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Guidelines on the conversion of underground mine working into water reservoir

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1. Introduction

In order to store water pumped from the surface it is necessary to select and identify workings suitable for the construction of the reservoir. Typically in coal mines the type of support used in (drifts) headings is an arched roof support. This type of support leaves the floor uncovered and in time the contraction of the support reduces the cross section of the heading.

Therefore, it is necessary to select either proper support to prevent the contraction e.g. concrete lining or select parts of the mine where large workings (such as pump, machine chambers or shaft stations) are available. This task summarizes results of analysis of potential use of underground workings as underground water reservoirs. During the course of the task and discussion with the project team it occurred that horizontal workings in mines despite theoretically large volumes are difficult to convert into water reservoirs. The focus of this task was mainly on the behaviour of support during the operation of the Underground Pumped Storage Power Systems (USPS) and selection of potential places within the countries of the consortium partners that could be suitable to develop such systems. The problems that may occur during the operation phase of USPS differ from those that occur during the operational phase of the mine (Fig. 1).

Energy storage phase	• Corrosion • Constant load (rockmass) • Cyclic loading (water pressure) • Convergence • Abbrasion from particles suspended in water
Operation phase	• Corrosion • Rather constant load • Convergence

Fig. 1 Different factors impacting the stability of the support in mines during normal operation phase and energy storage in USPS.

An analysis of the suitability of underground workings as potential water reservoirs should consider not only their volume, as is sometimes simplistically done, but also the way they are reinforced or lined and the implications of the state of excavations for the operation of energy storage facilities.

Corridor workings, which are mainly horizontal or slightly inclined galleries, account for the vast majority of the total length of a mine's underground workings. An average mine of smaller size excavates at least a few and the largest, such as LW "Bogdanka" even a dozen kilometers of new corridor workings each year (Chmielewski et al.). Although these workings are largely decommissioned, each mine has a network of at least several dozen kilometers of undecommissioned workings at any given time, and this state is also maintained until a decision is made to close the mine, whether for economic, resource depletion or environmental reasons. At the decommissioning stage, the number and total length of the excavations is systematically reduced.

The vast majority of these several tens of kilometers of workings are excavations drilled in coal seams, a rock that is relatively easy to mine mechanically and allows high efficiency (progress) of excavation drilling.

The support of these workings under Polish conditions consists almost exclusively of steel sets spaced (arch roof support) a few tens to a hundred tens of centimeters apart, connected by steel connecting elements of small cross-section (struts). The space between the steel sets and the rock mass is filled with steel mesh, or prefabricated reinforced concrete elements laid alternately (Fig. 2).

Sometimes used in Poland, more often in the Czech Republic, rock bolting is similar in its essence in terms of challenges and problems in the adaptation of excavations reinforced with it as water storage for energy storage purposes. Lack of tightness, possible severe corrosion of standard mesh and anchors after many years of operation is a well-known fact (Fig. 3).



Fig. 2. View of an example intersection of horizontal excavations protected by a typical steel arch support. (Inżynieria Górnicza 2020/1).



Fig. 3. Rock and cable bolts with mesh installed in the exploratory roadway at LW Bogdanka S.A. (photo by M. Antoniuk) from (Rak Z and Stascia 2020).

These types of support as a whole are first of all not air- or water-tight, secondly, they are not designed to ensure long-term stability of the workings with safety coefficients required for building structures, and thirdly they are subject to severe corrosion due to exposure to the mine atmosphere and especially to saline mine water.

The completely exposed floor, and the largely exposed ribs (side-walls) and roof of such an excavation means that through the inevitable cracks and fissures around it, formed both at the stage of drilling of the gallery and the impact of the increased rock pressures resulting from extracting useful minerals in its vicinity, firstly, dangerous gases such as methane or carbon dioxide may release, and secondly, through air migration, there may be self-heating of coal in the vicinity of these galleries and, with the changing ventilation of the mine, the so called endogenous fires.

Cracks and fissures will also provide migration and escape routes for water from potential storage. Exposed ribs and roof and, most importantly, a completely unprotected floor means that small rock fragments and coal dust will be deposited in the workings. What's more, after potential filling with water in such a condition, the debris will keep coming. Contamination of water with rock fragments, in the form of lumps, crumbs and dust poses a very great challenge to the pumping system, the cost of pumps capable of operating in such an environment would be significant and the service life would be much shorter than that of classic pumps in water of adequate purity (see for example Fig. 1).

In view of the above challenges, the desire to adapt these horizontal excavations would *de facto* entail the need for a completely new sealed lining. Its cost in relation to the scale of the challenge, specifically usually the very corroded steel elements including V-shaped steel sets, would be very significant (Fig. 3 & 4).

All the more so because its load-bearing capacity, and thus its thickness, would have to ensure not only isolation from the coal seam in which the excavation was drilled and tightness, but also sufficient support to ensure the stability of the excavation loaded with the weight of rock blocks in the heavily jointed rock mass.

Both of these types of support are open, which means that in principle the floor of the excavations remains completely exposed.



Fig. 3. Examples of steel arch support corrosion in Ziemowit part of Piast - Ziemowit coal mine: a - 1st level , northern crosscut, b – 2nd level, gallery 338, c – 3rd level, crosscut P-1, d - 3rd level, crosscut C-2.) (Rozmus & Ficek 2020)

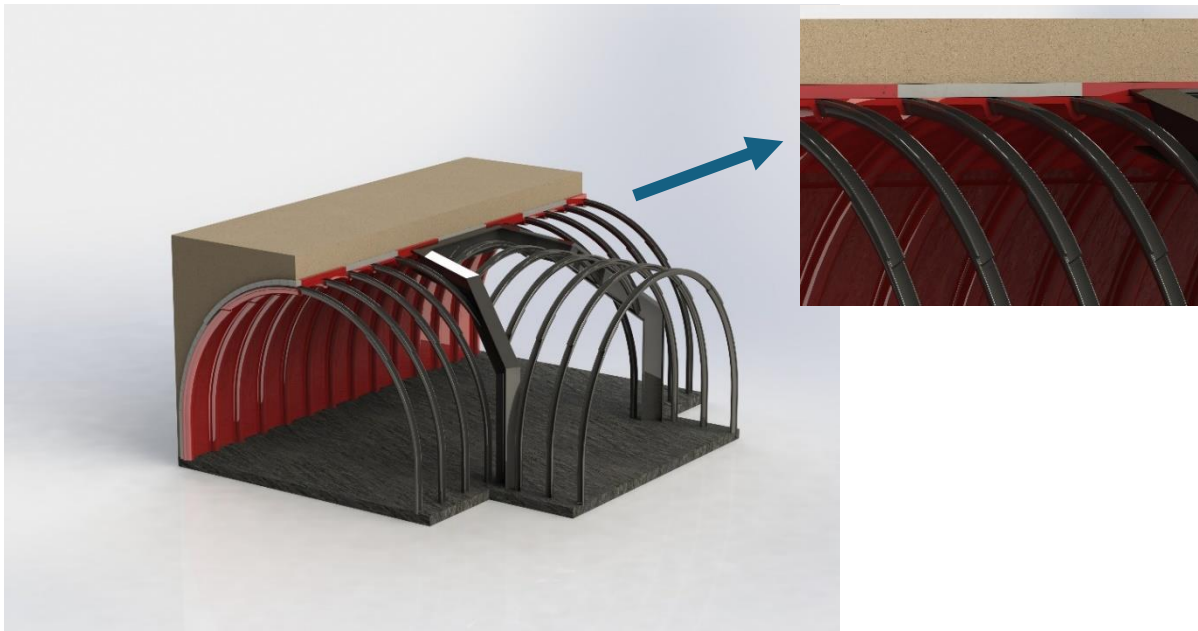


Fig. 4. A concept of sealing yielding steel arch support with liners (in red) (Lutyński et al. 2019)

The lining would also have to inhibit or at least significantly reduce the convergence of the excavation drilled usually at considerable depths and resulting from the rock mass pressures prevailing at these depths and the rheological properties of the rock mass (Fig. 5).



