SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 182

METHOD OF ESTIMATING THE EXPENDITURES REQUIRED TO CARRY OUT THE LIQUIDATION PROCESSES OF A MINING SITE

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Purpose: This paper proposes a new method for the initial estimation of expenditures necessary to carry out mine decommissioning processes.
Design/methodology/approach: A tool for preliminary estimation of the expenditures necessary to carry out the designed liquidation process was used, based on selected estimated component costs of coal mine liquidation. In designing the method, a certain functional similarity of the analyzed mining plants was assumed.
Findings: Estimation of liquidation costs at the preliminary stage of design work is important support for the company designing the mine liquidation process. The method described is based on a statistical evaluation of costs and allows an analysis independent of the scale of the liquidation task. A forecast can be obtained once the costs of at least one of the liquidation component processes have been correctly determined. Adding each additional cost improves the accuracy of the estimation.
Practical implications: A key issue for the Polish energy sector is to meet the requirements of the European Green Deal to achieve climate neutrality by 2050. A Just Transition is a process of moving away from coal mining and consumption, considering the needs and concerns of communities living in coal regions. It involves the liquidation of the coal sector in the Polish economy, which, in accordance with the adopted Sectoral Agreement, assumes that the last mine will be closed by 2049. The decommissioning of hard coal mines is a complex and lengthy process, but above all one that requires large economic outlays.
Originality/value: A new method of preliminary estimation of mine liquidation costs has been proposed. The proposed method can be used as a tool in the possible processes of designing the liquidation of other mines or parts of mines. The proposed method is a useful auxiliary tool in engineering work and preliminary design work for the restructuring of post-mining assets.

Keywords: cost management, restructuring of mining companies, liquidation of a hard coal mine, decision-making, multi-criteria analysis.

Category of the paper: Research paper.

1. Introduction

Spółka Restrukturyzacji Kopalń S.A. (SRK S.A., Mines Restructuring Company) is a mining company referred to in Article 8(1) of the Act of 7 September 2007 on the functioning of the coal mining industry (Polish Journal of Laws 2018, item 1374, as amended). The Company's core business is to conduct mine liquidation, protect neighboring mines from water, gas and fire hazards, effectively develop, rehabilitate and revitalize the acquired post-mining areas, protect cultural and industrial heritage sites from destruction, restructure employment through the creation of new jobs and care for the environment.

In line with market conditions, the hard coal mining industry is carrying out restructuring activities (Bluszcz, Smoliło, 2021; Dragan, Zdyrko, 2023; Krzemień et al., 2023; Prusek, Turek, 2018; Urych et al., 2021). As a result of the European Union's policy to achieve climate neutrality, member states must prepare to withdraw from burning fossil fuels, including coal (Kozioł, Kozioł, 2019; Midor et al., 2021; Riesgo Fernández et al., 2020; Salom, Kivinen, 2020; Tokarski et al., 2021). For the mining industry, the transition is a complex and lengthy process. Despite this, little space in the literature related to the industry is devoted to issues related to mine liquidation and decommissioning activities (Biały, Midor, 2021; Biały et al., 2020; Bluszcz, Smoliło, 2021; Bluszcz, Manowska, 2021). Restructuring, revitalization or decommissioning activities of the mining sector in Poland are spread over many years and result from the policy of the European Union. The European Green Deal document is a kind of road map for the transformation of the European Union towards achieving climate neutrality by 2050 (Prakash et al., 2022; Schotten et al., 2023; Smith, Underwood, 2000). One form of restructuring the mining industry is the closure of permanently unprofitable mines. Mine closure is the final, natural and inevitable stage of mining operations. Rational disbursement of funds for the effective management of post-mining areas has not been the subject of any comprehensive scientific research to date (Badakhshan et al., 2023; Chmiela, Smoliło, 2023; Turek, Lubosik, 2008). The available studies in this area are few and cover only selected issues (Biały, Cymler, 2015; Fernandez et al., 2020; Gajdzik et al., 2022; Shavarskyi, et al., 2000; Wrona, 2017).

