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Analysis of the use of unexploited coal resources in liquidated mines: a case study of the Upper Silesian Coal Basin, Poland

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The reactivation of unexploited coal deposits is complicated and expensive. Profits in the event of success of such a task in liquidated mines would probably only slightly exceed incurred outlays. Nevertheless, when market conditions change, a return to unexploited resources should be considered. Assessment of the possibility of using unexploited hard coal resources in liquidated mines has not yet been scientifically studied, with available literature being concerned only with some general issues of this field. We propose a simple method that informs on the possibility of developing unexploited hard coal resources as a tool to support decision-making processes. The information obtained can be used as a reference point for detailed analysis and multi-criteria evaluation of potentially resources that are ready to use. This method is dedicated to mines that are liquidated. However, after some modifications, the method might also be used by more widely. Given current political and economic circumstances, no attempt is being made to reactivate coal reserves that are left behind. However, it cannot be ruled out that, in the face of a potential energy crisis, changes to the political consensus and climate protection agreements may be considered. In both Europe and Asia, some mines were liquidated according to procedures that did not cut off the possibility of a return to mining – the shafts and part of the infrastructure were protected.

Key words: liquidation of a mine, unexploited deposits, decision-making, development, restructuring of mining enterprises.

INTRODUCTION

Improved effectiveness of mining companies has been sought in the putting a mine or its ineffective parts into liquidation (Bluszcz and Manowska, 2021; Bluszcz and Smoliło, 2021). In mines that are considered permanently unprofitable (Prusek and Turek, 2018; Chmiela and Smoliło, 2023) and consequently liquidated, only where there has been complete exhaustion of resources are no unused parts of the deposit left (Smith and Underwood, 2000; Smoliło et al., 2021). Currently, changing market conditions made it reasonable to consider the possibility of returning to unexploited resources in the event of coal shortages on the European Union market (Li, 2012; Dragan and Zdyrko, 2023; Mhlongo, 2023). Means of assessing the prospects for the development of unexploited coal resources in hard coal mines that have been put into liquidation have not yet been subject to comprehensive scientific research (Nieć and Radwanek-Bąk, 2014; Mhlongo and Amponsah-Dacosta, 2016; Noor Salim and Prasetia, 2022). Issues considered to date concern only some general issues related to problems of return to unexploited hard coal deposits (Turek and Lubosik, 2008; Różański, 2018; Shavarskyi et al., 2022). Important determinants (Kopacz, 2014; Biały, 2015; Biały and Cymler, 2015) that shape the conditions for implementation of mining reactivation in Polish mines are (Turek, 2013; Kozioł and Kozioł, 2019):

- occurrence of numerous often associated natural hazards,
- age of the mines,
- multi-deck operation,
- depth exploitation,
- urbanization and rich infrastructure at the mining area surface.

In addition to these factors, the following must be taken into account at the beginning of the decision-making process:

- complete flooding of mines (as in Lower Silesian Coal Basin, Poland),
- non-economic factors: administrative, sociological, environmental, etc.

We present a method for assessing the possibility of reactivating unexploited coal seams. The method takes into account Polish experience as regards geological, technical and economic conditions. The design of the method allows modification

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of the factors analysed. Owing to flexibility of the method, it may be applied in any geological-mining and economic environment, not limited to Poland.

MATERIAL AND METHODS

SCOPE AND AIM OF WORK

There is no current method of supporting decision-making as regards the effective planning and implementation of processes of assessing the potential use of hard coal resources in liquidated mines. The development of such a method would make it possible to increase the available resource base, which is a matter of considerable significance in the light of changing political, economic and technical conditions.

SRK S.A. (Mine Restructuring Company, Poland) pursuant to the Act of 7th September 2007 of the functioning of hard coal mining (Riesgo Fernández et al., 2020; Chmiela et al., 2022), took over, together with the liquidated mines (Bluszcz and Smoliło, 2021; Kaczmarek, 2022; Krzemień et al., 2023), part of the coal resources of which the exploitation was considered economically unjustified (Bluszcz and Manowska, 2021; Krzemień et al., 2022). Such resources were most often documented as pillars that were created for the protection of surface objects (Biały et al., 2020; Gajdzik et al., 2022; Yousuf et al., 2023), including those related to the functioning of the mining plant (Kudełko et al., 2014; Nieć and Młynarczyk, 2014; Kaczmarek et al., 2022).

According to the current situation related to Russia's aggression against Ukraine, it may be reasonable to consider the advisability of their exploitation to maintain the energy security of Poland and the European Union. In this case, the economic calculation of the costs of their extraction would not have to be a decisive condition for returning to mining. In this regard, it would be also necessary to amend the applicable legal regulations regarding the swift obtaining of a license for the extraction of hard coal from the deposits (Wodarski et al., 2017; Wysocka et al., 2019; Samolej et al., 2023).

RESEARCH METHODS

The study was carried out on the basis of data referring to completed and currently realized mine liquidation processes and the analysis of left resources. The basis was documentation, programs and liquidation plans in the period from 2015 to 2023. The implementation of the scope of work proceeded in accordance with Figure 1. and involved the use of research methods described in Table 1.

