European Journal of Business and Management Research
www.ejbmr.org

The Choice of the Optimal Variant of the Mine Liquidation due to the Possibility of Obtaining Methane from Goafs

Andrzej Chmiela

ABSTRACT

The publication analyses the possibility of reducing the costs of mine liquidation in terms of obtaining methane from goafs. Obtaining methane from goafs can bring financial, ecological and social benefits for many years. In areas where mining activity is reduced, any potential way to restore workplaces should be considered. The possible variants of technical solutions were presented and the conclusions resulting from each variant were indicated. Optimal variants were selected from the proposed liquidation variants by means of single-criterion and multi-criteria analysis. The analysis showed the main factors influencing the course of the mine liquidation and methane drainage process.

Keywords: Decision-Making, Liquidation of a Mine, Methane Drainage Process, Multi-Criteria Analysis, Restructuring of Mining Enterprises.

Submitted: April 06, 2023

Published: May 18, 2023

ISSN: 2507-1076

DOI: 10.24018/ejbmr.2023.8.3.1947

A. Chmiela*
Spółka Restrukturyzacji Kopalń S.A., Bytom, Poland
ORCID: 0000-0002-0833-0923
(e-mail: achmiela@srk.com.pl)

****Corresponding Author***

I. Introduction

The so-called methane regulation, which is being adopted in the European Parliament, limits the possibility of methane emissions into the atmosphere. The publication contains an analysis of the possibility of reducing the maintenance costs of a liquidated hard coal mine in the event of a threat to the energy independence of the country. The investment aimed at obtaining methane from the deposits of closed mines will reduce their environmental impact by reducing greenhouse gas emissions. In addition, the investment aimed at obtaining methane from the deposits of closed mines will reduce environmental impact by reducing greenhouse gas emissions. Liquidation of a mine is the last and natural stage of mining activity. The tasks of the legal successor of mining operations include activities related to the liquidation of redundant mining facilities and securing the abandoned mining facilities, performance of security works and projects to prevent environmental threats. The effect of applying any of the proposed variants may be the creation of alternative workplaces to mining and the guarantee of effective asset management, which will be conducive to energy transformation, environmental protection and revitalization of post-mining areas.

II. A Capture and Use of Methane from Liquidated Mines

Selective mining of hard coal seams causes the formation of post-mining goafs. A desorption of methane and its migration towards post-mining voids accumulates it in goafs also after the end of exploitation. In order to reduce methane emissions to the atmosphere from a closed mine, this gas should be extracted from areas with high methane accumulation (Badura *et al*., 2016, Ren & Armstrong, 2004, Mhlongo & Amponsah-Dacosta, 2016). In recent years, the largest emissions of methane from closed mines in Europe were recorded in Poland, where 78% of total emissions (2022) came from mining activities, 19% from post-mining activity, and 3% from closed mines (Gatnar, 2010, Kaliski *et al*., 2013, Konsek, *et al*., 2020, Łukaszczyk, 2019). It should be expected that with the liquidation of hard coal mines there is an increase in interest in the economic use of methane for the production of electricity and heat (Nawrat & Gatnar, 2009). Obtaining methane from coal deposits has been recognized as one of the activities leading to the increase of the energy security of the state. Spółka Restrukturyzacji Kopalń S.A. dealing with the management of mine assets put into liquidation, has experience in capturing methane from the space of liquidated mines. Estimated methane resources shows a number of benefits of this project (Turek & Jonek-Kowalska, 2013).

III. Research Problem

The analysis presents the case of putting into liquidation a mining plant called “Mine Alpha”. The liquidation of the mine is carried out in the model with the infrastructure necessary for carrying out methane drainage from goafs. Due to the complexity and multidimensionality of the problem, six variants of restructuring were proposed. The conducted analysis should indicate which of the proposed liquidation variants of the mine will prove to be the optimal solution in the current complicated economic conditions (Smith & Underwood, 2000).

IV. The Model of Liquidated Mine

The area of the liquidated "Mine Alpha" is located in the administrative borders of the city and two communes, the area of the excavations and old goafs is 6.4 km^2. The total resources of methane deposit are estimated as 232 million m^3 CH_4, which will enable at least several years of capturing methane. An isolation through the installation of insulating plugs and dams, makes it possible to treat the goafs as anthropogenic reservoirs of free methane.