Due to the large scope of work required, the mine liquidation is complex and costly undertaking. One of the reasons limiting improvements in decommissioning efficiency is the lack of instruments and tools to support cost management (Chmiela, Smoliło, 2023; Kaczmarek, et al., 2022; Kaczmarek, 2022; Kustra, Sierpińska, 2013; Różański, 2018a; 2018b; Segeth-Boniecka, 2017). This work presents a method for estimating liquidation costs based on a volume analysis of selected sub-costs.

The task of decommissioning a mine is a lengthy process, difficult to implement and requiring significant support from the state budget. This is due to the large volume of work required to be carried out during the task. Estimating the expenditures required to abandon

a mine is a lengthy process due to the complexity of the processes involved in abandoning a coal mine. The traditional methods of valuing a business are the income method, the comparative method, and the asset method. In the case of the income method, the valuation of a company boils down to an analysis of the company's development potential and the potential to generate future income. It is possible to use the discounted cash flow method or the free cash flow method. In the case of the comparative method, the method of stock market multiples and comparable transactions is used. In other words, the value of the company is estimated based on the value of comparable companies. The last method is the asset method, which uses the adjusted net asset method or the liquidation method. The expenditure required to carry out liquidation varies greatly; for example, the cost of liquidating the largest mines is several tens of times higher than the cost of decommissioning the smallest mines. Each case of mine liquidation is an individual case, but important regularities can be distinguished (Smith, 2000; Smoliło et al., 2021a; 2021b; Smoliło, Chmiela, 2021). The aim of this research was to develop and propose a tool for preliminary estimation of the expenditures necessary to carry out the designed liquidation process based on selected estimated component costs of mine liquidation. In designing the method, a certain functional similarity of the analyzed mining plants was assumed. It was assumed that each of the analyzed mines has a similar set of facilities, differing only in scale (Panahi Borujeni, Gitinavard, 2021).

2. Materials and methods

The research plan was carried out based on the analysis of programs and plans for the liquidating of coal mines carried out by the company from 2015 to 2023. After analyzing the available literature and collecting the documentation discussed, a statistical method for estimating the final cost of mine liquidation was proposed. The intention of the method was to statistically estimate mine decommissioning costs based on knowledge of selected component costs. Finally, a survey of experts (liquidation planners and liquidation managers) carried out at the end of the study allowed the validity of the estimation carried out according to the proposed method to be verified.

The research began with an analysis of the literature thematically related to the restructuring of industrial sites and facilities. Unfortunately, the literature in this area is extremely scarce. The analysis of the literature showed that in the design of future liquidation processes, it is possible to approximate the magnitude of the expenditures for the individual component processes and the total cost by knowing the costs of the selected component process(es) possible to determine already at the initial stage of the design work for a new mine liquidation task.

The next stage of the research was to determine the costs, knowledge of which would allow the most accurate estimation of the remaining component costs and the total cost. The correctness of the proposed assessment tool was verified by comparing the estimated costs for the actual mine liquidation processes carried out with the actual costs. The research was concluded by conducting a survey of the Company's engineering and technical staff involved in practice in the processes of liquidating and management of post-mining assets. The research verified an unconventional statistical method for preliminary cost assessment. The survey research made it possible to propose potential innovative measures for reducing the capital intensity of liquidation and post-liquidation processes carried out by the Company. Consultations in the form of face-to-face interviews with experts in charge of liquidating processes, confirmed the validity of the results and allowed the causes of more significant deviations from expected values to be clarified.

3. Results and discussion

3.1. The method for the preliminary assessment of mine liquidation time and costs

Mine liquidation processes are broad concepts so it would be difficult to treat them as just one process. According to the principles of process management (Chmiela et al., 2022; Chmiela, 2022; Noor Salim, Prasetia, 2022) and the practice at the company, mine liquidation processes are divided into 10 smaller sub-processes. Each of the processes shown in Table 1 includes its characteristic operations and activities.

Table 1.
Mine liquidation processes at SRK S.A.