During the research, after the identification of the research problem, an analysis of the available literature was carried out. The collected data allowed development of the following conclusions, which were used to construct the assumptions of the method, allowing for the assessment of possible development of resources remaining in the liquidated mining areas.

Following this survey and interviews, a preliminary scope of requirements of the method of assessing the resources of liquidated mines was prepared. Firstly, to design an appropriate resource assessment method, definition of the criteria with their valorization had to be taken into account. For this purpose, an analysis of on-board maps was carried out in order to select parameters for the analysis of the deposits (Chmiela, 2023; Chmiela and Smoliło, 2023). The study compared the previously used deposit assessment methods, which were based on the analysis of available documentation, and statistical and published studies (Dinanty, 2022). Moreover, case studies, interviews and questionnaires were also used to select the method to determine the assessment criteria for the deposits analysed (Fig. 2). At the beginning, after a series of discussions, we relied on the opinions of most of the engineering and technical employees of the Company's (SRK) Branches. Then we asked them to fill in questionnaires, which were completed by 157 respondents (out of ~2,400 total SRK employees). Subsequent surveys were already conducted with smaller groups of respondents. The final phase of the questionnaire survey involved a group of 63 persons of the Company's top technical management (directors, chief and chief engineers and some of the senior supervisory staff). The questionnaire contains tens of detailed questions divided into groups on geological criteria, deposit availability (formal and technical factors) and environmental problems.

After a series of interviews and consultations, we used a slightly different description of the sub-assessments, due to better, more precise and more complete means of describing the assessment criteria used.

During the analysis of maps and expert research supported by literature analysis, it was found that while assessing the potential development of unexploited hard coal deposits, three basic evaluation criteria with corresponding partial grades (sub-criteria) shown in Table 2 should be taken into account (Ayeni et al., 2022; Gupta, 2023). As the hierarchical assessment method analysed the determined assessment criteria in most completely, this was selected for further research. The adapted Analytical Hierarchy Process Method (aAHP) aims to group observations of the stages of the objects analysed into groups (clusters) based on similarities between observations (Ram-

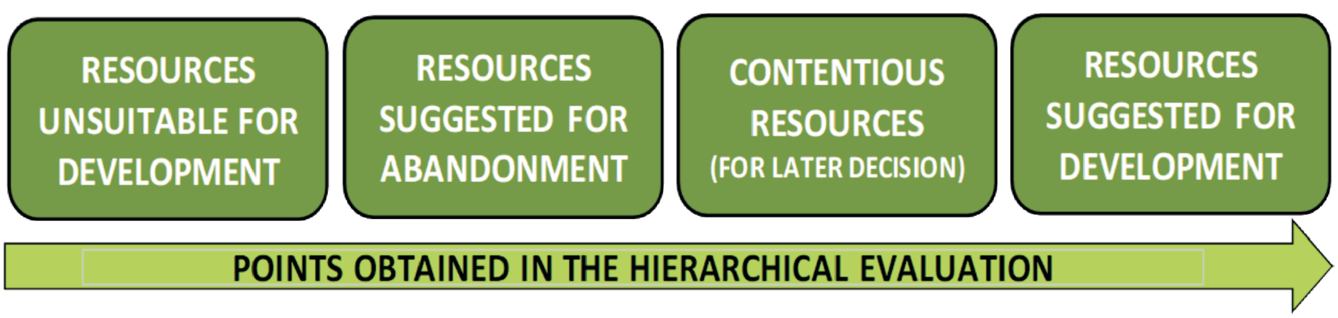

Fig. 1. Research procedure

Table 1

Research methods and the results of their use

Research methods	Results of their use
Literature study	indication of basic areas and research problems
Analysis	development of survey and interview forms
Synthesis	construction of schemes for assessing deposits of liquidated mines
Direct interview – discussions	development of a preliminary model for the deposit assessment method
Panel studies	verification and modifications of deposit evaluation method models
Survey research – questionnaires	development of the final model for the deposit assessment method
Analysis of documents	
Analysis of onboard maps	
Case studies	

