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RESEARCH ARTICLE

Evaluation of undeveloped hard coal deposits and estimation of hard coal reserves in the Upper Silesian Coal Basin, Poland

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Abstract

The article presents the results of works concerning evaluation of undeveloped deposits in the Upper Silesian Coal Basin and an estimation of hard coal reserves which can be developed by 2050. Evaluation of hard coal deposits was established on criterions choice and their score determination. On the basis of obtained the final score and after consultations with experts in the field of hard coal mining, there were selected three areas of undeveloped deposits with the amount of about 1.99 Gt (billion metric tons) of anticipated economic resources which can extend the coal reserve base located in the direct vicinity of operating hard coal mines. Additionally, one undeveloped coal deposit with estimated resources amounts to about 1.15 Gt was selected as a potential deposit whose resources could be included in the reserves of operating mines, up to the depth of 1,500 metres. Deposit areas were selected and hard coal reserves were estimated with a view to building new coal mines. For Oświęcim-Polanka deposit, there was built a 3D geological model with estimated the amount of 924 Mt (million metric tons) of anticipated economic resources of coal. An example of a deposit development with ventilation, extraction and transport/haulage underground roadways connecting coal seams with the surface are presented. The designed mine working was placed in the 3D geological deposit model which is a useful tool for designing spatial deposit management.

Keywords: coal resources, coal reserves, 3D geological model, petrel software, Upper Silesian Coal Basin

1. Introduction

Mineral resources are one of basic natural resources, which have direct influence on the economic growth of a country and, in turn, on the standard of life of people living there. That is why information on deposit exploration and its development, documented reserves and the volume of production, is such an important issue. It is estimated that, around the world, there is available over 1 trillion metric tons (1×10^{12}) of marketable coal reserves, whose exploitation may be economically feasible. It means that, at the present production rate, the reserves of coal will last approximately 150 years. In comparison, the world reserves of oil and gas will last respectively about 50 and 52 years, at the present production rate [1].

After many years of works aimed at searching for and surveying mineral deposits around the world, locations, volume and characteristics of most coal deposits are quite well known. The world coal reserves, as of 2018, are estimated to be 1,055 billion metric tons (1.055×10^{12}). The countries with the largest coal reserves are: the USA (24%), Russia (15%), Australia (14%) and China (13%) [2]. Details of coal reserves in given countries are presented in Table 1 and in Fig. 1.

In Poland there is applied a classification of solid mineral resources based on the reporting system developed in 1941 in the USSR and implemented in the middle of the 20th century in Poland as a legal norm in the form of the Geological and Mining Law [3]. According to the classification, resources are

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Table 1. Total proved reserves of coal, as of the end of 2018 [2].

Million tonnes	Anthracite and bituminous	Sub-bituminous and lignite	Total
Canada	4346	2236	6582
Mexico	1160	51	1211
US	220167	30052	250219
Total North America	225673	32339	258012
Brazil	1547	5049	6596
Colombia	4881	–	4881
Venezuela	731	–	731
Other S. & Cent. America	1784	24	1808
Total S. & Cent. America	8943	5073	14016
Bulgaria	192	2174	2366
Czech Republic	110	2547	2657
Germany	3	36100	36103
Greece	–	2876	2876
Hungary	276	2633	2909
Poland	20542	5937	26479
Romania	11	280	291
Serbia	402	7112	7514
Spain	868	319	1187
Turkey	551	10975	11526
Ukraine	32039	2336	34375
United Kingdom	29	–	29
Other Europe	1109	5172	6281
Total Europe	56132	78461	134593
Kazakhstan	25605	–	25605
Russian Federation	69634	90730	160364
Uzbekistan	1375	–	1375
Other CIS	1509	–	1509
Total CIS	98123	90730	188853
South Africa	9893	–	9893
Zimbabwe	502	–	502
Other Africa	2756	66	2822
Middle East	1203	–	1203
Total Middle East & Africa	14354	66	14420
Australia	70927	76508	147435
China	130851	7968	138819
India	96468	4895	101363
Indonesia	26122	10878	37000
Japan	340	10	350
Mongolia	1170	1350	2520
New Zealand	825	6750	7575
Pakistan	207	2857	3064
South Korea	326	–	326
Thailand	–	1063	1063
Vietnam	3116	244	3360
Other Asia Pacific	1326	687	2013
Total Asia Pacific	331678	113210	444888
Total World	734903	319879	1054782
of which: OECD	322234	177484	499718
Non-OECD	412669	142395	555064
European Union	22612	53356	75968