1.	Decommissioning and securing mine workings
2.	Decommissioning and securing fore-shafts and shafts
3.	Protecting neighboring mines from water, gas and fire hazards
4.	Liquidation of mine infrastructure
5.	Land reclamation
6.	Maintenance of facilities to be decommissioned in order to ensure safe liquidation of a mining site
7.	Carrying out safety work and risk prevention measures in connection with a decommissioned mining site
8.	Preparation of required projects, documentation, opinions, expertise and analyses related to mine liquidation
9.	Repair of damage caused by the motion of a mining plant
10.	General management of the tasks performed during mine liquidation

Processes nos. 1, 2, 4, 6, 7, and 10 are carried out in every mine liquidation case. The conduct of the remaining processes (nos. 3, 5 and 9) is optional and results from the specifics of the liquidation task being carried out. Mine liquidation usually follows one of two options. These options are related to the construction of the target mine model. Due to the protection of neighboring mines, the mine can be decommissioned in its entirety or with the

pumping station remaining. The liquidation process is slightly different in each of these cases (Smoliło et al., 2023).

In the case of mine liquidating without leaving the mine wastewater pumping stations, the liquidation process ends with the transfer of the assets remaining after decommissioning to the Coal Mines in Full Liquidation or to a possible end user. The entire underground infrastructure (workings and shafts) is decommissioned. In this model, the process of decommissioning the workings (Process no. 1), and if the process of securing the neighboring mines (Process no. 3) is also carried out, must end before the process of decommissioning the last two shafts under Process no 2 begins (Pach et al., 2018). If a land reclamation process (Process no. 5) is to be carried out, it can only start after the processes of the liquidation of the mine infrastructure (Process no. 4) and maintaining the facilities to be liquidated (Process no. 6) have been completed. The remaining processes (Processes nos 7, 8, 9 and 10) are carried out throughout the entire mine liquidating period. If there is a need to conduct Process no 9 then this is also conducted throughout the mine decommissioning task.

In the case of liquidation with the pumping station remaining, the liquidation process ends with the transfer of the assets remaining after liquidation to the Coal Mines in Full Liquidation, and the prepared pumping station to the Central Mine Dewatering Plant. The entire underground infrastructure is being decommissioned, with the exception of the necessary shafts and workings being converted to a pumping station (Bondaruk et al., 2015; Chmielewska et al., 2020; Łabaj et al., 2020; Wysocka et al., 2019). In this case, the process of securing the neighboring mines is carried out (Process no. 3) and must continue until the end of mine liquidation. The timing of the start of this process is determined by the mine liquidation schedule (it does not have to start as soon as the liquidation process starts). The decommissioning of the shafts to be liquidated (Process no. 2) can proceed independently of the decommissioning of the workings (Process no. 1), the decommissioning of which can be carried out with the shafts remaining to service the pumping stations even until the end of the mine liquidation processes. As in the first case, if it is necessary to carry out the land reclamation process (Process no. 5), this process can only start after the processes of the liquidation of the mine infrastructure (Process no. 4) and maintenance of the facilities to be decommissioned (Process no. 6) have been completed, while Processes nos. 7, 8, 9 and 10 are carried out throughout the entire mine decommissioning period. The process no 9 is optional and if it is carried out it is done throughout the mine decommissioning period (Łupieżowiec et al., 2022; Mhlongo, Amponsah-Dacosta, 2016; Mhlongo, 2023; Rubio et al., 2019).

To increase the consistency of the component structure of liquidation costs, it was proposed to divide liquidated mines into 5 groups. To determine the reference groups, the analysis of the variation structure of the component process costs was analyzed using the coefficient of variation (Chmiela et al., 2022). The mines were divided into Very Large Mines (VLM), Large Mines (LM), Medium Mines (MM), Small Mines (SM) and a group of Very Small Mines (VSM) (Smolilo et al., 2021; Smoliło, Chmiela, 2021a; 2021b).

A tool has been prepared for the proposed method. The design interface of the tool is presented in Fig. 1. The interface contains fields with a white background. These fields are descriptive fields excluded from editing. The fields highlighted in yellow are the input fields, i.e. the estimated values of the components of the liquidation processes and the decision field, where the approximate size of the mine to be decommissioned should be determined. In the field highlighted in light blue, the method provides the suggested reference group most likely to the amount of the liquidation task component cost(s) entered. The boxes highlighted in grey are the resulting boxes, where the method gives the estimated size of the component costs of the liquidation process. In the same column, the last line in dark red gives the estimated total value of the liquidation process of the mine under analysis.