Fig. 5. The general view of main gate 25a – testing section I – only standing yielding support – the crushed coal in the sidewall with the left pillar (Małkowski and Niedbalski 2022)

It is worth noting that the convergence in excavations observed for typical steel arched support in polish conditions were reaching almost -8 % of vertical convergence per year and -5,4% of horizontal convergence per year. On average, these values for Bogdanka coal mine, were -5,1%

and 2,34% per year for vertical and horizontal convergence respectively (Marczak 2010; Małkowski et al 2008).

The solution which might be suitable for the workings which use steel arch roof support is a complete reinforcement using concrete. In this case however, the effective cross-section of the corridor workings is reduced significantly. The example of such reinforcement is shown in Figure 6.

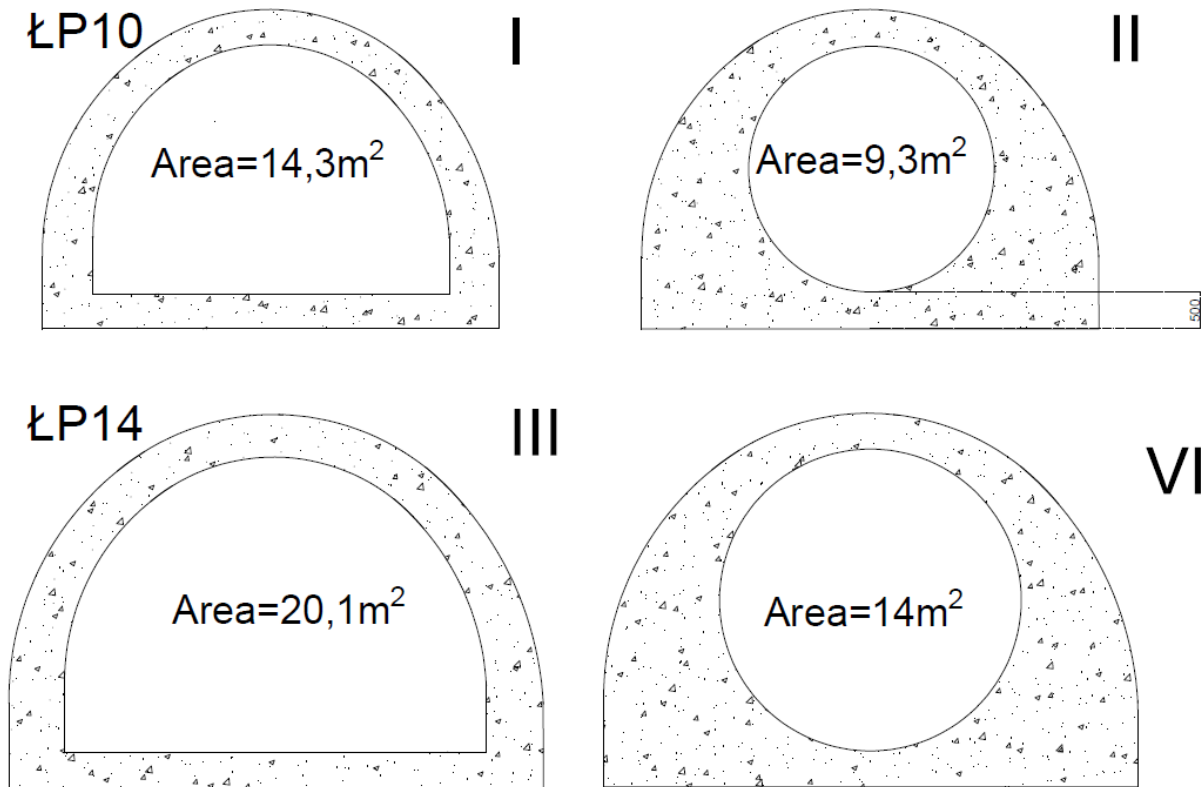


Fig. 6 Typical cross-sections of workings in mines and types of concrete support that could be used. Type I and III is the horseshoe-shaped concrete support and type I and II is the circular-shape concrete support. The cross sectional area is reduced from 23,1 m² (case I and II) and 32,3 m² (case III and IV).

Calculations of the reduction in effective cross-sections were carried out for typical arch roof support type Łp 10 /v29/a2 (horseshoe-shaped) with cross-sectional area of 23,1 m² (Fig 6 I and II). In the first case (I), the concrete lining is half a meter thick along the entire contour of the excavation, and in the second case, the concrete lining is half a meter thick in the thinnest point and has a circular-shaped cross-section. In the first case, 9.2 cubic meters of concrete should be used for each meter of the excavation and the cross-sectional area reduces to 14.3 m² (approximately 1 m³ of concrete per 1 m² of reinforced area). In the second case 14,3 cubic meters of concrete should be used for each meter of the excavation and the cross-sectional area reduces to 9,3 m².

In the third and fourth case, the example excavation is an Łp 14/v29/4/a/ii support with a cross-sectional area of 32,3 m³. For the horseshoe-shaped concrete support it is necessary to use 18,3 m³ of concrete and the effective cross-sectional area reduces to 20,1 m³. In the fourth case, 20.1

cubic meters of concrete should be used for each meter of the excavation and the cross-sectional area reduces to 14 m³.

The above shows that there is a considerable amount of concrete that should be used and the technique to construct such support is not well developed since it is not in current practice in mines.

It should be noted that the above calculations do not take into account the space between the individual support arches and between the concrete block insert and the top of the opening. The rock mass at the point of contact with the support is usually not solid, there are numerous cracks in it and behind the concrete block insert there is a lot of loose rubble. It is very difficult to estimate how much concrete will be needed to fill these spaces. Hence, the amount of concrete needed might increase in reality.

The above difficulties, challenges and associated costs are considerable, and it seems that a reasonable alternative, with less technical difficulty and, above all, much cheaper, is to use mine shafts, i.e., vertical, circular excavations drilled from the surface into the rock mass, as water reservoirs for energy storage (Fig. 7).



Fig. 7. An example of a view from the surface to the inside of a shaft lined with a brick masonry (Inżynieria Górnicza 2020/1).

It seems possible to use and adapt existing mining shafts in mines under closure as underground water reservoirs for energy storage purposes within a reasonable budget and acceptable risks levels.

The decision to decommission the mine or its part is usually accompanied by the decision of the liquidation of the shafts, which is implemented by constructing barriers at the so-called shaft stations which are the connection points of the shaft and the main horizontal excavations and subsequent backfilling of the interior of the shaft with different kinds of aggregate and placing a reinforced concrete cover at the land surface level.

In this way, those excavations whose drilling costs and equipment are counted in hundreds of millions of Euros are irretrievably lost and any (including economic) reuse is impossible. The shaft is the most important excavation of every mine and care for its condition (housing, equipment) is a priority throughout the life of each mining plant and incomparable to any other underground excavation. As an alternative for backfilling the decision to build a clean underground water reservoir for energy storage in the mine shaft at the stage of the decision on the liquidation of the mine allows the use of existing infrastructure in good condition in a way that increases the security of the country's power system, and thus is a model example of post-mining revitalization.