divided, according to the degree of their exploration, into categories D, C2, C1, B and A. Resources in Poland are classified as anticipated economic resources and sub-economic resources, economic resources, non-marketable resources, reserves and losses. The Geological and Mining Law contains guidelines for mineral deposits resources/reserves estimation and reporting, including hard coal, based on the cut off criteria and level of confidence. Essentially, it is an inventory of coal, which is recorded by state authorities, while entrepreneurs (mines), basing on their own criteria of economic feasibility, indicate reserves for future production. The criteria take into consideration geological and mining conditions, economic situation, surface protection aspects etc. In spite of the fact that the Polish classification is different from the ones applied abroad, according to experts, it can be compared with them [4-6].

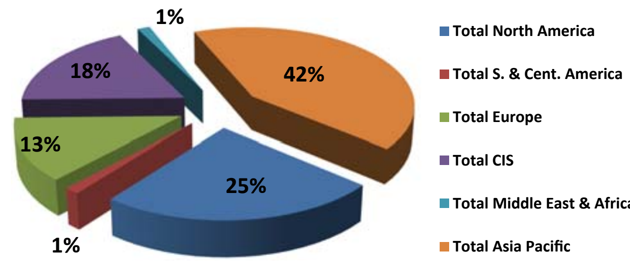


Fig. 1. Distribution of the world's proved reserves of coal in 2018 (based on data from Table 1 [2]).

In international classifications, in particular the JORC (Joint Ore Reserves Committee) Code System [7] which is a recognised international system of reporting minerals as resources and reserves, the emphasis is put on the manner of presenting data on resources/reserves and the degree of their formal and economic accessibility for exploitation. JORC Code System can be applied for all mineral resources, while there are special JORC guidelines for estimating and reporting coal deposits as resources and reserves [8,9]. International classifications, especially the JORC code, pay special attention to the way the data on reserves and their formal availability for exploitation are presented. The documentation of a deposit, following the guidelines of the international classification of resources approved by JORC code, is to provide information to what extent the deposits are explored, their economic feasibility and the progress of their development in given conditions of market economy [10-13].

Under the current market conditions, the classification of mineral resources should provide information for investors about the degree of resource recognition and level of confidence, economic assessment and the possibility of exploitation. In order to achieve this, every effort should be made to develop a Polish code for estimation mineral resources similar to the JORC code, as Russia has done by issuing its own code for the international classification of mineral resources named NAEN Code [14]. Comparison of both classifications and amount of the hard coal resources in Upper Silesian Coal Basin according to polish standards and JORC Code are presented in a synthetic way in other article [15].

The documented anticipated economic resources in hard coal deposits in Poland, as of 31 December 2018, are 61,436 million metric tons (Table 2). Steam coals constitute 69.6% of the resources, coking coals − 29.1%, and other types of coal constitute 1.3% of all the coal resources. The reserves in the developed deposits constitute 36.3% of anticipated economic resources and they are 22,308 million metric tons [16].

Economic resources of coal mines, determined in deposit development projects, were, as of the end of 2018, 3,605.45 million metric tons. At present, subeconomic resources are referred to in conjunction with the validity period of granted mining licences, thus, their actual volume in some deposits may be much greater [16].

Hard coal deposits in Poland occur in three basins. Hard coal production is currently conducted in two of them: the Upper Silesian Coal Basin (USCB) and the Lublin Coal Basin (LCB). Exploitation of five coal deposits in the Lower Silesian Coal Basin (LSCB) ceased approximately 20 years ago.

The Upper Silesian Coal Basin, with 80.3% of documented anticipated economic resources of hard coal, is the main basin of Poland. At present, all but one operating coal mines are located in the USCB (Fig. 2). The area of the Upper Silesian Coal Basin in Poland is estimated to be approximately 5,600 km^2.