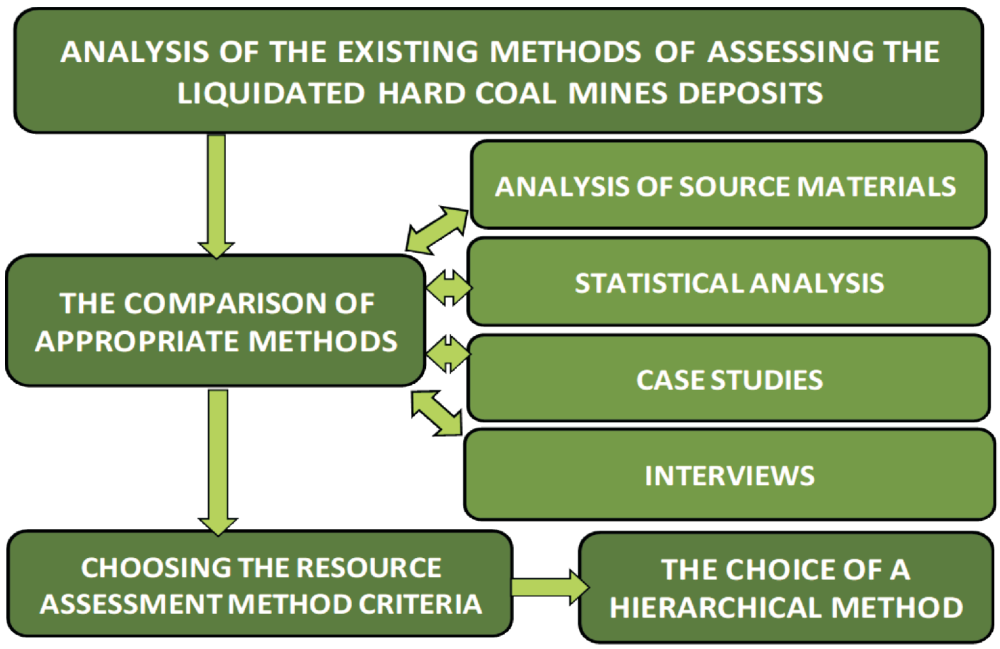

Fig. 2. The procedure of selecting a resource assessment method

dhani and Murtaqi, 2022; Rovaldi and Utama, 2023). In the method proposed, the evaluated resources are compared with model (benchmark) resources with optimal parameters (Wijaya, 2023). After each comparison, the evaluated example of the unexploited resources according to the "distance" from the model resources is placed into the appropriate cluster (resource group). On this basis, the decision-maker can make the final decision.

The last stage of the research was to develop an original hierarchical method for assessing the deposits of the liquidated hard coal mines. This stage of research consisted of the verification and modification of the initially adopted assessment method. In this phase of research, successive versions of the resource assessment method were consulted and corrected in order to obtain a final version that would meet all its requirements and changing conditions.

In order to adapt the method to the changing conditions, a quotient transformation was used to assign values to partial evaluations and obtain the final evaluation in the hierarchical method with the use of multi-criteria analysis methods. The multi-criteria analysis required the determination of weightings for individual partial ratings, which was achieved by means of subsequent surveys. The research was based on the re-presentation of the survey to the experts who were to assign a weighting to each of the partial assessments for each of the assessment criteria.

The adapted Analytic Hierarchy Process Method (aAHP) (Bijańska and Wodarski, 2017; Affandi and Novani, 2023) was verified using a prepared database of reference resources. The database includes examples of resources attractive for possible development, resources considered permanently unfit for extraction, and resources difficult to classify (Etlanda and Sutawidjaya, 2022; Khosravi et al., 2022). The verification showed that only minor formal corrections were needed, which did not result in significant changes to the structure of the method. For this reason, the revised method was considered correct.

THEORY AND CALCULATION

A NEW METHOD OF ASSESSING THE POSSIBILITY OF DEVELOPING DEPOSITS OR THEIR PARTS

The surveys conducted showed that in order to assess the possible re-use of unexploited resources, three criteria adopted for assessing the potential redevelopment of unexploited hard coal deposits shown in Table 2 should be taken into account.

Table 2

Criteria adopted for assessing the potential redevelopment of unexploited hard coal deposits

Formal and spatial criteria (accessibility to the deposit)	
K1A	possession of an active mining license
K1B	access to unliquidated shafts
K1C	access to unliquidated facilities of the mining plant
K1D	distance from the mine to the railway line
Geological and resource criteria for the assessment of hard coal deposits	
K2A	size of the industrial resources
K2B	moderate thickness of the coal seam
K2C	dominant types of coal
K2D	distance from sharing points
K2E	predicted natural hazards
Environmental criteria	
K3A	impact of the planned exploitation on surface objects
K3B	possibility of obtaining a qualified crew

Source: Pieszczek et al. (2023)

In accordance with the nature of the aAHP method (Etlanda and Sutawidjaya, 2022; Salvaña et al., 2023), the final evaluation of the example of resources examined assigns these resources to their appropriate decision-making cluster (group of resources). We note that the method is only a tool that supports the decision-maker and it is up to him/her to make the final decision so as to use the assessed resources effectively (Yavuz, 2015; Khosravi et al., 2022). Assumptions made are: the closer the operating mine workings (shaft, gallery, other) are located, the shorter the time to re-develop the deposit; the shorter the time since the mine was closed down, the easier it is to access to the abandoned parts. The questions contained in the questionnaire bring these issues closer. We emphasize that Polish regulations (Geological and Mining Law) set out rules for the safe decommissioning of workings, which will facilitate their safe reactivation.

In the aAHP method adopted, four decision clusters (groups of resources with similar parameters) were proposed, determining the possibility of reusing unexploited resources (Fig. 3):

– resources recognized by the method as permanently unsuitable for re-use;
– resources suggested for abandonment, considered by the method as unprofitable for re-use under current market conditions;
– disputed resources, in current market conditions, considered by the method as difficult to classify, are suggested for abandonment or development;
– resources suggested for economic development in the current market conditions.

After the initial verification of the method, incorrect placement of the unexploited resources analysed in the appropriate decision-making clusters was found in the case of resources clearly unsuitable for development. In some cases, such resources received such a high rating that the method classified them to the cluster of resources only suggested for abandonment. For the points obtained in the remaining criteria to compensate the lack of points in the criteria where “0” was obtained, a group of criteria allowing resources for further analysis was added.