The construction of the underground water reservoir for energy storage may be particularly advantageous in those locations where an industrial electricity producer (conventional power plant) is in the immediate vicinity of the decommissioned mine or part of it with the shaft/shafts. In most of the cases, also in Poland, such locations can be indicated (eg. Łaziska power plant near Bolesław Śmiały coal mine).

The mining shaft is protected against destructive influence of rock mass pressure (stress in rocks) with various types of lining (usually thick-walled reinforced concrete or segmented thick-walled iron tubing), which ensures its stability. The water stored inside it, with a range of pressures used in this type of installations, will exert pressure on the lining in the opposite direction to the action of the rock mass, so it will not add up to the impact of the rock mass, but on the contrary, will counteract its impact by inhibiting the convergence of the excavation. Due to the fact that - depending on the depth - the horizontal rock mass pressure acting on the lining may assume values similar to the pressure of the water acting in the opposite direction, e.g. at a depth of 400m - about 4 MPa, it is expected that there will be no need to install an additional lining at a considerable length (depth) of the future water reservoir but only supplementary elastic sealing layer. The shaft lining, in contrast to the lining of the vast majority of other mining excavations, is designed and constructed as relatively tight (due to water-bearing aquifers in the rock mass, often under pressure), which is another advantage. In addition, the rock temperature in the rock mass increases with depth, e.g. in the conditions of most Polish mines about 3 °C for every 100 m deep, so at a depth of 1000 m it is well over 30°C and is constant, hence heat from the rocks may solve any freezing problems in case of severe winter conditions.

Mining shafts on the main surface of the mine are drilled in at least in pairs, and most often as three or even four (or even more, albeit rarely) and are close to each other. These excavations, several dozen meters apart, are connected on several levels below the surface. These connections are made through openable dams or barriers or they can be easily installed. In many liquidated mines, the threat of flooding neighboring active mining plants (connected hydraulically by a jointed rock mass) has forced, enforces and will force in the future to leave at least one shaft to pump water active. The costs of pumping and maintaining shaft infrastructure in decommissioned mines are borne by the State Treasury. Liquidation of the pumping station is possible only after the last mine in the entire region of the exploited basin has been closed down. Construction of an energy storage in one of the shafts at the main surface in the presence of an adjacent shaft excavation, intended for pumping water, greatly facilitates the process of adaptation/construction of energy storage and access to renovation works or control visits.

The vast majority of mining shafts are fitted up, i.e. they have various types of equipment that can significantly facilitate construction and maintenance/repairs during their use as an underground water energy storage. This equipment includes shaft towers with hoisting

machines, steel guides used as guides for hoisting vessels/shaft cages, evacuation ladder compartments along the entire length of the shaft, various types of pipelines (water, methane drainage, fire protection, etc.), electric and telephone cables, often also fiber optics. The use of this infrastructure, otherwise useless, may also reduce the costs of building and using a storage facility. However, there are, although to a large minority, mining shafts not fitted up, that is, those in which no additional equipment has been installed (except for the shaft lining itself).

Shafts of this type are ventilation shafts (they are used to remove so-called used air or supply fresh air) and a significant part of them is located close to the border of the mining lease. Such shafts are also suitable for conversion to underground water reservoir, as the lack of shaft equipment does not mean that it cannot be adapted for storage purposes, it only entails other types of requirements for its adaptation process and subsequent use as a water reservoir energy storage facility.

The costs associated with sealing operations of the shaft lining to adapt to the storage of energy in water reservoir is expected to be acceptable in relation to the costs required for the construction of e.g. rock caverns or surface water reservoirs with dams and embankments. The building of the underground water reservoir energy storage facility can be carried out in locations where geological conditions does not allow for the construction of rock caverns, and surface water reservoirs but post-mining facilities are located. Adaptation of such infrastructure can be an interesting option for revitalizing of the post-mining regions. The proposal is an interesting alternative to the use of surface water reservoirs, where the mountainous landscape and favorable geological conditions are required.

2. Goal of the work

Despite the limitations listed above it was decided to perform a multicriteria decision analysis in order to select potential locations for USPS where headings near the shaft stations will serve as a lower reservoir. The underground infrastructure of the mine, its equipment, dimensions and depth, and the surroundings of the shafts were verified. Based on the requirements of the adopted hydroelectric power plant concept, its requirements were determined from the point of view of hydrogeology and geoengineering. A system for comprehensive assessment of the possibility of using corridor excavations as lower reservoirs of pumped-storage power plants was developed. It is worth noting that after the initial selection it is necessary to conduct further analysis and adjust results related to the availability of lower reservoir volumes to the fact that using concrete support will decrease the cross-section of the heading and the length of the available heading should increase respectively.

3. Identification of shafts and underground excavations

The mine shafts of individual companies were assigned to the mines in which they are located, and then to the internal units of these mines.

The list includes the number of shafts belonging to each mine. The description of each shaft includes:

- name of the mine shaft,
- function of the shaft,
- shaft diameter,
- shaft depth,

- change in diameter with depth,
- height of shaft collar,
- other information and comments such as: type of shaft lining, other shaft cross-section, levels connected to the shaft, equipment, etc.,
- information on shafts under construction, flooded and decommissioned.

The main results of the created list are the possibility of determining the total number of shafts in Poland, which due to their size can be adapted for energy storage purposes.

The list will also allow for estimating the total energy storage potential in megawatt-hours.

In order to transfer the project results to a European scale, a comprehensive tool was developed to assess the energy storage capacity in corridor excavations in the form of an Excel sheet.

4. Multi-criteria decision analysis for assessing shafts and underground workings as potential USPS

During the work carried out within the WP2, a multi-criteria decision analysis (MCDA) for assessing shafts was developed in terms of their potential future use for the purposes of an underground pumped-storage power plant.

4.1. Shaft assessment criteria

Identification of factors determining the possibility of using a liquidated shaft for the purposes of an underground pumped-storage power plant was made. The shaft assessment criteria were based on these factors.

4.1.1. Shaft depth

The parameter with the greatest impact on the amount of water energy that can be stored is the depth of the shaft. This energy, defined by the formula:

$$E = H_u \cdot V_z \cdot \rho \cdot g$$

is directly proportional to the net head H_u in the water turbine. The greater the net head in the turbine, the smaller the volume of water V_z that should be stored, therefore the upper and lower water reservoirs will be smaller.

Whereas using this equation:

$$V_z = Q_p \cdot t_p$$

we obtain:

$$E_p = H_u \cdot Q_p \cdot t_p \cdot \rho \cdot g$$

From the above relationship it follows that the shorter the time of pumping water t_p to the upper water reservoir or the lower the volumetric efficiency of the pump Q_p , the lower the energy consumption for pumping E_p , which will result in higher efficiency of the energy storage.

The underground vertical workings of the mine can be used as the lower water tank. In order to prevent washing out of the rock and penetration of contaminants into the stored water, it is beneficial to use insulation of the reservoir walls, e.g. concrete lining. As it was pointed out in the introduction section there are many limitations to this concept. In the case of a lower reservoir in headings or galleries, its length is inversely proportional to the cross-sectional area of the working.

The temperature of the rock mass increases with depth, therefore water stored at a greater depth will heat up more. Additional benefit resulting from this concept is the possibility of heat extraction from the water in heat exchangers but in it not within the scope of this WP.

4.1.2. Surface for the upper water reservoir

In the vicinity of the shaft, on the land belonging to the mine, there must be available space for the construction of an upper water tank with an area of approx. 1000 m² to 8000 m², depending on the net head in the water turbine used.

4.1.3. Hoisting equipment

Due to the need of maintenance work and service of turbine-pump hydro unit located at the bottom of the mine, access is necessary by an inspection and emergency hoist installed in one of the adjacent shafts. The hoist must also be able to transport material for installation and repair purposes.