V. Research Methods

After analyzing the proposed variants of mine liquidation, based on a direct interview with experts, the scope of liquidated mine excavations and the necessary expenditures was determined for each variant. The experts were researchers and practicing miners who directly conducted the processes of liquidation of mining plants and methane drainage.

In the next step, experts were asked about the potential criteria for evaluating the "Mine Alpha" liquidation options. A database of six assessment criteria with assigned weights was obtained (Table IX.). On the basis of the established evaluation criteria, price research was carried out (surveys), which allowed for a single-criteria analysis, and then a multi-criteria analysis of the proposed liquidation variants (Table X).

The obtained results made it possible to select the optimal variant of liquidation. In the calculations, all costs are given in hypothetical research [units] expressed as a randomly selected multiple of the costs incurred.

VI. Research Results

A. "Mine Alpha" Liquidation Time Assessment

The mine that is dedicated to liquidation is a part of mining plant and contributes to the processes of restructuring, revitalization and liquidation of the structure of a one-movement mine with 4 shafts, 4 active levels, a network of excavations with a total length of 32 km, 11 buildings and 19 structures on the surface. This scope of assets corresponds to the total time of restructuring, revitalization, liquidation and recultivation procedures equal to 2, 3 or 4 years. Finally, six variants of liquidation were accepted for evaluation, and for each of them 3 types of liquidation cycle were adopted, resulting in 18 different decision situations.

B. Expenditures on the "Mine Alpha" Liquidation

Six variants of liquidation were proposed for comparison: 4 variants (I, II, III and IV) with full liquidation of the underground mine infrastructure, variant V with 1 shaft left and variant VI with 2 shafts left. In the case of variants V and VI, leaving the shafts and part of excavations has the intention to operate the goaf drainage system of the liquidated mine (Smoliło & Chmiela, 2021a, Smoliło *et al.*, 2021b).

If two shafts are left and streamlined ventilation is used, usually up to 10 km of drifts should be left for methane drainage. For one shaft and duct ventilation, the length of the heading excavations may not exceed the maximum length of the excavations specified by the regulations.

TABLE I: Cost of Maintenance and Liquidation of the Shafts [Units]

	variant I, II, III and IV	variant V	variant VI
Cycle of 4-years liquidation			
Maintenance	17290,1	18221,9	19481,9
Liquidation	26447,3	18533,3	12077,4
Sum (M and L)	43737,4	36755,2	31559,3
Cycle of 3-years liquidation			
Maintenance	12906,5	13838,3	15098,3
Liquidation	26447,3	18533,3	12077,4
Sum (M and L)	39353,8	32371,6	27175,7
Cycle of 2-years liquidation			
Maintenance	7229,7	8161,5	9421,5
Liquidation	26447,3	18533,3	12077,4
Sum (M and L)	33677,0	26694,8	21498,9

In the analysis, significant cost components include the liquidation of mine shafts and excavations and the cost of their maintenance until liquidation (Table I). In the "Mine Alpha", the main shafts are A and B, and the auxiliary shafts are C and D. According to the procedures of the liquidation of mining plants, the auxiliary shafts should be liquidated first in the initial period of the processes, and the main shafts later (Chmiela *et al*., 2022, Smoliło & Chmiela, 2021b). For the 2-year liquidation cycle, it was assumed that shafts C and D will be liquidated in the first year, in the 3- and 4-year cycle, shaft C will be liquidated in the first year and shaft D in the second. On the other hand, shafts A and B, regardless of the type of cycle, will be liquidated in the last year of the mine liquidation process, i.e. in the 2nd, 3rd or 4th year, respectively. Expenditures on the liquidation and maintenance of the shafts were estimated from the documentation of the liquidation of the neighboring mine on the basis of similarity (Smoliło *et al.*, 2021a, Chmiela, 2022). Adoption of such an approximation will not significantly affect the results of the analysis.

The cost of liquidation of excavations depends mainly on the number of sidings that can be insulated with dams or plugs and natural hazards. In the event of a methane hazard, the increase in the cost of excavation liquidation results from the need to install anti-explosion plugs (Table II).