Based on the analysis of the literature, admission criteria (Table 3) were established as a range of questions that could only be answered “Yes” or “No”. Answering “No”, to at least one of these questions (Chmiela and Smoliło, 2023; Samolej and Franus, 2025), results in failure to meet the entire range of admission criteria and exclusion of the resources under consideration from further assessment (Turek and Lubosik, 2008; Yousuf et al., 2023).

Due to the arrangement of typical mining and geological conditions in the Upper Silesian Coal Basin and Lublin Coal Basin, the prepared set of admission criteria prepared is dedicated to deep deposits. The set does not cover all possible combinations of mining and geological parameters. Additional individual assessment should be carried out in specific circumstances. The need for an individual assessment may arise, for example, when analysing the possibility of developing shallow deposits with low stratal dip. For this type of exploitation, much smaller resources may be of interest than in the classical exploitation of deeper deposits (Salom and Kivinen, 2020). In general, an exemplary set of criteria is presented based on Polish experience and geological and technical conditions, but these criteria can be modified and adapted for different settings.

The method assumes that the values of partial grades, wherever possible, will be given in the form of primary values and then converted into dimensionless values. This allows comparison of partial grades expressed in different units. The ratio transformation also reduces partial grades to the range from “0” to “1”, which enables comparison of partial grades, regardless of the absolute size of the number describing the original value of a given partial grade. In the ratio transformation, the standardized values of “stimulant” assessments are calculated by dividing the tested value by the optimal value (in this case the largest) in accordance with formula [1] below (Przybyła and Chmiela, 1997; Chmiela, 2023).

$$NV_{istym} \quad \frac{h_i}{h_{i\,\max}} \qquad [1]$$

where: NV_{istym} – value of the partial grade in the ratio transformation for the “stimulant”; i – partial grade number; $h_{i\max}$ – optimal (maximum) value of the “stimulant” rating; h_i – partial grade value analysed.

For a “de-stimulant” feature, the ratio transformation provides the calculation of a normalized value by dividing the optimal value for this partial grade, in this case the smallest value, by the value of the partial grade analysed according to formula [2] below (Przybyła and Chmiela, 1997; Chmiela, 2023).

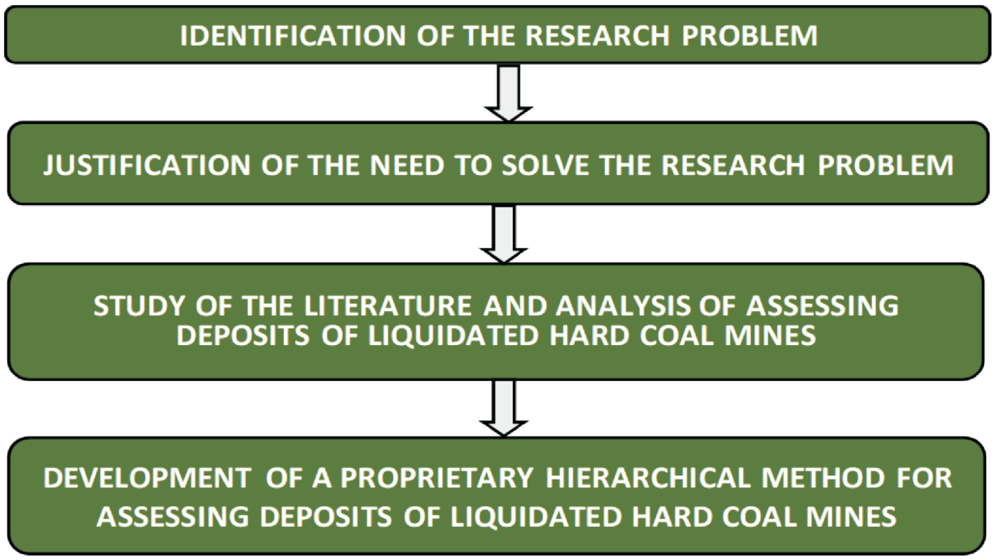

Fig. 3. Division of the deposits analysed into suitability clusters (groups of resources) for re-development

Table 3

Criteria allowing further hierarchical evaluation of the resources analysed

Criterion allowing the valorization of hard coal deposits	Yes	No
Is the exploitation of the deposit considered technically possible?		
Does the exploitation of resources leave the deposits above undamaged?		
Is the maximum depth of exploitation <1200 m?		
Is the minimum calorific value of the coal at least Qr = 20 MJ/kg?		
Do the projected impacts of mining exploitation damage the facilities?		
Does the income from the exploitation of the deposit exceed the costs of its extraction?		
Does the average coal thickness in the calculation plot exceed 1.50 m?		
Is the average sulfur content in the coal <Sr = 1.6%?		
Is there >30% of the resources in question in the protective pillars?		
Is the deck contamination <20% by volume?		
Do the lot's resources exceed 200,000 Mg?		

Source: Pieszczek et al. (2023)

$$NV_{idest} \quad \frac{h_{i\,min}}{h_i} \qquad [2]$$

where: NV_{idest}– value of the partial grade in the ratio transformation for the "de-stimulant"; i – partial grade number; h_{imin} – optimal value for a "de-stimulant" assessment; h_i – partial grade value analysed.