4.1.4. Methane hazard

In the case of methane mines, methane is constantly extracted from goafs, the effective methane drainage or installation of the dams in underground conditions may be difficult or impossible. Due to probable rock mass movements in the dam, leaks may occur, through which methane will penetrate into the area of the underground pumped-storage power plant. In addition, there is a risk of methane drainage into the workings. Therefore, continuous monitoring of methane concentration is necessary. The presence of methane in workings connected to a given shaft imposes explosion-proof construction conditions for the hydro unit, auxiliary equipment and power supply and control system, as well as the use of safety systems. This generates higher investment costs.

4.1.5. Shaft drainage

When selecting a shaft suitable for the installation of an underground pumped-storage power plant, the balance of groundwater flowing from all the workings connected to the shaft should be taken into account. This additional volume of mine water, with a high degree of salinity, high content of minerals, metal compounds, often also radium, should not mix with the water circulating in the pumped-storage power plant system and should be discharged to the collector by an independent pumping system. In addition to the costs associated with the operation of an

additional pump station, this may generate a problem with the purification of discharged mine water.

4.2. Individual criteria scoring

The conditions presented above have been included in mathematical relationships, and individual parameters or pairs of parameters have been assigned a specific score, reflecting their impact on the efficiency of the potential energy storage system located in the assessed mine shaft. This score is discussed below and presented in tables.

4.2.1. Shaft depth

Table 1 presents the calculated volumes of the V_z tank, allowing for the storage of 10 MWh of energy, depending on the net head in the turbine (shaft depth) H_u and the number of points assigned to them, determined for the lower reservoir tank located in the underground horizontal workings of the mine. The values of the arithmetic mean of the volume of the V_z reservoir were assigned 0 points, and the remaining ones proportionally from 10 points for the largest volumes to -10 points for the smallest volumes.

Table 1. Volumes of the lower reservoir V_z relative to the net head in the turbine (shaft depth) H_u and the points assigned to them.

Lower reservoir volume [m ³]															
H_u [m]	1000	950	900	850	800	750	700	650	600	550	500	450	400	350	300
V_z [m ³]	5246	5523	5829	6172	6558	6995	7495	8071	8744	9539	10493	11659	13116	14990	17488
Score	10	10	9	8	8	7	6	5	4	3	1	0	-3	-6	-10

4.2.2. Area for the construction of the upper water reservoir

The scoring for shafts depending on the availability of area for the construction of the upper water tank is defined in Table 2.

Shaft locations with the availability of the area necessary for the construction of the upper water reservoir were given 2 points. The shaft rating was reduced to -2 points when it is not possible to build this tank due to the lack of available space.

Table 2. Scoring for the availability of the area for the construction of the upper water reservoir.

Scoring – availability of the area for the construction of upper water reservoir	
available	2
not available	-2

4.2.3. Shaft configuration

Depending on the shaft configuration, the individual shafts were assigned the number of points defined in Table 3.

The operating conditions of the pumped-storage power plant equipment located underground in the mine can be compared to the operating conditions of a stationary pumping station. In both cases, ventilation of the underground voids is necessary, for the implementation of which two shafts are required. The case where there is a connection of the considered shaft with the neighboring shaft was given 2 points. When the connected shaft is located at a distance, then the number of points given is equal to 0. A single shaft was given a negative value of -5 points, due to the difficulties in ventilation system.

The assumptions of the Hybrid Energy Storage System (HESS) refer to the location of individual energy storages in the area of one post-mining area, therefore the vicinity of a shaft selected for the compressed fluid energy storage and the thermal energy storage is preferred. Such a location was given 5 points.

Table 3. Scoring for shaft configuration.

Scoring depending on the shaft configuration (location)	
neighboring shaft selected as the CAES	5
2 connected neighboring shafts	2
2 connected remote shafts	0
single shaft	-5

4.2.4. Hoisting devices

Depending on the availability of hoisting devices, individual shafts were assigned the number of points defined in Table 4.

If the shaft in question has a hoist tower with an active man/material hoist, then such a case was given 2 points. 0 points were awarded to the case in which there is no man/material hoisting machine but the existing hoist tower on one of the shafts is adapted to install an auxiliary emergency and inspection mine hoist. The case of no hoisting devices in the connected shafts and the shafts not adapted to their installation was awarded -2 points.

Table 4. Scoring for the availability of hoisting devices.

Point for the availability of hoisting devices	
hoisting tower with man/material hoisting machine at least in one shaft	2
adaptation for the installation of an auxiliary emergency and inspection mine hoist	0
lack of hoisting equipment	-2

4.2.5. Methane hazard

Depending on the category of methane hazard (according to polish classification) occurring in the workings of a given mine, individual shafts were assigned the number of points defined in Table 5.

Non-methane mine shafts were given 5 points because they do not require explosion-proof construction devices or efficient ventilation. Methane mine shafts were given negative points, lowering their rating in proportion to the increasing methane hazard category. Category I was given -1 point, category II -2 points, category III -3 points, and category IV -4 points.

Table 5. Scoring for the methane hazard.

Points depending on the methane hazard	
Non-methane coal mine(<0.1 CH ₄ /t coal _{daf})	5
Category I (0.1-2.5 m ³ CH ₄ /t coal _{daf})	-1
Category II (2.5-4.5 m ³ CH ₄ /t coal _{daf})	-2
Category III (4.5-8.0 m ³ CH ₄ /t coal _{daf})	-3
Category IV >8.0 m ³ CH ₄ /t coal _{daf})	-4

4.2.6. Drainage of workings

Depending on the water conditions in the workings of a given mine, individual mine shafts were assigned the number of points defined in Table 6.

If the water inflow balance to the workings of a given mine is negative, drainage installations do not need to be maintained. This case receives 3 points. When the water inflow balance is positive and does not exceed 1 m³/min, then the amount of energy for drainage is relatively small in relation to the amount of energy stored in the pumped-storage power plant. This case received 3 points. 0 points were awarded when the water inflow balance to the mine workings is greater than 1 m³/min and does not exceed 3 m³/min. For the inflow of groundwater to the mine workings exceeding 3 m³/min, the scoring is -3.

Table 6. Scoring depending on water drainage.

Number of points depending on the requirements of water drainage	
≤ 0 m ³ /min	3
0 m ³ /min ≤ 1 m ³ /min	3
1 m ³ /min and ≤ 3 m ³ /min	0
> 3 m ³ /min	-3

4.2.7. Weighs for individual criteria

In addition to points, all criteria were given specific weights presented in Table 7, which included their percentage impact on the overall assessment of individual shafts.

Table 7. Weights assigned for individual evaluation criteria.

Weights for individual evaluation criteria	
Lower reservoir volume (V_z)	50%
Upper tank area	10%
Shaft configuration	10%
extraction equipment	10%
methane content	10%
water drainage	10%
total weight	100%

5. Scoring for the shafts under assessment

As a result of the results analysis of mine shaft inventory database and the application of a multi-criteria shaft assessment system, all shafts were given a summary score. As a result of descending sorting of the records in the “Mine Shafts in Poland” database in relation to the summary score for the lower reservoir located in the side shaft workings, the shafts with the highest scores were selected.

The list of shafts that received a score >4.7 is presented in Table 8.

Table 8 Results of MSDA analysis for shafts and neighboring underground workings potentially suitable for pumped-storage power plant (threshold above 4.7) in Poland.