The article presents the results of works concerning evaluation of undeveloped deposits in the Upper Silesian Coal Basin and an estimation of hard coal reserves which can be developed by 2050. All the results concerning coal deposits refer to the anticipated economic resources following the classification of solid mineral resources applied in Poland.

Evaluation of hard coal deposits was established on criterions choice and their score determination. There were selected areas of undeveloped deposits, located in direct vicinity of operating mines, which can extend their hard coal reserve base. The anticipated economic resources of selected deposits at the depth of 1,000−1,500 metres were estimated. Moreover, deposit areas were selected and hard coal reserves were estimated with a view to building new coal mines. For selected deposits there were built spatial geological models considering arrangement of coal seams and the structure of the rock mass.

The results of the research presented in this article are important in view of the fact that hard coal has significant role in Polish economy. Knowledge of hard coal reserves and their appraisal can be basis for decision making in supreme authorities of state.

Presented methodology and results of this study may be helpful in studies concerning determination of the areas of deposits that can extend the reserve base of hard coal in active mines, for the selection of prospective areas for development and for the determination of the current reserves of hard coal in the area of USCB.

2. Materials and Methods

Estimations of undeveloped deposits, as objects qualifying for prospective development, are a complex issue. Attempts to estimate deposits are usually based on scoring basic qualities of a deposit or basic aspects associated with its development. The total of all the points scored by given deposits may form the basis for the classification of the analysed deposits [17-19].

The starting point is choosing estimation criteria. In the paper, the applied spatial criterion, which determines if a deposit is accessible or not, is the location of an undeveloped deposit in the vicinity of an operating mine. Another group of criteria includes the volume of coal resources in the deposit, main types of coal in a deposit, together with geological and mining conditions which characterize given deposits. The conditions include possible exploitation hazards such as: coal dust explosion hazard, water hazard, methane hazard, fire hazard, rock burst hazard, gas and rock outburst hazard. The analysed environmental criteria include the degree of urbanisation of the surface, occurrence

Table 2. Hard coal deposits and resources in Poland [16].

Region	Geological resources [million metric tons]		Economic	Number of deposits	
	Anticipated economic	Anticipated sub-economic		Total	Exploited deposits
Upper Silesian Coal Basin	49,351	14,546	3,074	144	42
Lublin Coal Basin	11,662	5,093	531	10	1
Lower Silesian Coal Basin	424	37	–	7	–
Poland	61,436	14,546	3,605	161	43