For a partial grade of a "nominant", a standardized grade is awarded in intervals. In the interval where the increase in the absolute value is perceived positively, the normalized value is calculated as for a "stimulant", in accordance with formula [1], and in the interval where the increase in the absolute value of the partial grade is perceived negatively, the calculations are performed as for the "de-stimulant" grade (Przybyła and Chmiela, 1997; Chmiela, 2023), in accordance with formula [2].

The final a AHP grade is calculated in accordance with formula [3] below. The standardized values of partial grades assigned are multiplied by a weight reflecting the impact of this partial grade on the final a AHP grade (Przybyła and Chmiela, 1997; Chmiela, 2023). The a AHP assessment indicates the "distance" of the example analysed of unexploited resources from a hypothetical ideal deposit, with optimal parameters, authorizing a decision to re-develop it.

$$aAHP_i = {}_{wK1A} \cdot K1A_i + {}_{wK1B} \cdot K1B_i + {}_{wK1C} \cdot K1C_i + {}_{wK1D} \cdot K1D_i + {}_{wK2A} \cdot K2A_i + {}_{wK2B} \cdot K2B_i + {}_{wK2C} \cdot K2C_i + {}_{wK2D} \cdot K2D_i + {}_{wK2E} \cdot K2E_i + {}_{wK3A} \cdot K3A_i + {}_{wK3B} \cdot K3B_i \qquad [3]$$

where: K1A, K1B, K1C, K1D, K2A, K2B, K2C, K2D, K2E, K3A and K3B – represent standardized values of a AHP partial grades; w – the weighting of the partial grade reflecting its impact on the final grade; i – another example analysed of unexploited resources subjected to hierarchical assessment.

The weighting of each partial grade is its impact on the final grade. The weighting is different for each partial score and may change as market conditions change. Thanks to the use of weightings, the method becomes much more flexible and can be more easily adapted to changing economic, technical or political situations.

At the beginning of 2023, the values of the weightings for the partial assessment criteria for the validation of unexploited resources were established, based on an expert opinion survey. The management team of liquidated hard coal mines and senior supervisors of mining specialties were used as experts. The weighting values and the nature of the partial scores are shown in Table 4. The weighting values are adequate only for this period, and rapid changes in economic conditions require further research to be carried out when political and market conditions normalize, at least temporarily.

Table 4

Nature and importance of partial assessments of hard coal deposits' valorization criteria

Name and nature of partial evaluation		Weight "w"
Possession of an active mining license	S	0.0904
Access to unliquidated shafts	N	0.1407
Access to unliquidated facilities of the mining plant	S	0.0593
Distance from the mine to the railway line	D	0.1037
Size of the industrial resources	S	0.1481
Moderate thickness of the coal seam	N	0.0919
Dominant types of coal	S	0.0741
Distance from sharing points	D	0.1319
Predicted natural hazards	D	0.0593
Impact of the planned exploitation on surface objects	S	0.0785
Possibility of obtaining a qualified crew	S	0.0222

S – stimulant, D – de-stimulant, N – nominant

DESCRIPTION OF PARTIAL GRADES

FORMAL AND SPATIAL CRITERION FOR THE VALORIZATION OF HARD COAL DEPOSITS (ACCESS TO THE DEPOSIT) (K1)

Partial grade K1A. Possessing an active mining license. When a license to extract a mineral from a deposit expires, the resources are assigned as dimensionless number "0". Whereas, when the mine has a valid license to extract a mineral from a deposit, the resources are assigned as the number "1". An increase in the absolute value is perceived positively and classifies this partial grade as a "stimulant" with an optimal value equal to "1".

Partial grade K1B. Access to unliquidated shafts. In this partial assessment, it was proposed to provide the number of unliquidated shafts. At first, it was decided that the more potential shafts, the better, so the partial assessment was given the character of a "stimulant". However, the economic assessment of such a situation indicated that the costs of maintaining additional shafts may be high enough to render such a project ineffective. It was decided that two shafts (an inhalation and an exhalation one) were optimal, and each subsequent one reduced the attractiveness of the project. Ultimately, the partial grade has the character of a "nominant". In the range from "0" to "2" it has the character of "stimulant", and from the value of "3" it changes its character to "de-stimulant".

Partial grade K1C. Access to unliquidated mining plant facilities. In the absence of unliquidated mining plant facilities, the resource is assigned a value of "0"; for a partially completed liquidation of mining plant facilities, the resource is given a "1"; and for a full complement of liquidated mining plant facilities, the resource is given a "2" . An increase in the absolute value is perceived positively and classifies this partial grade as a "stimulant" with an optimal value of "2".

Partial assessment K1D. The distance from the mine to the railway line. An increase in the absolute value of this partial grade is perceived negatively, which makes the partial grade a "de-stimulant". The optimal case is the value "0", which would make, regardless of the distance, a zero in the numerator in formula [3], always returning the value "0" without differentiating the partial grades. To avoid such a situation and "dividing by zero", the method technically adds the value "1" to the number of threats in all resources analysed and takes the number "1" as the optimal value for this partial assessment.