TABLE II: Expenditures on the Maintenance of Excavations of the Liquidated "Mine Alpha" [Units]

Cycle	4-years liquidation	3-years liquidation	2-years liquidation
Expenditures on the maintenance of excavations	6880	5504	4128

Based on the analysis of mining maps, the quantitative range of insulating dams and explosion-proof plugs necessary to be made in each of the variants was determined (Table III).

TABLE III: Expenditures on the "Mine Alpha" Excavations Liquidation [units]

Variant	Isolation dams	Explosion-proof plugs	Expenditures
I, II, III and IV	4	27	1011
V	8	33	1286
VI	13	35	1437

TABLE IV: EXPENDITURES ON LIQUIDATION IN ACCORDANCE WITH VARIANTS I AND II [UNITS]

Variant I	Shafts liquid	Excavations liquidation	Excavations maintenance	Methane drainage installation	Sum
4-years	43737	1011	2752	2520	50021
3-years	39354	1011	2202	2520	45087
2-years	33677	1011	1651	2520	38860
Variant II					
4-years	43737	1011	2752	3892	51393
3-years	39354	1011	2202	3892	46459
2-years	33677	1011	1651	3892	40232

C. Estimated Expenditures on Liquidation of the "Mine Alpha" in Accordance with the Subsequent Variants

1) Expenditures on liquidation in accordance with variants I and II

Variants I and II provide the full liquidation of the entire structure of excavations and four shafts named: A, B, C and D. Methane drainage will be conducted through holes from the surface to the goafs in seams 505/2 and 510. The costs of methane drainage holes from the surface have been assumed as expenditures on the methane drainage system. Goaf drainage will be carried out through 2 (variant I) or 3 holes (variant II) from the surface. The total length of the drilled holes is approximately 2.8 km. Expenditures on the methane drainage installation were assumed as the costs of making 2 or 3 wells (Table IV).

2) Expenditures on liquidation in accordance with variant III

In variant III, full liquidation of the entire structure of excavations and four shafts A, B, C and D is planned. Methane drainage will be carried out through holes led from excavations. The main methane drainage pipeline will be built and left in the liquidated shaft I. The analysis of mine maps showed that it will be necessary to build about 5,410 m of methane drainage pipeline.

In shaft A, it will be necessary to build a pipeline from level 600 to the surface, with a length of approximately 870 m. Expenditures for the methane drainage system, the total costs of making methane drainage holes from excavations, installation of methane drainage pipelines in excavations and methane drainage pipelines in the shaft were assumed. The total costs of methane drainage holes in excavations, installation of methane drainage pipelines in excavations and methane drainage pipelines in the shaft were assumed as the expenditures for the execution of the methane drainage system. According to experts, it is practically impossible to maintain the methane drainage pipeline in the shaft being liquidated, and the possible hypothetical protection of such a pipeline would be about eight times higher than the construction of such a pipeline in normal conditions (Table V).

3) Expenditures on liquidation in accordance with variant IV

Variant IV provides the complete liquidation of the entire structure of excavations and four shafts A, B, C and D. The main methane drainage pipeline will be connected to the methane drainage pipeline installed in the borehole to the level -240 located at the liquidated shaft D. The analysis of mine maps showed that it will be necessary to build about 5,410 m of methane drainage pipeline.

In shaft A, it will be necessary to build a pipeline from levels -600 and -800 to level -240 (approximately 400 m), and then connect this pipeline to the existing methane drainage network. In order to ensure proper operation of the vertical part of the methane drainage pipeline, it will be necessary to extend the borehole at shaft VI to the level of -800 m. In this borehole, a methane drainage pipeline of the same length should be installed and connected to the existing methane drainage pipeline in the upper part of the borehole. Based on the map analysis, it was estimated that the total length of the new methane drainage pipelines in the excavations in this variant will be 5530 m.

The total costs of methane drainage holes in excavations, installation of methane drainage pipelines in excavations and the cost of installation of methane drainage pipelines in the shaft were assumed as expenditures for the execution of the methane drainage system (Table VI).

4) Expenditures on liquidation in accordance with variant V

Variant V provides the partial liquidation of excavations and three shafts B, C and D, leaving shaft A and the part of workings. The remaining excavations (about 1.1 km of excavations) are to be ventilated with separate ventilation, which involves the purchase and installation of a duct installation with fans of the main ventilation (change of the function of shaft A). The main planned methane pipeline will be located in shaft I (total length of approximately 870 m).