	Thousand PLN	assessed cost mln PLN
Process 1 (decommissioning of workings)		0,000
Process 2 (decommissioning of shafts)		0,000
Process 3 (securing neighboring mines)		0,000
Process 4 (liquidation of mine infrastructure)		0,000
Process 5 (land reclamation)		0,000
Process 6 (maintenance of decommissioned facilities)		0,000
Process 7 (safety work and risk prevention measures)		0,000
Process 8 (projects, expert opinions, etc.)		0,000
Process 9 (mining damage)		0,000
Process 10 (general management)		0,000
Total cost		**0,000**

Figure 1. Interface model of a tool for estimating the expenditures required to carry out the liquidation processes of a mining site.

In the method, the user enters between one and nine estimated component costs of liquidation processes into the calculations. It has been assumed that the entered costs will be given in thousands of PLN and the estimated costs will be presented in millions of PLN. To the entered value of the component cost, the method assigns the same entered value in the result field, which remains unchanged in further calculations. The user can enter from 1 to 9 known component process costs out of a possible 10. While it is technically possible to enter ten component costs, such a case does not lead to a cost forecast. On the basis of the entry of each value, the method statistically estimates the size of the remaining component liquidation costs beyond those already entered. The average value of the estimated values is reported as the result. In the last line, the value of the total mine liquidation cost, which is the sum of the entered costs and the averaged estimated values of the remaining component costs, is given in dark red. The introduction of each successive component process value increases the accuracy of the estimation of the remaining component costs and the total cost.

The proposed method, on the basis of the entered values, statistically determines the most probable membership of the analyzed mine to one of the reference groups. After the first value is entered, a probable reference group is determined using single-criteria analysis for the analyzed size of the liquidation cost component. The introduction of the next or subsequent liquidation cost component values results in the determination of the membership of one of the reference groups already being carried out by multi-criteria analysis (Aleskerov et al., 2003; Chmiela, 2023; Chmiela et al., 2023; Smolilo, Chmiela, 2021). This increases the correctness of the assignment of the liquidation task to the correct reference group. The user's identification of the correct reference group helps to ensure correct cost estimation. Each of the reference groups, due to the different scope of activities carried out, has a slightly different cost structure. The user may disagree with the result of the reference group estimation and ask for the calculation of what he/she believes to be the correct scope of the liquidation process as defined by another reference group (Stankevich, 2017).

3.2. Verification of the proposed method and discussion

The verification of the method took place in three phases. In the first phase, all 19 mines analyzed were examined for compliance of the calculated results with the values obtained in liquidation practice. As there is only one example of a liquidation carried out in the group of very small mines (VSM), which is also the benchmark, 100% conformity of the forecast with reality was achieved for this mine. To ensure that this example did not distort the verification with too perfect results, it was considered that it should not be taken into account in further analyses. The verification of the method in the first stage consisted of entering one of the component processes into the analysis and each time preparing a forecast of the amount of the remaining costs of the component processes and the total cost. A full study was carried out for the remaining 18 examples of the processes of the completed and decommissioned mining plant. For each forecast, a comparison with the actual results was prepared. In two cases out of 18, results differing from reality were obtained. The analysis of the documentation (liquidation plans and programs), the statistical evaluation and the interviews with the experts (persons in charge of the liquidation processes) indicated that these 2 cases were cases that were not in line with the other examples. According to the experts, their non-conformity was due to the specificity of the decommissioning processes carried out due to the atypical scope of the activities carried out. In the case of other mining sites, the inconsistencies obtained were due to the atypical nature of the liquidation component process itself. Good cost estimation results were associated with the component processes that were carried out in all cases analyzed, and the best for those representing the largest percentage of the total cost (processes 6, 7 and 10). Estimation on the basis of processes that can only occur during mine liquidation (optional processes 3, 5 and 9) gave the largest discrepancies with reality, and in some cases it was not possible to prepare a forecast. This occurred, for example, when the entered value of the process liquidation cost was equal to "0". After excluding these cases from the verification of the

method, according to the experts, the results of estimating the component and total liquidation costs based on a single value were satisfactory.