GEOLOGICAL AND RESOURCE CRITERION FOR THE VALORIZATION OF HARD COAL DEPOSITS (K2)

K2A partial assessment. The size of industrial resources. An increasing amount of resources is perceived positively, so it was determined that this partial assessment is of "stimulant" nature. The experts also decided that the reference point as the optimal value would be 400 million Mg, because when analysing the available unexploited deposits, this value is not exceeded. The experts considered this partial assessment to be the most important partial assessment when assessing the potential suitability for development and gave it a weight of 0.1481.

K2B partial assessment. Moderate thickness of the coal seam. There is an optimal thickness of the seam extracted, which is 4.0 m for mining with a roof collapse, and 2.8 m for mining with backfilling. Increasing the absolute value of the seam thickness is perceived positively until the optimal value is reached, while further increases in the thickness makes extraction more difficult. For this reason, this partial assessment was considered as a"nominant", the optimal value of which will depend on the extraction technology (4.0 m for roof caving and 2.8 m for mining with backfilling).

K2C partial assessment. Dominant types of coal. Increasing the number denoting the type of coal is not always perceived positively, but for the purposes of the initial assessment of resources, such a simplification of reality was adopted. Under this assumption, partial assessment should be considered as a "stimulant". However, the simplification used will not significantly affect the operation of the method, and the precise valorization of this partial assessment will require additional research. The optimal value is the dimensionless number 43.

K2D partial assessment. Distance from sharing points. An increase in the absolute value of this partial grade is perceived negatively, which makes the partial gradea "de-stimulant". The optimal case is the value "0", but, similarly to the K1D criterion (the distance from the mine to the railway line), to avoid "dividing by zero", a technical "1" is added and at the same time the number "1" is assumed as the optimal value.

K2E partial assessment. Predicted natural hazards. When valorizing this aspect of resource assessment, it was decided that only the number of natural hazards in the deposit analysed should be taken into account, without assigning them a degree, class or category. This simplification was considered sufficient for the initial assessment of unexploited deposits in terms of their possible development. One point is awarded for each predicted threat to the resources assessed. Awarding point classifications in this way (the more the worse) places this criterion in the "de-stimulant" group. The optimal case is the value "0", but in order to avoid "dividing by zero", the method, similarly to the K1D and K2D assessment, adds a technical "1" and takes the number "1" as the optimal value for this partial assessment.

ENVIRONMENTAL CRITERION FOR THE VALORIZATION OF HARD COAL DEPOSITS (K3)

Partial grade K3A. The impact on the planned exploitation of surface objects. For areas with a high degree of urbanization, resources are assigned as a dimensionless number "0"; for areas with an average degree of urbanization; resources are assigned the number "1", and for areas with a low degree of urbanization, resources are assigned the number "2". An increase in the absolute value is perceived positively, which classifies this partial grade as a "stimulant", with an optimal value equal to "2".

Partial grade K3B. The possibility of obtaining qualified crew. For this partial assessment, the original value will be taken as a percentage of the ability of local Labour Offices to meet the demand for qualified employees. Increasing the absolute value of the partial assessment (the possibility of employing unemployed people from local Labour Offices) is perceived positively, so this criterion was considered as a "stimulant", with an optimal value of 100%.

AWARDING THE FINAL GRADE FOR THE aAHP METHOD

The last stage of preparation for the calculations was to determine the point range corresponding to individual clusters. Determining the boundaries between clusters for hierarchical analysis was obtained after conducting another expert opinion survey. The experts were again people from the management of the liquidated mines and from higher operational supervision of the relevant specialties. The respondents were asked to provide the score range of individual decision clusters of the aAHP method (Grmela et al., 2018; Zhou et al., 2018). The boundary values between clusters obtained from all experts were very similar, which resulted in an exceptionally high convergence of their opinions, at the level of approximately 97% (Bijańska and Wodarski, 2017; Affandi and Novani, 2023). Specialists were provided with a sample table of potentially reactivable resources, with an assigned aAHP score, obtained according to the method described above, and made a decision about belonging to one of the clusters. Based on the results obtained, it was possible to determine the boundaries between the clusters. In Table 5. a system of aAHP rating values awarded to decision-making clusters is included. The calculated final aAHP rating places the assessed resources within decision-making clusters (Cao et al., 2010; Etlanda and Sutawidjaya, 2022).

The final diagram of the proposed adapted Analytic Hierarchy Process (aAHP) method, using the ratio transformation, is shown in Figure 4. The resource analysis procedure begins with outlining potential resources on maps and reading basic data characterizing the assessed part of the deposit. The next step in the assessment is to check whether the assets being assessed

Table 5

Division of the assessment results, according to the aAHP assessment obtained, into decision clusters

Decision-making cluster for the valorization of hard coal deposits	aAHP [scores]
Resources unsuitable for development	to 0.3
Resources suggested for discontinuation	to 0.4
Contentious resources (to be decided later)	to 0.5
Resources suggested for development	>0.5

Source: Pieszczek et al. (2023)