As in the case of the previous variants, based on the analysis of mine maps, it was estimated that it will be necessary to build approximately 5,410 m of methane drainage pipeline.

Based on the price research (November 2022), it was determined that the control and regulation of the methane drainage network in the excavations of the pit of shaft named I will increase the costs of maintaining the workings by 0.5% annually. The total costs of methane drainage holes in excavations, installation of methane drainage pipelines in excavations and the cost of installation of methane drainage pipelines in the shaft were assumed as expenditures for the execution of the methane drainage system. To these values, the purchase cost of the air duct installation with two fans of the main ventilation was added (Table VII).

5) Expenditures on liquidation in accordance with variant VI

Variant VI provides a partial liquidation of excavations, leaving two shafts - A and B. Shafts C and D will be liquidated and residual circulation ventilation with minimal air flow will be left. It is planned to replace the main ventilation fans with "weaker ones". The main planned methane pipeline will be located at level -600 and in shaft A. Based on the map analysis, it was determined that the backbone of the "Mine Alpha" will consist of approximately 9.5 km of maintained excavations at level -600 and shafts A and B.

TABLE V: EXPENDITURES ON LIQUIDATION IN ACCORDANCE WITH VARIANT III [UNITS]

Variant III	Shafts liquid	Excavations liquidation	Excavations maintenance	Methane drainage installation	Sum
Cycle 4-years	43737	1011	2752	19673	67174
Cycle 3-years	39354	1011	2202	19673	62240
Cycle 2-years	33677	1011	1651	19673	56012

TABLE VI: EXPENDITURES ON LIQUIDATION IN ACCORDANCE WITH VARIANT IV [UNITS]

Variant IV	Shafts liquid	Excavations liquidation	Excavations maintenance	Methane drainage installation	Sum
Cycle 4-years	43737	1011	2752	2354	49855
Cycle 3-years	39354	1011	2202	2354	44921
Cycle 2-years	33677	1011	1651	2354	38694

TABLE VII: EXPENDITURES ON LIQUIDATION IN ACCORDANCE WITH VARIANT V [UNITS].

Variant V	Shafts liquid	Excavation liquidation	Excavations maintenance	Methane drainage installation	Sum
Cycle 4-years	36755	1286	2766	4475	45283
Cycle 3-years	32372	1286	2213	4475	40346
Cycle 2-years	26695	1286	1659	4475	34116

TABLE VIII: EXPENDITURES ON LIQUIDATION IN ACCORDANCE WITH VARIANT VI [UNITS]

Variant VI	Shafts liquid	Excavations liquidation	Excavations maintenance	Methane drainage installation	Sum
Cycle 4-years	31559	1437	2769	5195	40960
Cycle 3-years	27176	1437	2215	5195	36023
Cycle 2-years	21499	1437	1661	5195	29792

It was also recognized that it will be necessary to build approximately 5,410 m of methane drainage pipeline. In addition, it will be necessary to build a pipeline of approximately 870 m in shaft A.

Based on the price research (November 2022), it was determined that the expenditure for the purchase of two main ventilation fans with a complete set of accessories will amount to approximately 5195 [units]. It was also agreed that the maintenance and ventilation of the excavations connecting shafts A and B with methane drainage areas, as well as the control and regulation of the methane drainage network in unliquidated excavations, would increase the cost of maintaining the excavations by 0.6% annually. As expenditures for the methane drainage system, the total costs of making methane drainage holes from excavations, installation of methane drainage pipelines in excavations and the cost of installing methane drainage pipelines in the shaft were assumed. The cost of purchasing two main ventilation fans with a complete set of accessories was added to these values (Table VIII).

VI. THE CHOICE OF OPTIMUM VARIANT

A. The Choice Method

Before the assessment, experts' opinions were examined to determine the criteria for evaluating the adopted variants of the "Mine Alpha" liquidation model. Experts decided that the criteria presented along with their weight in Table IX should be used to assess the variant of the liquidation model.