No.	Company	Mine	Division	Shaft	Depth [m]	Diameter [m]	Total score
1	2	3	4	5	6	7	8
148	SRK	Oddział CZOK	PS Centrum	Budryk	982,26	7,60	5,9
168	Bogdanka	LW "Bogdanka"		2.2	1018,25	7,50	5,8
165	Bogdanka	LW "Bogdanka"		1.3	1030,15	7,50	5,6
169	Bogdanka	LW "Bogdanka"		2.1	1097,74	7,50	5,6
135	SRK	Oddział CZOK	PS Pstrowski	Gigant	874,55	8,00	5,4
146	SRK	Oddział CZOK	PS Śląsk I	I	1081,00	8,00	5,4
47	PGG	KWK ROW	Marcel	II (Antoni)	1011,28	5,50	5,3
164	Bogdanka	LW "Bogdanka"		1.2	995,00	6,00	5,3
166	Bogdanka	LW "Bogdanka"		1.4	995,82	7,50	5,3
11	JSW	KWK Borynia-Zofiówka-Bzie	Bzie	1-Bzie Jan Paweł	1164,00	8,00	5,3
17	JSW	KWK Knurów-Szczygłowie	Knurów	Jan (III)	1023,44	7,50	5,3
13	JSW	KWK Budryk		II	1157,45	9,00	5,2
29	JSW	KWK Pniówek		II	1039,70	8,00	5,2
142	SRK	Oddział CZOK	PS Makoszowy	I	883,00	5,73	5,2
64	PGG	KWK Ruda	Halemba	Grunwald IV	1057,60	6,50	5,1
42	PGG	KWK ROW	Jankowice	8	1103,70	8,50	5
25	JSW	KWK Knurów-Szczygłowie	Szczygłowie	III	946,91	6,00	5
14	JSW	KWK Budryk		III	1089,89	9,00	4,9

51	PGG	KWK ROW	Rydułtowy	Leon IV	1210,70	8,50	4,9
56	PGG	KWK Ruda	Bielszowice	III	1055,19	7,20	4,9
63	PGG	KWK Ruda	Halemba	Grunwald III	1112,50	7,50	4,9
167	Bogdanka	LW "Bogdanka"		1.5	989,50	7,50	4,9
7	JSW	KWK Borynia-Zofiówka-Bzie	Zofiówka	IIz	1071,00	7,20	4,7
12	JSW	KWK Budryk		I	1157,20	9,00	4,7
16	JSW	KWK Budryk		VI	1319,60	9,00	4,7
58	PGG	KWK Ruda	Bielszowice	V	1111,60	7,50	4,7

Table 9 lists 4 Czech shafts that could be used to build a pumped-storage power plant. The remaining shafts are being already closed (backfilled) or a decision for closure has been made.

Table 9. Results of MSDA analysis for shafts and neighboring underground workings potentially suitable for pumped-storage power plant (threshold above 4.7) in Czechia.

No.	Company	Mine	Division	Shaft	Depth [m]	Diameter [m]	Total score
1	2	3	4	5	6	7	8
1	OKD	ČSM	ČSM Sever	Sever (exhaust ventilation)	1005,0	7,5	5,7
2	OKD	ČSM	ČSM Sever	Sever (intake)	1104,4	7,5	6
3	OKD	ČSM	ČSM Jih	Jih (exhaust ventilation)	972,1	7,5	5,2
4	OKD	ČSM	ČSM Jih	Jih (intake)	1103,9	7,5	5,7

Due to their shallow depth, none of the Slovenian shafts and mine workings are suitable for building an energy storage facility with a capacity of 10 MWh (Table 10).

Table 10. Results of MSDA analysis for shafts and neighboring underground workings potentially suitable for pumped-storage power plant (threshold above 4.7) in Slovenia

No.	Company	Mine	Division	Shaft	Depth [m]	Diameter [m]	Total score
1	2	3	4	5	6	7	8
1	Premogovnik Velenje, d. o. o.	Velenje	-	Transport shaft Nove Preloge (A)	416,42	7,2	-2,1
2	Premogovnik Velenje, d. o. o.	Velenje	-	Ventilation shaft Nove Preloge (A)	390,7	6,15	-2,4
3	Premogovnik Velenje, d. o. o.	Velenje	-	Ventilation shaft Pesje (A)	141,76	4	-4,4
4	Premogovnik Velenje, d. o. o.	Velenje	-	Intake shaft Šoštanj II(A)	332,57	5	-4,4

6. Conclusions

The work performed in this task allowed development of a scoring system that can be used as a universal tool for shaft and neighboring underground workings as a lower reservoir in pumped-storage hydro plant. It worth noting that limitations related to the use of underground working for pumped were highlighted and after initial selection a further more advanced individual assessment should be done, particularly related to the economic factors. Nevertheless, as a result of defining the scores for individual parameters and determining the weights for the assessment criteria, it was possible to select mine shafts and their accompanying workings that best met the necessary conditions.

Logical functions were built, which were used to automatically determine the scores for individual criteria based on data collected for each shaft, such as: shaft depth and diameter, availability of space for the development of the upper water reservoir, shaft configuration, methane hazard category and drainage of workings.

Mathematical formulas were created, which, based on the defined weights and the determined partial score, allowed for determining the total score for the analyzed cases.

The developed multi-criteria shaft assessment system allows for sorting the records of the database system as it was presented above.

7. Summary of guidelines on the conversion of underground mine working into water reservoir for Underground Pumped Storage Power Systems (USPS)

The reuse of underground mining infrastructure for Underground Pumped Storage Power Systems (USPS) is a pioneering approach that fully aligns with the principles of Smart Mine Closure. This concept promotes the sustainable transition of mining regions by transforming former mining assets into elements of a modern, low-emission energy system. Instead of complete decommissioning and abandonment, Smart Mine Closure encourages innovative repurposing of shafts, workings, and surrounding infrastructure for new, value-creating purposes.

The USPS concept exemplifies this philosophy by converting mine shafts and associated excavations into functional water reservoirs, enabling energy storage and grid stabilization. Such transformation not only supports the decarbonization of the energy sector but also mitigates the socio-economic impacts of mine closures. It provides a long-term use case for mining infrastructure while fostering innovation, circularity, and resilience in post-mining regions. The methodology outlined in this section demonstrates a structured and technically sound path for evaluating the feasibility of such transformation – from data collection and site selection to technical adaptation – rooted in the broader vision of sustainable post-mining land use.

1. Collection and Analysis of Geological and Mining Data

The stage of collecting and analyzing geological and mining data forms the foundation for adapting mining workings into water reservoirs for Underground Pumped Storage Power Systems (USPS). Documentation is obtained from national and international sources, including geological and mining maps, mining plans, and historical reports on subsidence. These are supplemented with GIS data to integrate location, topography, and technical data. Quality verification and calibration ensure consistency, enabling the development of multi-layer terrain models for identifying high storage potential zones. The process concludes with a report including thematic maps, numerical data, and initial selection criteria.

2. Preliminary Candidate Selection

Preliminary selection identifies workings with the greatest adaptation potential for USPS systems. This begins with analyzing historical data on subsidence and deformation, prioritizing structurally stable workings. Adequate volume is assessed to ensure energy storage parameters. Geological conditions, such as rock type and mass consistency, are considered for deformation resistance. Accessibility to adjacent infrastructure is evaluated to enhance system capacity. A preliminary ranking highlights promising candidates for further analysis.

3. Upper Reservoir Location Assessment

The assessment examines terrain availability (1000–8000 m²) and geotechnical conditions, including soil load capacity, groundwater level, and landslide risk. Terrain slope is crucial for effective height difference utilization. Local infrastructure (roads, energy networks) is evaluated for construction and operational feasibility. Environmental and regulatory compliance ensures minimal ecological impact. This comprehensive approach identifies optimal locations for efficient and stable USPS operation.