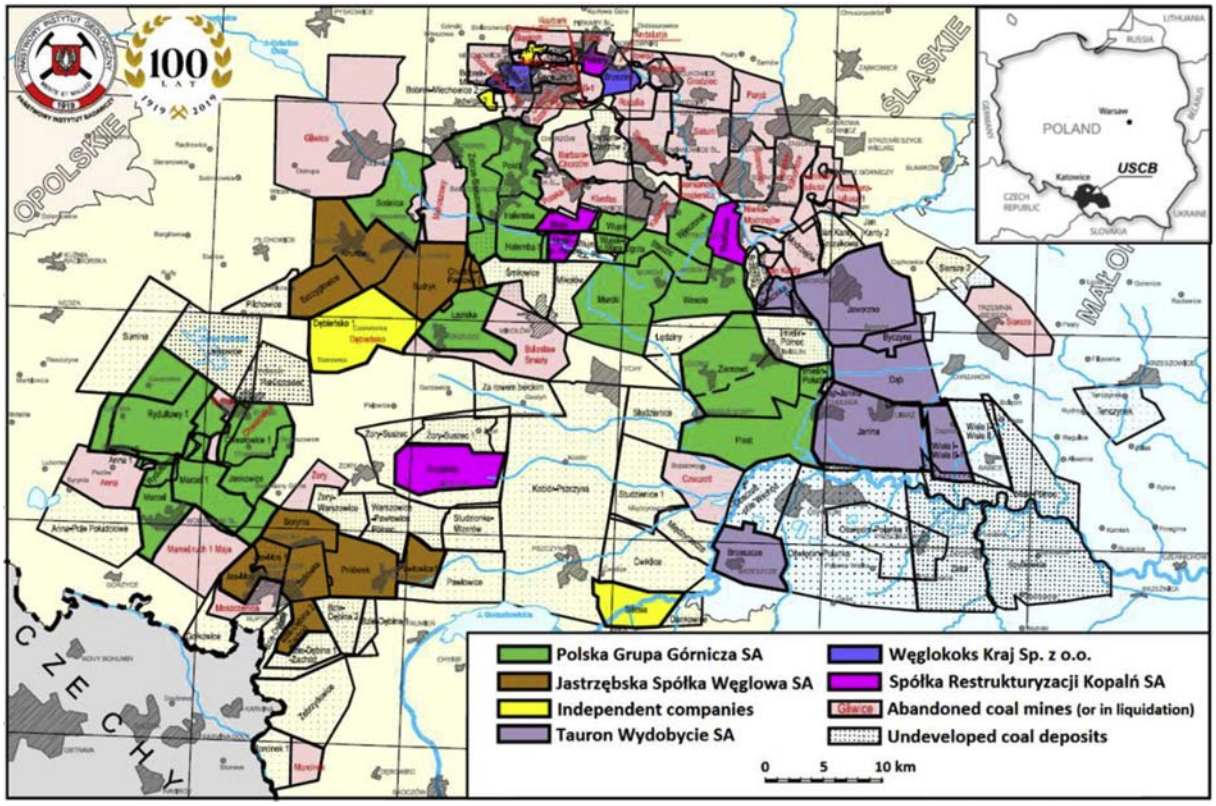


Fig. 2. Map of distribution and development of hard coal deposits of the Upper Silesian Coal Basin as of 31 December 2018 ([16], modified).

of protected objects and other vulnerable elements of the environment, as well as possible environmental hazard associated with mineral extraction and processing. Table 3 presents the assumed estimation criteria together with the point scale attributed to given features of a deposit.

While estimating the undeveloped deposits with a view to the presence of protected objects and other vulnerable elements of the environment, it was analysed whether there are present any components of the environment which are protected by law such as nature reserves, Nature 2000 areas, landscape parks and other forms of environmental protection, as well as forests which cover over 50% of the deposit area (Fig. 3).

Following the assumed methodology, there were selected areas of undeveloped deposits adjacent to operating mines whose reserves they may extend. Applying Petrel Schlumberger software [21], for selected deposits there were built 3D geological models.

Basic input material applied to build a 3D lithological model of the deposit included lithological data from boreholes. The lithofacies from the available core profiles were given numerical codes. Then, such processed data were implemented in the structural model which had been prepared before. The results of well logs, in discrete form, were scaled up.

Statistical algorithm *Most of*, which assigns a given interval to a lithological type which is the most common in the averaging interval, was applied for the lithological data. Accuracy of matching the average data in the model depends mainly on the vertical resolution of the model, i.e. its division into litho-stratigraphic layers. To build a lithological model, *Sequential Indicator Simulation* algorithm, belonging to a group of stochastic algorithms, was applied. Detailed construction of the 3D geological model of Oświęcim-Polanka deposit and possibility of employing it in the project of the deposit development were discussed in our previous work [22].

During the next stage, there was prepared a database of boreholes in the area of deposits of selected operating mines. There were prepared coal-bearing potential maps, and anticipated economic resources in selected deposits at the depth of 1,000–1,500 metres were calculated.

Finally, there was selected a potential deposit area with a view to building a new hard coal mine in the

Table 3. Estimation criteria for undeveloped deposits.