TABLE IX: EVALUATION CRITERIA FOR LIQUIDATION VARIANTS OF THE ANALYZED MINING PLANT

	Evaluation criteria	Weight
1.	Expenditures on liquidation [research units].	0,16445183
2.	Expenditures on infrastructure maintenance for 5 years after the end of liquidation [research units].	0,18853821
3.	Length of liquidation process [years].	0,11766334
4.	Is the liquidation model in line with the target model of the mine? [Y/N].	0,19988926
5.	Planned amount of extracted methane [m^3].	0,1769103
6.	Does the liquidation model ensure the protection of neighboring mines? [Y/N]	0,15254707

The selection of the variant was carried out in two stages. In the first stage of the assessment, a single-criterion assessment was used for individual criteria, and if more than one variant was selected, the variant with the lowest liquidation costs was finally selected. In the second stage, a multi-criteria analysis was carried out, taking into account all assessment criteria for the analyzed 18 cases of mine liquidation.

B. Assessment of Expenditures on the Liquidation of the "Mine Alpha"

In Table X, the costs of liquidation of the mining plant in the analyzed 18 cases of liquidation were listed. The calculations showed that **variant VI** is the cheapest liquidation variant, followed by variant V. Lower expenditures in variants V and VI result from the abandonment of liquidation one or two shafts.

TABLE X: EXPENDITURES ON LIQUIDATION OF THE ANALYZED MINE [UNITS]

	Cycle 4-years	Cycle 3-years	Cycle 2-years
Variant I	50020,71	45086,71	38859,51
Variant II	51392,71	46458,71	40231,51
Variant III	67173,51	62239,51	56012,31
Variant IV	49855,11	44921,11	38693,91
Variant V	45282,50	40345,75	34115,80
Variant VI	40960,25	36022,95	**29792,45**

C. Assessment of Expenditures on Infrastructure Maintenance for 5 Years After the End of the Liquidation of the "Mine Alpha"

In Table XI, expenditures on the maintenance of the abandoned infrastructure in the period of 5 years after the end of the "Mine Alpha" liquidation processes are presented. To facilitate the calculations, due to the similar scope, it was assumed that the maintenance of drainage holes and pipelines in all variants is similar and has been omitted, as it will not significantly affect the total cost. In variants I, II, III and IV, no shafts or excavations are maintained, in variant V, one shaft and 1.1 km of excavations are maintained, and in variant VI, 2 shafts and 9.5 km of excavations. Due to the amount of expenditure on liquidation processes (Table X), **variant IV was selected**.

TABLE XI: EXPENDITURES ON THE MAINTENANCE OF THE ABANDONED INFRASTRUCTURE IN THE PERIOD OF 5 YEARS AFTER THE END OF THE MINE LIQUIDATION PROCESSES

Variant	I	II	III	IV	V	VI
Expenditures	0,00	0,00	0,00	0,00	53,97	466,11

D. Evaluation of the Time of Conducting "Mine Alpha" Liquidation Processes

Due to the assumption of the length of the liquidation cycle, the most optimal option is to carry out liquidation within two years, as each year of liquidation of a "statistical" mining plant consumes approximately 15 million EUR. The criterion for assessing the time of liquidation processes met the same extent by all variants, therefore due to the amount of expenditures on conducting the liquidation processes (Table X), **variant VI was selected**.

E. Evaluation of the Compliance of the Mine Liquidation Model Adopted in the Variant with the Target Model of the Liquidation

The decision on the shape of the target model of the liquidated mine is made on the basis of the development of the water hazard for the neighboring mines caused by the liquidated mining plant. The inflow of natural water in the "Mine Alpha" is 0.159 m^3/min and therefore the incoming water will be discharged to the neighboring active mine through a common main drainage system. It is not planned to leave the pumping station in the liquidated "Mine Alpha", which means full liquidation of all shafts and underground excavations. Variants I, II, III, and IV provide for such a situation, and due to the amount of expenditure on liquidation processes (Table X), **variant IV was selected.**

F. Evaluation of the Planned Amount of Methane Obtained After the "Mine's Alpha" Liquidation is Completed

In Table XII. predicted amounts of methane possible to be obtained are included depending on the adopted variant of mine liquidation and goaf drainage.