In all cases of cost projections, the actual value was subtracted from the estimated value and the deviation expressed as a percentage was calculated from the resulting difference. For the deviations, the median for the whole group of mines and the median for the reference group were determined. In Tables 2 and 3, analyzing the median deviation from the actual value, values not exceeding 20% are highlighted in yellow. Table 2 shows the results of the liquidation cost estimation derived from the analysis of the process no. 10. The process no.10 is one of the processes that estimates liquidation costs well. In contrast, Table 3 shows the estimation based on process 3, which is one of the processes optionally carried out in decommissioned mines and therefore its use as a benchmark gives poorer estimation results.

Table 2.
Median deviations of estimated liquidation costs from actual value when estimating based on process no. 10

	TOTAL	VLM	LM	MM	SM
Process 1 (decommissioning of workings)	-67%	-8%	-36%	-66%	-75%
Process 2 (decommissioning of shafts)	-44%	-53%	-263%	3%	2%
Process 3 (securing neighboring mines)	0%	-102%	59%	70%	0%
Process 4 (liquidation of mine infrastructure)	-8%	17%	-11%	-52%	12%
Process 5 (land reclamation)	0%	-254%	21%	70%	0%
Process 6 (maintenance of decommissioned facilities)	10%	-39%	12%	18%	-12%
Process 7 (safety work and risk prevention measures)	-16%	-7%	-57%	-9%	-5%
Process 8 (projects, expert opinions, etc.)	3%	3%	5%	2%	7%
Process 9 (mining damage)	4%	-2%	-11%	-212%	29%
Process 10 (general management)	0%	0%	0%	0%	0%
Total cost	-5%	-13%	-3%	-1%	9%

The method rather slightly overestimates liquidation costs. In most of the reference groups, the median deviation does not exceed 30% "up" and "down". The best estimation was obtained for the analysis of all mines as one group and for the group of small mines (SM).

Table 3.
Median deviations of estimated liquidation costs from actual value when estimating based on process no. 3

	TOTAL	VLM	LM	MM	SM
Process 1 (decommissioning of workings)	-94%	-94%	-283%	-30%	-61%
Process 2 (decommissioning of shafts)	-46%	39%	-403%	-106%	-4%
Process 3 (securing neighboring mines)	0%	0%	0%	0%	0%
Process 4 (liquidation of mine infrastructure)	-30%	4%	-63%	-52%	-7%
Process 5 (land reclamation)	0%	4%	-33%	0%	0%
Process 6 (maintenance of decommissioned facilities)	-17%	38%	-17%	-173%	-26%
Process 7 (safety work and risk prevention measures)	-68%	-89%	-80%	-229%	7%
Process 8 (projects, expert opinions, etc.)	-67%	-82%	-85%	-67%	2%
Process 9 (mining damage)	-8%	-47%	12%	-143%	27%
Process 10 (general management)	-25%	-15%	-64%	-23%	-11%
Total cost	-15%	-14%	-21%	-20%	-2%

In the second verification phase, a similar analysis was already carried out for two component processes. As expected, adding another component process to the analysis improved its accuracy. The unpublished part of the study shows that each time an additional data in the form of the cost of another component process was added, the accuracy of the estimation improved. According to the preliminary results of the analysis from the first stage of verification, the best results were obtained for the component cost pairs accounting for the largest part of the total cost and also conducted in all cases of liquidation. The best estimation results were obtained for the combined analysis of process 6 and 7 (Table 4).

Table 4.
Median deviations of estimated liquidation costs from actual value when estimating based on processes nos 6 and 7

	TOTAL	VLM	LM	MM	SM
Process 1 (decommissioning of workings)	-37%	17%	-76%	-24%	-28%
Process 2 (decommissioning of shafts)	-11%	-17%	-217%	28%	2%
Process 3 (securing neighboring mines)	0%	-62%	66%	68%	0%
Process 4 (liquidation of mine infrastructure)	2%	1%	7%	-13%	-31%
Process 5 (land reclamation)	0%	-172%	34%	68%	0%
Process 6 (maintenance of decommissioned facilities)	0%	0%	0%	0%	0%
Process 7 (safety work and risk prevention measures)	0%	0%	0%	0%	0%
Process 8 (projects, expert opinions, etc.)	0%	-8%	11%	-30%	0%
Process 9 (mining damage)	-33%	-13%	-18%	-133%	7%
Process 10 (general management)	1%	-11%	9%	-6%	-20%
Total cost	3%	2%	7%	-6%	1%

