such as eutrophication of aquatic ecosystems, acidification of forests and degradation of air quality [72, 73].

Political transformation and accession to the European Union have contributed to the improvement of the natural environment. Being obliged to comply with the European guidelines, Poland monitors the state of atmospheric air pollution and takes measures to improve its condition: boiler regulation from 01.07.2017, which prohibits the sale of boilers for solid fuels with an emission class lower than V; drones supporting the control of the fuel burned; programmes of local government units of LEEP; changes in transport; investments in RES; and places on the Polish map which are self-sufficient in energy and many others. They [74] wrote about local

self-sufficiency in Germany. However, there are still no guidelines on the quality of the fuel burned in households, to which the authors draw attention with respect to improving the quality of the air inhaled. The key goal of the sustainable development strategy of the EU is the policy of sustainable consumption and production, while Poland is one of the countries that most effectively implement a policy of sustainable production [75].

However, the new requirements resulting from the IED Directive [76] has led to many existing investments limiting emissions of harmful substances in the energy sector which will not protect installations from renewed modernisation or exclusions from traffic. Previous technical solutions will not always be able to meet the new emission requirements. In addition, the manufacturing sector in Poland will have to meet extremely demanding environmental standards in the coming years, which have been defined in the BAT conclusions for large combustion plants (LCP) [77].

In this situation, the technologies presented in this article appear to provide a strong solution. This issue was considered through the prism of global examples and experiences of the use of mine water energy as one renewable energy source. Among the many inspiring solutions, one can distinguish a Netherlands project [11] leading to the creation of a sustainable energy node or the idea of the use of mine water heat in the Rostov region [78, 79]. The authors are aware that the solutions currently presented are not an alternative, but a complement to existing solutions (stable role of fossil fuels [80, 81]). A further stage of research may hence provide a detailed inventory of the technical condition of existing shafts in the Wałbrzych region with their energy potential and local infrastructure on the surface being then required. Mine waters can thus help to create new (heat) energy clusters at the local level as an additional source of renewable energy [82, 83].



**Fig. 3** Location of shafts of abandoned mines near the Science and Art Centre Stara Kopalnia in Wałbrzych



**Abbreviations**

BAT: Best available techniques; CE: Circular economy; CSR: Corporate social responsibility; EU: European Union; IED: Industrial Emission Directive; LCP: Large combustion plants; LEEP: Low-emission economy plans; PERO: Polish Energy Regulatory Office; PM: Particulate matter; RES: Renewable energy sources; USCB: Upper Silesian Coal Basin

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**Ethics approval and consent to participate**

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The authors declare that they have no competing interests.

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