4. Calculation of Lower Reservoir Capacity

This stage determines if existing workings can store sufficient water using the formula $E = H_n \cdot V_x \cdot \rho \cdot g$. Effective head, volume, and gravitational constants are calculated to determine energy potential. If capacity is insufficient, options include integrating additional workings or applying sealing technologies.

5. Analysis of Shaft-Adjacent Workings

This evaluates additional storage capacity near shafts. Geometric surveys define cross-sections and volumes. Only concrete-lined workings are suitable after proper sealing. Accessibility for adaptation and maintenance is analyzed, including the potential installation of isolation dams to separate inactive mine areas. Results determine if these workings can supplement the main reservoir.

6. Verification of Shaft Infrastructure Condition

Technical documentation is reviewed for pipelines, cable paths, platforms, and hoisting guides, all originally designed for coal extraction. Full removal is required to obtain an empty shaft casing suitable for USPS adaptation.

7. Assessment of Shaft Lining and Equipment Condition

Focuses on structural integrity, identifying cracks or degradation affecting strength or sealing. Engineering drawings and material specs are reviewed to determine concrete and reinforcement properties. Findings guide adaptation interventions ensuring safety and stability.

8. Water Inflow Analysis and Drainage Design

Available flow and water balance data are analyzed to locate areas where inflow exceeds safety thresholds. This identifies risks of uncontrolled water flow and informs protective USPS system guidelines.

9. Multi-Criteria Decision Analysis (MCDA)

- Criteria definition (e.g., volume, terrain, shaft condition, risks)
- Ranking of candidates and optimal site selection in accordance with assumptions in Section 4

10. Implementation Actions – USPS System Design

- Design of shaft bottom plugs to seal workings
- Shaft sealing, modernization, and lining repair
- Pumping and piping systems for efficient water transfer

11. Disqualifying Factors by Stage

Geological & Mining Data: Incomplete or inconsistent datasets.

Preliminary Selection: Workings with major deformation or inadequate volume.

Upper Reservoir: Insufficient land or poor geotechnical conditions.

Lower Reservoir: Volume too low for energy needs.

Shaft-Adjacent Workings: Lacking concrete lining.

Shaft Infrastructure: No disqualifiers; removal planned.

Shaft Lining: Unrecoverable sealing/load-bearing properties.

Water Inflow: Excessive flow threatening stability.

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9. Appendix 1

Results of MSDA analysis for the database of shafts and neighboring underground workings potentially suitable for pumped-storage power plant in Poland, the Czech Republic, and Slovenia (selected data).

Poland

No.	Company	Mine	Division	Shaft	Depth [m]	Diameter [m]	Total score
1	2	3	4	5	6	7	8
1	JSW	KWK Borynia-Zofiówka-Bzie	Borynia	I	936,95	7,20	3,8
2	JSW	KWK Borynia-Zofiówka-Bzie	Borynia	II	980,00	7,20	4,5
3	JSW	KWK Borynia-Zofiówka-Bzie	Borynia	III	868,65	7,20	4
4	JSW	KWK Borynia-Zofiówka-Bzie	Borynia	V	847,50	5,50	4
5	JSW	KWK Borynia-Zofiówka-Bzie	Borynia	VI	740,39	8,00	3
6	JSW	KWK Borynia-Zofiówka-Bzie	Zofiówka	Iz	982,76	7,20	4,4
7	JSW	KWK Borynia-Zofiówka-Bzie	Zofiówka	IIz	1071,00	7,20	4,7
8	JSW	KWK Borynia-Zofiówka-Bzie	Zofiówka	IIIz	742,00	5,50	2,9
9	JSW	KWK Borynia-Zofiówka-Bzie	Zofiówka	IVz	930,90	7,50	3,9
10	JSW	KWK Borynia-Zofiówka-Bzie	Zofiówka	Vz	907,50	8,00	3,9
11	JSW	KWK Borynia-Zofiówka-Bzie	Bzie	1-Bzie Jan Paweł	1164,00	8,00	5,3
12	JSW	KWK Budryk		I	1157,20	9,00	4,7
13	JSW	KWK Budryk		II	1157,45	9,00	5,2
14	JSW	KWK Budryk		III	1089,89	9,00	4,9
15	JSW	KWK Budryk		V	1005,00	9,00	4,3
16	JSW	KWK Budryk		VI	1319,60	9,00	4,7
17	JSW	KWK Knurów-Szczygłowice	Knurów	Jan (III)	1023,44	7,50	5,3
18	JSW	KWK Knurów-Szczygłowice	Knurów	Aniołki	471,80	6,00	-2
19	JSW	KWK Knurów-Szczygłowice	Knurów	Foch I	676,80	6,00	2,5

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20	JSW	KWK Knurów-Szczygłowie	Knurów	Foch II	694,62	6,00	2,8
21	JSW	KWK Knurów-Szczygłowie	Knurów	Paweł	868,50	6,00	4,5
22	JSW	KWK Knurów-Szczygłowie	Knurów	V	549,80	7,20	0
23	JSW	KWK Knurów-Szczygłowie	Szczygłowie	I	874,80	7,20	4,5
24	JSW	KWK Knurów-Szczygłowie	Szczygłowie	II	720,00	7,20	3
25	JSW	KWK Knurów-Szczygłowie	Szczygłowie	III	946,91	6,00	5
26	JSW	KWK Knurów-Szczygłowie	Szczygłowie	IV	328,00	7,50	-5,5
27	JSW	KWK Knurów-Szczygłowie	Szczygłowie	VI	867,00	9,00	3,9
28	JSW	KWK Pniówek		Ludwik	920,90	8,00	4
29	JSW	KWK Pniówek		II	1039,70	8,00	5,2
30	JSW	KWK Pniówek		III	865,30	7,50	4,2
31	JSW	KWK Pniówek		IV	969,04	7,50	3,7
32	JSW	KWK Pniówek		V	992,00	7,50	4,1
33	PGG	KWK ROW	Chwałowice	I	415,66	5,00	-3
34	PGG	KWK ROW	Chwałowice	II	723,58	7,00	2,5
35	PGG	KWK ROW	Chwałowice	V	401,80	6,00	-4
36	PGG	KWK ROW	Chwałowice	VII	543,00	7,50	-0,5
37	PGG	KWK ROW	Chwałowice	VIII	729,70	8,50	2,5
38	PGG	KWK ROW	Jankowice	2	436,30	6,60	-1,5
39	PGG	KWK ROW	Jankowice	³ (Poniatowski)	421,30	6,80	-1,7
40	PGG	KWK ROW	Jankowice	4	273,50	5,00	-6
41	PGG	KWK ROW	Jankowice	7	634,20	7,50	1,8
42	PGG	KWK ROW	Jankowice	8	1103,70	8,50	5
43	PGG	KWK ROW	Marcel	III (Julia)	866,65	7,00	4,1
44	PGG	KWK ROW	Marcel	IV (Bartek)	755,75	4,00	2,3
45	PGG	KWK ROW	Marcel	Marklowice I	592,52	4,50	1,8
46	PGG	KWK ROW	Marcel	I (Wiktor)	615,48	4,20	1,8
47	PGG	KWK ROW	Marcel	II (Antoni)	1011,28	5,50	5,3
48	PGG	KWK ROW	Marcel	Marklowice II	556,75	7,50	0,4