Also as expected, the worst liquidation cost estimation results were obtained for the component processes which were optionally carried out during decommissioning. Table 5 shows the decommissioning cost projection based on component process nos 3 and 5. Due to the lack of input data, for small mines (SM) the method was not able to determine the total cost for some of the mines, as indicated in Table 5. According to the experts, the accuracy obtained was again considered sufficient for this stage of potential design work.

Table 5.
Median deviations of estimated liquidation costs from actual value when estimating based on process nos 3 and 5

	TOTAL	VLM	LM	MM	SM
Process 1 (decommissioning of workings)	-71%	0%	-363%	-30%	-61%
Process 2 (decommissioning of shafts)	-45%	-59%	-164%	-106%	-4%
Process 3 (securing neighboring mines)	0%	0%	0%	0%	0%
Process 4 (liquidation of mine infrastructure)	-47%	-148%	-41%	-52%	-7%
Process 5 (land reclamation)	0%	0%	0%	0%	0%
Process 6 (maintenance of decommissioned facilities)	-63%	-61%	-81%	-173%	-26%
Process 7 (safety work and risk prevention measures)	-26%	3%	-89%	-229%	7%
Process 8 (projects, expert opinions, etc.)	-44%	-42%	-57%	-67%	2%
Process 9 (mining damage)	-31%	-49%	-31%	-143%	27%
Process 10 (general management)	-36%	-46%	-52%	-23%	-11%
Total cost	-63%	-21%	-63%	-236%	

In the third verification step, a hypothetical example of mine liquidation was analyzed. The average value of the liquidation costs for all analyzed examples carried out since 2015 and ongoing mine liquidation processes was used as comparative data. The projection was based on the two largest liquidation component processes (process nos 6 and 7) assigning the analyzed mine consecutively to all reference groups. Tables 6 and 7 show selected estimates for the different reference groups.

Table 6.
Forecast of the amount of liquidation costs based on process 6 and 7 for the group of medium-sized mines (MM)

	Thousand PLN	**assessed cost, mln PLN**
Process 1 (decommissioning of workings)		5,790
Process 2 (decommissioning of shafts)		20,951
Process 3 (securing neighboring mines)		25,876
Process 4 (liquidation of mine infrastructure)		20.641
Process 5 (land reclamation)		15,497
Process 6 (maintenance of decommissioned facilities)	83,618.73	83,619
Process 7 (safety work and risk prevention measures)	159,110.92	159,111
Process 8 (projects, expert opinions, etc.)		2,990
Process 9 (mining damage)		24,648
Process 10 (general management)		63,432
Total cost		422,553

Despite using the same values of processes nos 6 and 7, a difference in the amount of estimated costs is observed in Tables 6 and 7. The difference of more than PLN 100 million between the projected costs is due to the fact that in the case of medium-sized mines (MM), the assumed cost values of processes nos. 6 and 7, which are too high for the reality of this reference group, correspond to much higher costs of the component processes and, at the same time, to the total cost.

Table 7.
Forecast of the amount of liquidation costs based on process 6 and 7 for the medium-sized (MM) group of mines

	Thousand PLN	**assessed cost, mln PLN**
Process 1 (decommissioning of workings)		2,583
Process 2 (decommissioning of shafts)		21,277
Process 3 (securing neighboring mines)		0,627
Process 4 (liquidation of mine infrastructure)		20,507
Process 5 (land reclamation)		11,630
Process 6 (maintenance of decommissioned facilities)	83,618.73	83,619
Process 7 (safety work and risk prevention measures)	159,110.92	159,111
Process 8 (projects, expert opinions, etc.)		4,970
Process 9 (mining damage)		105,914
Process 10 (general management)		112,375
Total cost		**522,613**