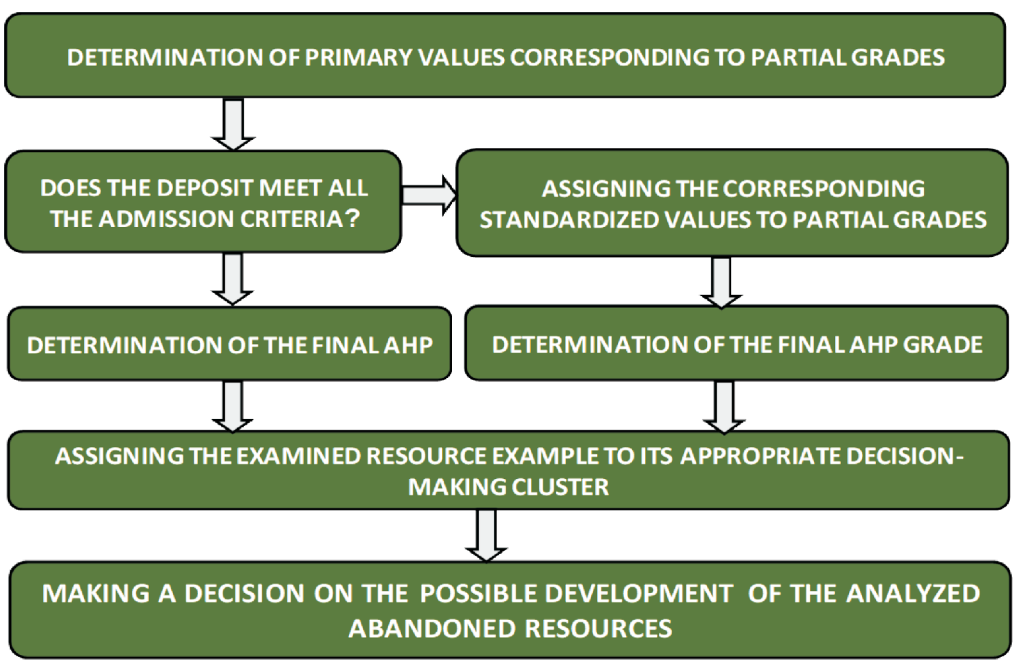

Fig. 4. Scheme of the hierarchical analysis method with an additional group of admission criteria

Table 6

Database of unexploited resources potentially suitable for redevelopment

Partial assessment / No of resources	K1A	K1B	K1C	K1D	K2A	K2B	K2C	K2D	K2E	K3A	K3B	AHP
1	0	0	0	3	9	1.70	31	4	3	0	95	**0.138**
2	0	0	1	0.7	21	1.70	34	2.7	2	0	90	**0.194**
3	0	0	0	1	15	2.30	31	2.1	7	1	90	**0.195**
4	0	0	1	2	1	1.50	31	4	7	1	100	**0.196**
5	0	0	2	2	17	3.50	33	0.5	4	0	80	**0.264**
6	0	0	2	2	6	4.10	32	0.5	4	0	80	**0.267**
7	0	1	1	1	14	1.50	33	3	7	1	70	**0.273**
8	0	0	2	2	55	4.20	33	0.5	4	0	80	**0.285**
9	0	1	1	2	3	4.30	31	0.5	4	0	80	**0.301**
10	1	0	2	0.7	23	1.90	34	1.5	5	0	100	**0.316**
11	1	0	2	0.5	21	2.50	31	3.5	5	0	100	**0.324**
12	1	0	2	2	5	1.50	31	2	2	1	90	**0.331**
13	0	3	1	0.7	22	1.90	34.2	1	2	1	90	**0.341**
14	0	3	1	0.8	41	2.40	34	2	2	1	90	**0.351**
15	0	3	2	2	11	2.70	32	2.3	5	1	100	**0.356**
16	1	1	1	1	25	1.50	34	3	7	1	70	**0.369**
17	1	0	2	2	48	4.40	34	0.5	4	0	80	**0.371**
18	1	1	1	1	52	1.50	31	3	7	1	70	**0.374**
19	0	2	0	3	8	2.60	33	2.40	3	2	95	**0.383**
20	0	2	0	3	65	2.80	33	2.60	3	2	95	**0.408**
21	1	3	0	3	2	2.30	34.2	2.10	3	2	95	**0.421**
22	1	3	2	0.7	40	2.10	34.2	0.5	5	0	100	**0.438**
23	1	3	0	3	34	2.75	34	2.60	3	2	95	**0.441**
24	0	2	2	0.45	99	2.60	33	3.5	4	1	100	**0.453**
25	1	3	1	2	7	2.50	32	1.3	2	2	90	**0.462**
26	1	2	1	0.45	6	2.20	33	1.1	2	1	90	**0.484**
27	1	3	2	0.8	63	2.60	34	1	4	2	100	**0.523**
28	1	4	2	0.2	67	2.60	34	0.5	5	2	95	**0.552**
29	1	2	2	0.45	150	2.40	33	2.3	2	2	90	**0.575**

meet a set of eligibility criteria. Failure to meet at least one of the qualifying criteria eliminates the deposit from further evaluation. It is assigned an aAHP rating value of "0" and is automatically classified into the cluster of deposits unsuitable for development. When the deposit meets all the acceptance criteria, the partial assessments are assigned their normalized values and the method, using a ratio transformation, in accordance with formula [3], assigns the resources being considered a final aAHP assessment, which classifies the resources analysed into decision-making clusters. The information obtained in this way is the basis to help the designer make the final decision on the possible re-development of abandoned resources. It should be emphasized that, despite the suggestion resulting from the analysis (penultimate element in Figure 4), the decision-maker can agree or reject the suggestion. The decision-maker can act according to his/her knowledge. However, the entirety of the analysis carried out and the resulting suggestions rationalize the decision-making process.