ID	Criterion	Range	Point scale
Spatial criterion determining accessibility of deposit			
P1	Deposit location	Undeveloped deposits, adjacent to mined deposits	1
Geological, resource and mining criteria			
G1	Volume of resources [million metric tons]	0−20	0
		20−40	2
		40−60	4
		60−80	6
		80−100	8
		100−120	10
		120−140	12
		140−160	14
		160−180	16
		180−200	18
		>200	20
G2	Main types of coal in the deposit	Steam coals	0
		Coking and special coals	2
G3	Geological and mining conditions	Very difficult	0
		Difficult	1
Environmental criteria			
S1	Effects of deposit exploitation on the surface	Highly urbanised areas (compact building design)	0
		Areas of medium degree of urbanisation (dispersed development, important transportation infrastructure)	1
		Lowly urbanised areas (farming areas and forests)	2
S2	Protected objects and other vulnerable elements of environment	Nature reserves, Nature 2000 areas, forests covering over 50% of deposit area	0
		No protected objects, no forests covering over 50% of deposit area	2
S3	Possible environmental hazards caused by extraction and processing minerals	No hazards indicated or fewer than three hazards	1
		More than three hazards (including: mass wasting, subsidences, flooding, surface deformations, noise, rock bursts, dust, disturbed water environment in the rock mass, air pollution, water salinity, emission of coal preparation chemicals, ground water pollution)	0

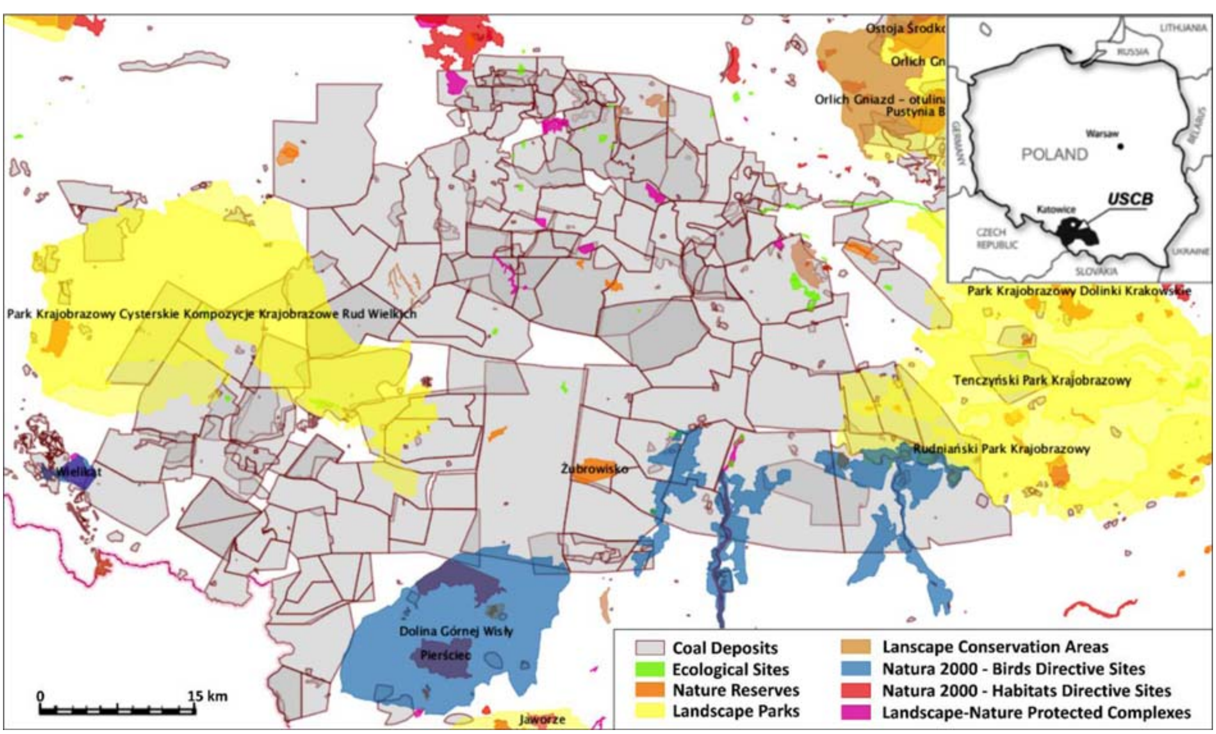


Fig. 3. Forms of nature protection and other vulnerable important elements of the environment [20].

USCB. There was built a 3D geological model of the deposit which included arrangement of coal seams and the structure of the rock mass.