As in the second stage, the percentage deviation from the baseline value was calculated. Table 8 shows the deviation of the estimated liquidation costs from the baseline calculated after the analyzed hypothetical mine was classified successively into all reference groups. The forecast was most accurate for large mines (LM) and very large mines (VLM), and worst for small mines (SM) and very small mines (VSM). The forecast for the smallest mines was particularly unfavorable. This was due to the overly high value of the introduced process costs 6 and 7 and, according to their amount, the method estimated results corresponding to other larger reference groups. The most favorable results were obtained for the group of large mines (LM), which was consistent with the mine size suggested by the method (see Table 6). In this case, deviations from the baseline value did not exceed 30%.

The method best estimated the total decommissioning cost and the costs of carrying out processes 2, 4, 5 and 8 especially for the groups of medium (MM), large (LM) and very large (VLM) mines.

Table 8.
Deviation of estimated liquidation costs from the mean value when estimating based on process 6 and 7 for different reference groups

	VLM	**LM**	**MM**	**SM**	**VSM**
Process 1 (decommissioning of workings)	-33%	2%	56%	-1%	98%
Process 2 (decommissioning of shafts)	13%	-1%	-3%	-160%	74%
Process 3 (securing neighboring mines)	-88%	24%	98%	100%	100%
Process 4 (liquidation of mine infrastructure)	-23%	11%	11%	-66%	95%
Process 5 (land reclamation)	2%	-26%	6%	100%	100%
Process 6 (maintenance of decommissioned facilities)	0%	0%	0%	0%	0%
Process 7 (safety work and risk prevention measures)	0%	0%	0%	0%	0%
Process 8 (projects, expert opinions, etc.)	-24%	23%	-28%	-79%	54%
Process 9 (mining damage)	-5%	28%	-209%	25%	100%
Process 10 (general management)	-1%	11%	-58%	-96%	92%
Total cost	-8%	6%	-17%	-15%	43%

A hypothetical example of mine liquidation was presented for evaluation to persons in charge of SRK S.A. branches. The interviewed experts (persons managing the liquidation processes), in a face-to-face interview, confirmed the compatibility of the results with past practice. The experts confirmed the correctness of the method with the accompanying software.

The method performs best in estimating the total cost and the liquidation cost components (process 6, 7 and 10). These are the processes most influencing the total cost, and their sum is about 70% of the total cost. By correctly estimating the total cost and the cost of these largest component processes, the estimated results are close to the real ones. The difference between the projected cost and the real amount of processes 1, 2, 3, 4, 5, 8 and 9 expressed as a percentage appears to be large. However, it should be borne in mind that their total impact on the total cost is small and amounts to only about 20%. In view of this, the differences expressed in PLN will not be so high and, according to experts, such a small discrepancy, when the large components are correctly estimated, ensures correct coverage of expenditures for the entire mine liquidation process.

4. Conclusions

The method described is based on a statistical evaluation of costs and allows an analysis independent of the scale of the liquidation task. A forecast can be obtained once the costs of at least one of the liquidation component processes have been correctly determined. Adding each additional cost improves the accuracy of the estimation.

It has been established that, for the validity of the estimation, relying on the costs of optionally conducted processes should be avoided. Their analysis can sometimes lead to an indeterminate situation, which can make the estimation impossible. Relying the estimate on the processes carried out in each case of the liquidation of a mine site, usually leads to satisfactory results of the forecast carried out.

The method performs best in estimating the large components of the liquidation costs (processes nos 6, 7 and 10) and the total liquidation cost. The correct estimation of these large components, even with significant variations for the other small components, ensures adequate inputs for the correctness of the overall mine liquidation process.

The method proposed for the preliminary assessment of mine liquidation costs can be used as a tool in the eventual processes of designing the liquidation of further mines or parts of mines. With some modification and adaptation, the method can be applied by any company dealing in the liquidation of mines.

An unresolved problem is the estimation of liquidation costs, taking into account cases of abnormalities in the main mine liquidation processes. There applies only the unstructured knowledge of practitioners.

The proposed method requires further research, but already in its present form it can be a very useful auxiliary tool in engineering work and in preliminary design work for the restructuring of post-mining assets.

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