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49	PGG	KWK ROW	Marcel	Podsadzkowy	359,66	3,00	-4,9
50	PGG	KWK ROW	Rydułtowy	Leon II	838,80	7,32	3,2
51	PGG	KWK ROW	Rydułtowy	Leon IV	1210,70	8,50	4,9
52	PGG	KWK ROW	Rydułtowy	Powietrzny I	582,50	4,50	0,6
53	PGG	KWK ROW	Rydułtowy	Powietrzny V	592,40	5,00	0,4
54	PGG	KWK Ruda	Bielszowice	I	687,50	5,50	2,4
55	PGG	KWK Ruda	Bielszowice	II	970,87	5,58	4,2
56	PGG	KWK Ruda	Bielszowice	III	1055,19	7,20	4,9
57	PGG	KWK Ruda	Bielszowice	IV	637,70	7,00	1,5
58	PGG	KWK Ruda	Bielszowice	V	1111,60	7,50	4,7
59	PGG	KWK Ruda	Bielszowice	VI	1023,26	7,50	4,7
60	PGG	KWK Ruda	Bielszowice	Pawłów Grn. I	801,65	6,50	3,4
61	PGG	KWK Ruda	Bielszowice	Pawłów Grn II	691,40	7,50	2
62	PGG	KWK Ruda	Halemba	Grunwald II	587,63	7,50	1,6
63	PGG	KWK Ruda	Halemba	Grunwald III	1112,50	7,50	4,9
64	PGG	KWK Ruda	Halemba	Grunwald IV	1057,60	6,50	5,1
65	PGG	KWK Ruda	Halemba	Wschodni	801,00	7,50	2,8
66	PGG	KWK Ruda	Halemba	Północny I	506,00	6,00	-0,3
67	PGG	KWK Ruda	Halemba	Północny II	663,00	8,50	1,5
68	PGG	KWK Piast-Ziemowit	Piast	I	675,00	7,50	2,8
69	PGG	KWK Piast-Ziemowit	Piast	II	710,50	7,50	3,1
70	PGG	KWK Piast-Ziemowit	Piast	III	671,80	7,50	2,8
71	PGG	KWK Piast-Ziemowit	Piast	IV	656,00	6,50	2,6
72	PGG	KWK Piast-Ziemowit	Pompownia Wola	1 (K-1)	670,00	7,50	1,8
73	PGG	KWK Piast-Ziemowit	Ziemowit	I	670,70	7,10	2,8
74	PGG	KWK Piast-Ziemowit	Ziemowit	II	667,50	5,50	2,8
75	PGG	KWK Piast-Ziemowit	Ziemowit	III	710,00	7,50	3,1
76	PGG	KWK Piast-Ziemowit	Ziemowit	Szewczyk	659,00	7,00	2,6
77	PGG	KWK Piast-Ziemowit	Ziemowit	W1 (Wiatrok)	580,50	5,00	1,7
78	PGG	KWK Piast-Ziemowit	Ziemowit	W2	651,75	7,50	1,8

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79	PGG	KWK Bolesław Śmiały		Aleksander I	430,00	5,00	-0,7
80	PGG	KWK Bolesław Śmiały		Aleksander II	366,16	3,50	-5,2
81	PGG	KWK Bolesław Śmiały		Aleksander III	447,00	7,50	-0,9
82	PGG	KWK Bolesław Śmiały		Bujaków II	688,50	7,50	2,7
83	PGG	KWK Sośnica		III d. Christian Kraft	583,26	6,80	1,4
84	PGG	KWK Sośnica		IV	814,20	7,50	3,4
85	PGG	KWK Sośnica		V	561,70	7,50	-0,2
86	PGG	KWK Sośnica		VII	1047,00	8,00	4,7
87	PGG	KWK Sośnica		VI	992,36	8,00	4,4
88	PGG	KWK Sośnica		Bojków	584,88	5,50	1,2
89	PGG	KWK Sośnica		Podsadzkowy	56,00	3,00	-5,5
90	PGG	KWK Staszic-Wujek	Wujek	Lechia	710,84	7,50	2,6
91	PGG	KWK Staszic-Wujek	Wujek	Krakus	729,58	7,50	2,4
92	PGG	KWK Staszic-Wujek	Wujek	Wentylacyjny I	613,39	5,50	1,4
93	PGG	KWK Staszic-Wujek	Wujek	Wentylacyjny II	690,57	5,00	2,4
94	PGG	KWK Staszic-Wujek	Murcki-Staszic	I	794,10	7,20	3,3
95	PGG	KWK Staszic-Wujek	Murcki-Staszic	II	751,00	7,20	3
96	PGG	KWK Staszic-Wujek	Murcki-Staszic	IV	655,50	7,00	2
97	PGG	KWK Staszic-Wujek	Murcki-Staszic	V	571,40	7,00	0,5
98	PGG	KWK Staszic-Wujek	Murcki-Staszic	VII	1126,00	9,00	4,6
99	PGG	KWK Staszic-Wujek	Murcki-Staszic	Zygmunt	659,00	7,50	1,6
100	PGG	KWK Mysłowice-Wesoła	Wesoła	Bronisław	529,58	7,10	0,2
101	PGG	KWK Mysłowice-Wesoła	Wesoła	Piotr	895,30	7,50	3,7
102	PGG	KWK Mysłowice-Wesoła	Wesoła	Karol	746,00	7,50	2,5
103	PGG	KWK Mysłowice-Wesoła	Wesoła	Wacław	721,00	7,20	2,2

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104	PGG	KWK Mysłowice-Wesoła	Wesoła	Wentylacyjny II	493,75	6,00	-0,3
105	PKW	Zakład Górniczy Brzeszcze		Andrzej I	236,50	4,00	-5,1
106	PKW	Zakład Górniczy Brzeszcze		Andrzej II	536,00	5,00	0,4
107	PKW	Zakład Górniczy Brzeszcze		Andrzej V	740,00	8,00	2,7
108	PKW	Zakład Górniczy Brzeszcze		Andrzej VIII	1040,00	7,50	4,7
109	PKW	Zakład Górniczy Brzeszcze		Andrzej IX	727,30	8,00	1,8
110	PKW	Zakład Górniczy Janina		Janina I	310,50	4,40	-4,6
111	PKW	Zakład Górniczy Janina		Janina III	394,80	7,50	-2,2
112	PKW	Zakład Górniczy Janina		Janina IV	369,50	5,50	-2,2
113	PKW	Zakład Górniczy Janina		Janina VI	822,50	7,50	4,3
114	PKW	Zakład Górniczy Janina		Zachodni	235,90	4,00	-5,7
115	PKW	Zakład Górniczy Sobieski		Sobieski III	526,00	7,50	1,3
116	PKW	Zakład Górniczy Sobieski		Traugutt II	410,60	5,20	-2,2
117	PKW	Zakład Górniczy Sobieski		Kazimierz	754,00	7,50	3,4
118	PKW	Zakład Górniczy Sobieski		Leopold	301,82	4,60	-4,8
119	PKW	Zakład Górniczy Sobieski		Karolina	502,62	4,50	0,2
120	PKW	Zakład Górniczy Sobieski		Helena	526,00	6,70	0,7
121	PKW	Zakład Górniczy Sobieski		Grzegorz	353,00	7,50	-4,9
122	SRK	Oddział CZOK	PG Saturn	Paweł	193,56	6,40	-5,1
123	SRK	Oddział CZOK	PG Grodziec	II	219,34	7,50	-5,1
124	SRK	Oddział CZOK	PG Niwka-Modrzejów	Kazimierz I	412,27	6,00	-3,1
125	SRK	Oddział CZOK	PG Katowice	Bartosz II	457,53	6,00	-1,6
126	SRK	Oddział CZOK	PG Kleofas	Fortuna II	570,50	6,30	0,4
127	SRK	Oddział CZOK	PG Gliwice	II	380,13	6,40	-3,1
128	SRK	Oddział CZOK	PG Wieczorek II	Roździeński	609,63	7,50	1,4