3. Results and Discussion

3.1. Initial classification of undeveloped deposits

During the initial analysis of undeveloped deposits, the ones of anticipated economic resources which fall only into category D of deposit verification (Pilchowice, Studzionka-Mizerów, Sumina) were excluded from the further procedure of deposit estimations. These are undeveloped deposits with prognostic/perspective hard coal resources tentatively recognized in category D with error in estimating the average values of the deposit parameters and amount of resources which may exceed 40% [23].

Moreover, coal deposits with indicated anticipated economic resources lower than 40 million metric tons of coal (Anna-Pole Południowe, Barbara-Chorzów 2, Jan Kanty 2, Libiąż-Janina) were excluded from further analyses as well. Undeveloped deposits with relatively small prognostic/perspective estimated reserves of coal may only be relevant in the case when their highest resourceful parts are directly adjacent to the mined deposits. However, it requires increasing the degree of geological recognition and individual in-depth analysis of coal deposit.

As a result, there were 44 undeveloped deposits left which qualified for further analyses. The anticipated economic resources in given deposits are presented in Table 4.

Table 4. Initial classification of undeveloped deposits [16].

Deposit	Geological resources [thousand tons]	
	anticipated economic resources	sub-economic resources
Brzezinka	44,130	8,515
Brzezinka-2	320,520	48,916
Brzezinka-3	90,760	–
Bzie-Dębina 1	122,236	62,638
Bzie-Dębina 1 - Zachód	404,608	–
Bzie-Dębina 2	347,580	–
Bzie-Dębina 2 - Zachód	322,404	44,906
Czeczott -Wschód	434,914	185,180
Ćwiklice	499,332	94,138
Dankowice	115,684	13,914
Dąb	1,085,873	–
Gołkowice	77,078	154,978
Imielin Północ	766,228	–
Jan Kanty - Szczakowa	146,531	–
Jejkowice	166,245	93,971
Kobiór-Pszczyna	3,063,506	1,888,638
Lędziny	140,586	87,831
Marcel 1	266,054	–
Międzyrzecze	368,683	183,563
Mikołów	198,518	153,961
Modrzejów	46,505	140
Morcinek 1	591,368	60,738
Oświęcim-Polanka	2,142,426	–
Oświęcim-Polanka 1	534,002	–
Paruszowiec	486,337	–
Pawłowice	414,263	85,629
Powstańców Śląskich 1	48,021	–
Rydułtowy 1	1,158,570	–
Siersza 2	202,035	–
Spytkowice	662,614	37,352
Studzienice	327,106	134,290
Studzienice 1	1,335,563	–
Śmiłowice	737,620	–
Tenczynek	64,543	13,621
Warszowice-Pawłowice Płn.	162,961	117,500
Wisła I - Wisła II	822,766	84,432
Wisła Północ	303,969	6,196
Wujek-część południowa	253,428	
Za rowem bełckim	342,502	103,010
Zator	708,645	–
Zebrzydowice	108,439	59,956
Żory-Suszec	888,173	63,964
Żory-Suszec 1	542,623	–
Żory-Warszowice	151,916	93,680

3.2. Estimation of undeveloped deposits

In accordance with the assumed multi-criteria methodology for estimating undeveloped deposits, the scoring scale presented in Table 3 was used to assess the deposits. The selected deposits were analysed with a view to their potential use for future development. The final scores of the deposits are collected in Table 5.

As a result of the analyses of the deposits, considering geological and resource, mining, spatial and environmental aspects; there were selected seven deposits which scored the highest. The deposits and notes concerning their prospective development are presented in Table 6.

In the areas of the undeveloped deposits (Śmiłowice, Imielin Północ and Paruszowiec), it was concluded that it is possible to develop and exploit them. The selected deposits are located in the direct vicinity of operating mines and they can extend their hard coal reserves.

Paruszowiec deposit is considered to be the most promising with a view to possible development,

Table 5. Results of estimation of undeveloped deposits.