TABLE XII: FORECASTED AMOUNTS OF METHANE THAT CAN BE OBTAINED

Liquidation variant	Methane drainage specification	Methane captures up to 10 years
I	2 holes from the surface	21,8 mil. m^3 CH_4
II	3 holes from the surface	23,3 mil. m^3 CH_4
III, IV, V and VI	underground methane pipelines in goafs	17,5 mil. m^3 CH_4

The adopted variants from III to VI of liquidation do not provide for significant differences in the amount of extracted methane, only variants I and II provide for larger amounts. In borehole extraction of methane, better results are obtained with the variant using three production holes, therefore **variant II** was selected for implementation.

G. Evaluation of Ensuring the Protection of the Neighboring Mines by the Adopted Variant of Mine Liquidation

In accordance with the adopted principle of evaluating this criterion (meets or fails to meet it, i.e. "0" or "1"), all assessed variants meet the criterion of ensuring protection of neighboring active mines to an equal degree and all variants should be given an equal score.

However, when analyzing this case of mine liquidation, experts reported that leaving some of the excavations may facilitate possible risk prevention in the future. For this specific case of the decision situation, they proposed assigning a value of 1 for the variant with 2 shafts left, a value of 0.97 for the variant with 1 shaft left, and a value of 0.95 for the full liquidation of excavations. The classification of variants carried out in this way **indicated variant VI**. It should be noted that, in the unanimous opinion of experts, further research will be required by the system of assigning values for this criterion in the case of similar, but not identical, decision-making situations.

H. Multi-Criteria Assessment of the Adopted Variants of "Mine Alpha" Liquidation

The multi-criteria assessment of the adopted mine liquidation variants consists of obtaining a comprehensive assessment of the examined phenomenon, taking into account all criteria for the assessment of the liquidation variants. In the applied quotient transformation, the analyzed criteria should be classified into groups according to their nature (Przybyła & Chmiela, 1997). In this method, the analyzed criteria are divided into "stimulant" criteria, for which the increase in the absolute value is perceived positively, "destimulant" criteria, for which the increase in value is perceived negatively, and "nominant" criteria, for which the increase in the absolute value is perceived either positively or negatively. In the analyzed example, the criteria: "Expenditures on liquidation", "Expenditures on infrastructure maintenance for 5 years after the end of liquidation" and "The length of the liquidation process" apply to entities whose increase in absolute value is perceived negatively, and therefore they were assigned a "destimulant" character. According to the experts' suggestions, Criterion 6, " Does the liquidation model ensure the protection of the neighboring mines " classified as "stimulant" with an optimal value of "1". Criterion 4, " Is the liquidation model in line with the target model of the mine?" is a two-state criterion "yes" or "no". In order to make calculations possible, the value of "yes" was assigned a value of 1, and the value of "no" was assigned a value of 0. In criterion 5, " Planned amount of extracted methane", the total value of extracted methane for the first 10 years of exploitation of the boreholes was assumed. In criteria 4, 5 and 6, the increase in the absolute value is perceived positively, so these criteria were given the character of "stimulant". The weight values for individual assessment criteria are presented in Table IX.

The quotient conversion method used in the multi-criteria evaluation eliminates the problem of a possible difference in the units of the analyzed parameters and the difference in the absolute size of the numbers describing the individual criteria, placing the obtained indicators as dimensionless numbers in the range from 0 to 1 (Przybyła & Chmiela, 1997).