RESULTS AND DISCUSSION

VERIFICATION OF ASSESSMENTS CARRIED OUT FOR VARIOUS GEOLOGICAL, RESOURCE, FORMAL, LEGAL AND ENVIRONMENTAL CONDITIONS

An important stage in the design of the new resource assessment method was its practical testing. The verification of the correctness of resource allocation in the appropriate decision-making clusters was carried out on the basis of the database of unexploited hard coal resources in mines that had been put into liquidation. In the database of resources that are potentially possible to develop (Table 6) there are resources that meet the proposed set of admission criteria (Table 3). The database includes 29 potential areas for possible reactivation of mining.

DISCUSSION

The unexploited resources assessed vary in size, ranging from 1 to 150 million Mg. These resources are qualified as moderately thick deposits, their thickness starting from 1.5 m and reaching 2.8 m. Only in four cases did the thickness exceed 4 m, classifying the deposits as thick deposits. The resources analysed contain coals of types 31 to 34.2. Natural hazards are expected to occur in the resources. Most resources are remote from potential sharing points. In seven cases, the distance does not exceed 1 km, but these resources are most often located in the protective pillars designated for the main shafts. In the case of most of the resources analysed, the area of the main plant belongs to the mine being liquidated, and in nine cases the liquidated mine owns only a separate part of the area of the mining plant. The resources analysed are located under areas with varying degrees of urbanization. It was found that it was relatively easy to obtain local qualified crew.

Among the resources analysed (Table 6), the method classified eight regions as unsuitable for development, marked in red, eleven regions as suggested for abandonment, marked in orange, seven examples classified as disputed resources (marked in white) and only three regions classified as a cluster of resources suggested for development, marking them in green. The analysis in Table 6 pointed out the great importance given to partial assessments analysing the availability of unused shafts and the existing concession for the extraction of minerals from the deposit. In the case of nine of the worst results, the mine had lost its mining license, and in six cases the mine did not have operational shafts. Analysing the highest-rated resources, in eleven cases the mine has at least two active shafts, and in the best five cases it also has a mining license. For the highest-rated resources, a railway siding is still located at or immediately neighbours the mine. The progress of liquidation procedures has meant that for most of the lowest rated assets, the siding and the railway line had already been liquidated. The values of the remaining partial grades are varied, which proves their smaller impact on the final grade.

To confirm the correctness of the adopted resource assessment procedure, the same resource database and documentation were presented to the experts for evaluation. The experts agreed with the method assigning specific resources to the corresponding decision-making cluster. The proposed method is designed to assist the decision-maker at the initial stage of resource selection. However, all of them stipulated that the method could only be an auxiliary tool, so that the final decision, supported by a detailed assessment, was made by the decision-maker.

CONCLUSIONS

The problem of assessing the possibilities of using abandoned coal resources has not, to date, been the subject of detailed scientific research. The project of reactivating unexploited deposits is very complicated and expensive due to the large scope of preparatory work necessary. If such a task was successful in liquidated mines, the profits would probably only slightly exceed the expenditure incurred. Effective decision-making in assessing the feasibility of developing unexploited coal resources may be difficult due to the lack of procedures supporting the management of unexploited resources. The method outlined tries to at least partially fill this gap without exhausting the possibilities of further considering this issue. The proposed Analytic Hierarchy Process Method (aAHP), modified for such a specific application as the assessment of unexploited resources, is a simple support tool for the designer and decision-maker. The new elements introduced in the method and the use of multi-criteria analysis methods make the method easily adaptable to changing conditions in the coal market. The procedure described offers the designer a potential possibility of resource management in current market conditions, but the final decision on further action rests with the decision-maker, to whom the proposed method provides multi-criteria, multi-aspect information about the resources analysed, adapted to changes in market conditions. The decision-maker may, but does not have to, agree with the assessment of the method.

The proposed method for assessing the prospects for the development of unexploited hard coal resources can be used as a reference point for a detailed analysis and multi-criteria estimation of technical possibilities and planned costs. In the case of liquidated mines, the progress of liquidation procedures and the related passage of time make it impossible to develop the remaining part of the deposit. An unsolved problem is the scientific systematization of the impact of time on the possibility of re-development of unexploited resources, and the formation and development of natural hazards in parts of deposits unexploited in the past. In this respect, there is only the unsystematic knowledge of practitioners. There are many fewer restrictions in active mines, which means that the method, after certain modifications, can also be used in mines currently working, which will enable them to increase their resource base.

The method presented in this paper relates to a specific case study: liquidated mines managed by state-owned coal companies. In a different business environment, the method can be used for selecting deposits and mines that should be protected from infrastructural development. The method developed suggests how to carry out the methodical evaluation and valorization of abandoned deposits that should be protected by the state. Protected deposits and mines could even constitute a strategic reserve.

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