D.2.2. Guidelines on the conversion of underground mine working into water reservoir
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129	SRK	Oddział CZOK	PS Siemianowice	Bańgów	336,00	6,50	-4,4
130	SRK	Oddział CZOK	PS Siemianowice	Siemianowice III	360,16	5,00	-4,4
131	SRK	Oddział CZOK	PS Siemianowice	Kolejowy I	542,20	4,80	1,7
132	SRK	Oddział CZOK	PS Siemianowice	Zygmunt August II	638,50	5,00	2,6
133	SRK	Oddział CZOK	PS Jan Kanty	Witold I	290,30	5,20	-4
134	SRK	Oddział CZOK	PS Jan Kanty	Witold II	336,30	6,00	-4,4
135	SRK	Oddział CZOK	PS Pstrowski	Gigant	874,55	8,00	5,4
136	SRK	Oddział CZOK	PS Pstrowski	Staszic	594,00	4,00	2,5
137	SRK	Oddział CZOK	PS Szombierki	Ewa	837,80	5,00	4,7
138	SRK	Oddział CZOK	PS Dębieńsko	V Zachodni	587,17	6,00	2,1
139	SRK	Oddział CZOK	PS Dębieńsko	Król Jan III	799,40	5,10	4,7
140	SRK	Oddział CZOK	PS Boże Dary	I	508,31	5,00	1
141	SRK	Oddział CZOK	PS Boże Dary	II	618,78	5,00	2,9
142	SRK	Oddział CZOK	PS Makoszowy	I	883,00	5,73	5,2
143	SRK	Oddział CZOK	PS Makoszowy	Północny	865,00	7,50	4,4
144	SRK	Oddział CZOK	PS Mysłowice Wesoła I	Wschodni II	515,80	5,50	0,3
145	SRK	Oddział CZOK	PS Mysłowice Wesoła I	Wschodni I	336,20	4,00	-4,9
146	SRK	Oddział CZOK	PS Śląsk I	I	1081,00	8,00	5,4
147	SRK	Oddział CZOK	PS Pokój I	Wanda	846,85	7,50	4,5
148	SRK	Oddział CZOK	PS Centrum	Budryk	982,26	7,60	5,9
149	SRK	Oddział CZOK	PS Centrum	Staszic	776,99	6,00	4,4
150	SRK	Oddział CZOK	PS Bolko	Bolko	128,90	4,50	-4,2
151	SRK	Oddział w Jastrzębiu Zdroju	KWK Jastrzebie III	Jas I	1091,75	7,20	4,6
152	SRK	Oddział w Jastrzębiu Zdroju	KWK Jastrzebie III	Jas IV	892,10	6,00	3,6
153	SRK	EKO-PLUS		Went - Pods	336,30	6,00	-3,8
154	EKO- PLUS	EKO-PLUS		Kopernik	676,10	6,60	3,2

155	SILESIA	KWK SILESIA		Nr 1	518,62	4,20	-0,1
156	SILESIA	KWK SILESIA		Nr 2	515,30	4,60	-0,3
157	SILESIA	KWK SILESIA		Nr 3	592,00	5,20	1,4
158	SILESIA	KWK SILESIA		Nr 5	291,68	6,50	-6,1
159	SILTECH	ZG SILTECH		Mikołaj	429,30	4,00	-0,9
160	WĘGŁOK OKS	KWK Bobrek-Piekary	Bobrek	Józef	871,21	6,40	4,6
161	WĘGŁOK OKS	KWK Bobrek-Piekary	Bobrek	Bolesław	779,53	6,00	3,6
162	WĘGŁOK OKS	KWK Bobrek-Piekary	Bobrek	Ignacy	642,60	6,00	2,6
163	WĘGŁOK OKS	KWK Bobrek-Piekary	Bobrek	Zbigniew	756,10	5,00	3,6
164	Bogdanka	LW "Bogdanka"		1.2	995,00	6,00	5,3
165	Bogdanka	LW "Bogdanka"		1.3	1030,15	7,50	5,6
166	Bogdanka	LW "Bogdanka"		1.4	995,82	7,50	5,3
167	Bogdanka	LW "Bogdanka"		1.5	989,50	7,50	4,9
168	Bogdanka	LW "Bogdanka"		2.2	1018,25	7,50	5,8
169	Bogdanka	LW "Bogdanka"		2.1	1097,74	7,50	5,6

Czech Republic

No.	Company	Mine	Division	Shaft	Depth [m]	Diameter [m]	Total score
1	2	3	4	5	6	7	8
1	OKD	ČSM	ČSM Sever	Sever (exhaust ventilation)	1005,0	7,5	5,7
2	OKD	ČSM	ČSM Sever	Sever (intake)	1104,4	7,5	6
3	OKD	ČSM	ČSM Jih	Jih (exhaust ventilation)	972,1	7,5	5,2
4	OKD	ČSM	ČSM Jih	Jih (intake)	1103,9	7,5	5,7
5	OKD	ČSA	-	Jan	962,2	7,5	N.A.
6	OKD	ČSA	-	ČSA 2	1049,3	7,5	N.A.
7	OKD	ČSA	-	ČSA 3	994,8	7,5	N.A.
8	OKD	Darkov	-	Da-1	878,3	7,5	N.A.
9	OKD	Darkov	-	Mír 5	887,2	7,5	N.A.
10	OKD	Darkov	-	Mír 4	1011,5	7,5	N.A.
11	OKD	Jeremenko	-	Jeremenko 1	819,0	5	N.A.
12	OKD	Jeremenko	-	Jeremenko 2	1062,0	7,5	N.A.

Slovenia

No.	Company	Mine	Division	Shaft	Depth [m]	Diameter [m]	Total score
1	2	3	4	5	6	7	8
1	Premogovnik Velenje, d. o. o.	Velenje	-	Transport shaft Nove Preloge (A)	416,42	7,2	-2,1
2	Premogovnik Velenje, d. o. o.	Velenje	-	Ventilation shaft Nove Preloge (A)	390,7	6,15	-2,4
3	Premogovnik Velenje, d. o. o.	Velenje	-	Ventilation shaft Pesje (A)	141,76	4	-4,4
4	Premogovnik Velenje, d. o. o.	Velenje	-	Intake shaft Šoštanj II (A)	332,57	5	-4,4
5	Premogovnik Velenje, d. o. o.	Velenje	-	Škale Shaft (A)	168	3,9	-4,6
6	Premogovnik Velenje, d. o. o.	Velenje	-	Ventilation shaft Šoštanj I (A)	234,72	5,9	-4,8
7	Premogovnik Velenje, d. o. o.	Velenje	-	Ventilation shaft Hrastovec** (Sealed short mine-surface ventilation connection)	42,8	N.D	N.A.
8	Premogovnik Velenje, d. o. o.	Velenje	-	Kronprinz Rudolf Schacht* (Decommissioned)	118,2	N.D	N.A.
9	Premogovnik Velenje, d. o. o.	Velenje	-	Kronprinz Rudolf Wetterschacht* (Decommissioned)	93,5	N.D	N.A.
10	Premogovnik Velenje, d. o. o.	Velenje	-	Glinšek Shaft* (Decommissioned)	178+17,4	N.D	N.A.
11	Premogovnik Velenje, d. o. o.	Velenje	-	Preloge transport shaft* (Decommissioned)	373	N.D	N.A.
12	Premogovnik Velenje, d. o. o.	Velenje	-	Ventilation shaft Preloge* (Decommissioned)	336	N.D	N.A.

N.D. – no data

N.A. – no assessment (due to insufficient data)

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