TABLE XIII: MULTI-CRITERIA EVALUATION OF "MINE ALPHA" LIQUIDATION VARIANTS

	Criterion		1	2	3	4	5	6	Multi-criteria assessment	
	The weight of criterion		0,164	0,189	0,118	0,200	0,177	0,153		
1.	Variant I	4-years	0,60	1,00	0,50	1	0,94	0,95	0,855889	8
2.	Variant I	3-years	0,66	1,00	0,67	1	0,94	0,95	0,886218	5
3.	**Variant I**	**2-years**	0,77	1,00	1,00	1	0,94	0,95	**0,942853**	**2**
4.	Variant II	4-years	0,58	1,00	0,50	1	1,00	0,95	0,864422	7
5.	Variant II	3-years	0,64	1,00	0,67	1	1,00	0,95	0,894157	4
6.	**Variant II**	**2-years**	0,74	1,00	1,00	1	1,00	0,95	**0,949702**	**1**
7.	Variant III	4-years	0,44	1,00	0,50	1	0,75	0,95	0,797709	12
8.	Variant III	3-years	0,48	1,00	0,67	1	0,75	0,95	0,823101	10
9.	Variant III	2-years	0,53	1,00	1,00	1	0,75	0,95	0,871074	6
10.	Variant IV	4-years	0,60	1,00	0,50	1	0,75	0,95	0,823045	11
11.	Variant IV	3-years	0,66	1,00	0,67	1	0,75	0,95	0,85345	9
12.	Variant IV	2-years	0,77	1,00	1,00	1	0,75	0,95	0,910224	3
13.	Variant V	4-yeras	0,66	0,00	0,50	0	0,75	0,97	0,447592	18
14.	Variant V	3-years	0,74	0,00	0,67	0	0,75	0,97	0,480442	16
15.	Variant V	2-years	0,87	0,00	1,00	0	0,75	0,97	0,541839	14
16.	Variant VI	4-years	0,73	0,00	0,50	0	0,75	1	0,463586	17
17.	Variant VI	3-years	0,83	0,00	0,67	0	0,75	1	0,499591	15
18.	Variant VI	2-years	1,00	0,00	1,00	0	0,75	1	0,567255	13

TABLE XIV: DECISION MATRIX FOR THE CHOICE OF THE LIQUIDATION VARIANT

	Evaluation criterion	Optimal variant	Another variant
1.	Expenditures on liquidation.	**variant VI**	variant V
2.	Expenditures on infrastructure maintenance for 5 years after the end of liquidation.	**variant IV**	variant I
3.	The length of the liquidation process.	**variant VI**	variant V
4.	Is the liquidation model in line with the target model of the mine?	**variant IV**	variant I
5.	Planned amount of extracted methane.	**variant II**	variant I
6.	Does the liquidation model ensure the protection of the neighboring mines?	**variant VI**	variant V
7.	Multi-criteria analysis (all criteria combined)	**variant II**	variant I

The indicators in the multi-criteria analysis were calculated according to (1). The index closest to 1 is the most favorable.

$$FC_j = w_1 \frac{h_{i\,min}}{h_{1j}} + w_2 \frac{h_{i\,min}}{h_{2j}} + w_3 \frac{h_{i\,min}}{h_{3j}} + w_4 \frac{h_{4j}}{h_{i\,max}} + \\ + w_5 \frac{h_{5j}}{h_{i\,max}} + w_6 \frac{h_{6j}}{h_{i\,max}} \quad (1)$$

where,
FC_j - value of multi-criteria assessment for variant "j",
i - number of the criterion for evaluating liquidation options,
j - liquidation option number,
w_i - weight for criterion number "i",
$h_{i\,min}$ - the smallest value in the criterion number "i",
$h_{i\,max}$ - the highest value in the criterion number "i",
h_{ij} - value in criterion "i" for variant number "j".

In Table XIII, the results of the multi-criteria assessment of the Mine liquidation variants in all implementation cycles adopted for the assessment are included. The "Multi-criteria assessment" column consists of two columns. The first is the numerical value of the multi-criteria assessment assigned to each decision situation, and the second is the position in the rating ranking.

VII. CONCLUSIONS

Six variants of the "Mine's Alpha" liquidation were presented for analysis. All variants were considered technically feasible, but in the case of two variants there were doubts among practitioners. Variant V, in which one shaft and duct ventilation will be left, will require additional ventilation analysis of the resulting network, and variant III raises concerns whether the design of the methane drainage pipeline will fully secure its proper use in the liquidated shaft. The application of variant III of mine liquidation will require an additional technical opinion.

On average, each year of mine liquidation consumes about 15 million EUR. Therefore, the adoption of 2-year liquidation period seems to be the most advantageous. Under normal market conditions, this option would be optimal, but as of 2020, the world is mired in the pandemic of Covid-19, which leads to excessive prolongation of tender and appeal procedures. When choosing a variant for practical implementation, the possibility of adopting a safer 3-year liquidation cycle in this respect should be considered.
In Table XIV. acting as a decision matrix, the applied assessment criteria and the best liquidation variants assigned to them were presented. The final decision on the choice of the liquidation variant is left to the decision-maker, who can choose the best variant in his opinion, due to any evaluation criterion, or agree with the results of the multi-criteria evaluation and **choose the variant II with a 2-year (possibly 3-year) mine liquidation cycle** suggested by it.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

REFERENCES

Badura, H., Michna, A., & Czerwiński, S. (2016). Doświadczenia Zakładu Odmetanowania Kopalń „ZOK" Sp. z o.o. Jastrzębiu-Zdroju, *Systemy Wspomagania w Inżynierii Produkcji.*

Chmiela, A. (2022). Procesy restrukturyzacji i rewitalizacji kopalń postawionych w stan likwidacji. *Systemy Wspomagania w Inżynierii Produkcji, 11*(1).

Chmiela, A., Smoliło, J., & Gajdzik, M. (2022). A Multifaceted Method of Analyzing the Amount of Expenditures on Mine Liquidation Processes in SRK S.A. *Management Systems in Production Engineering, 30*(2), 130-139. https://doi.org/10.2478/mspe-2022-0016.

Gatnar, K. (2010). Energetyczne wykorzystanie metanu z pokładów węgla - doświadczenia JSW SA i perspektywy w aspekcie zmian w Prawie Energetycznym. *Zeszyty Naukowe IGSMiE PAN*.

Kaliski, M., Wojciechowski, R., & Szurlej, A. (2013). Zagospodarowanie metanu z pokładów węgla - stan obecny i perspektywy. *Polityka Energetyczna*.

Konsek, St., Lubryka, M. & Mężyk, K. (2020). Odmetanowanie I wykorzystanie metanu w SRK SA Oddział KWK „Jas-Mos-Rydułtowy I" Ruch Jas-Mos. *Systemy Wspomagania w Inżynierii Produkcji.*

Łukaszczyk, Z. (2019). *Pozyskiwanie i gospodarcze wykorzystanie metanu ze zlikwidowanych kopalń węgla kamiennego.* Wydawnictwo Politechniki Śląskiej.

Mhlongo, S. E., & Amponsah-Dacosta, F. (2016). A review of problems & solutions of abandoned mines in South Africa. *International Journal of Mining, Reclamation & Environment, 30*(4), 279-294,

Nawrat, S., & Gatnar, K. (2009). Wykorzystanie metanu z pokładów węgla w Polsce - stan i perspektywy. *SITG.*

Przybyła, H., & Chmiela, A. (1997). *Projektowanie rozwiązań techniczno–organizacyjnych stosowanych w wyrobiskach ścianowych.* Wydawnictwo Politechniki Śląskiej.

Ren, T. X., & Armstrong, W. (2004). Methane extraction & utilization from abandoned coal mines-China/UK technology transfer. *Report No. COAL R251 DTI/Pub URN 03/1609, University of Nottingham*.

Smith, F. W., & Underwood, B. (2000). Mine closure: the environmental challenge. *Mining Technology*, 202-209, DOI: 10.1179/mnt.2000.109.3.202.

Smoliło, J., Chmiela, A., Lubosz, A., & Wróblewski, P. (2021a). Dynamics of bearing of costs in processes leading to revitalization of mine assets in SRK SA. *Scientific Papers of Silesian University of Technology*, *series: Organization & Management, 153*.

Smoliło, J., Chmiela, A., Gajdzik, M., Menéndez, J., Loredo, J., Turek, M., & Bernardo-Sánchez, A. (2021b). A New Method to Analyze the Mine Liquidation Costs in Poland. *Mining, 1*(3), 351-363. https://doi.org/10.3390/mining1030022.

Smoliło, J., & Chmiela, A. (2021a). A liquidation of the mine in SRK S.A. in a processive approach. *Scientific Papers of Silesian University of Technology*, *series 153: Organization & Management*.

Smoliło, J., & Chmiela, A. (2021b). The mine liquidation processes in SRK S.A. in a cost approach. *Scientific Papers of Silesian University of Technology, series: Organization & Management, 151*.

Turek, M., & Jonek-Kowalska, I. (2013). Contemporary cost accounting as an inspiration for the cost accounting in the life cycle of a mining excavation. *Scientific Papers of Silesian University of Technology, series: Organization & Management, 66*, 113-184.