Deposit	Criterion ID							Total
	spatial	resource, geological and mining			environmental			
	P1	G1	G2	G3	S1	S2	S3	
Śmiłowice	1	20	2	1	2	2	1	29
Bzie-Dębina 1 - Zachód	1	20	2	0	2	2	1	28
Ćwiklice	1	20	0	1	2	2	1	27
Pawłowice	1	20	2	0	2	0	1	26
Imielin Północ	1	20	0	0	2	2	0	25
Paruszowiec	1	20	0	1	2	1	0	25
Bzie-Dębina 2	1	16	2	1	1	2	1	24
Czeczott-Wschód	1	20	0	1	1	0	1	24
Brzezinka-2	1	16	0	0	1	2	0	20
Studzienice	1	16	0	1	0	2	0	20
Marcel 1	1	12	2	1	2	2	0	20
Wujek-część południowa	1	12	0	1	1	2	1	18
Mikołów	1	8	2	1	1	2	1	16
Bzie-Dębina 1	1	6	2	1	2	2	1	15
Warszowice-Pawłowice Płn.	1	8	2	0	2	2	0	15
Żory-Warszowice	1	6	2	1	2	2	0	14
Centrum 1	1	10	0	0	0	2	0	13
Jan Kanty - Szczakowa	1	6	0	1	1	2	0	11
Lędziny	1	6	0	0	2	2	0	11
Jas-Mos 1	1	4	2	0	1	2	0	10
Brzezinka-3	1	4	0	0	1	2	1	9
Brzezinka	1	2	0	1	0	2	1	7
Dankowice	1	4	0	1	0	0	0	6
Powstańców Śląskich 1	1	2	0	0	0	2	1	6

hence there was built a spatial geological model for the area including the arrangement of coal deposits and the structure of the rock mass (Fig. 4). The software applied to build the static model of Paruszowiec hard coal deposit was Schlumberger Petrel version 2010.1 [21].

The structural model of Paruszowiec deposit was built with the use of data from the documentation and the deposit development project. The model was supplemented with the following structural elements: isolines of floors of given seams, isolines of the roof of the Carboniferous layer, isopach maps, faults, borehole data, and planned seam exploitation.

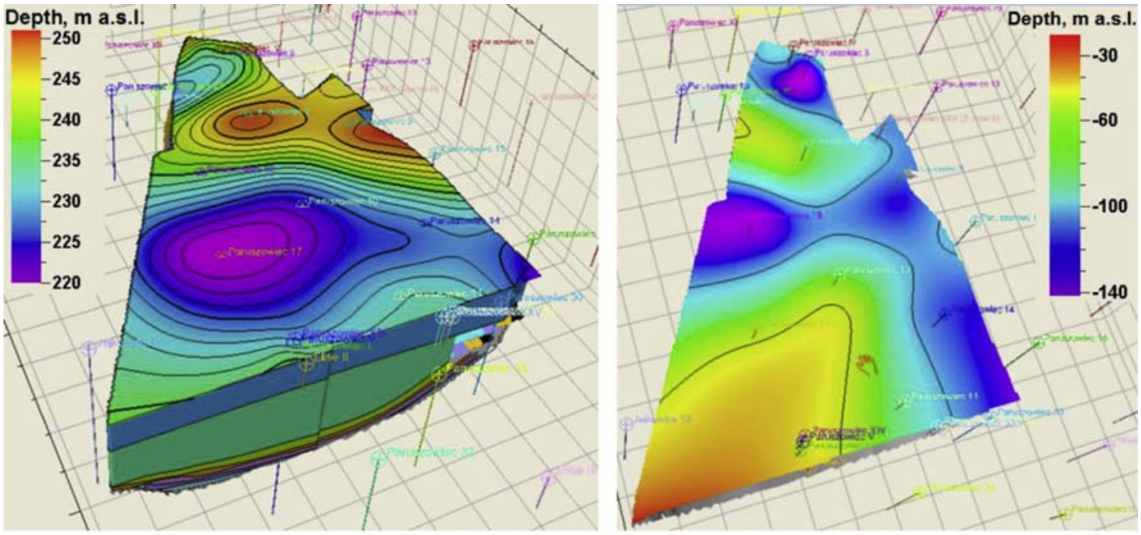
The model presents the arrangement of coal seams together with designed longwalls (Fig. 5). The model includes the following coal seams: 416, 418, 501, 502/3, 502/4, 503, 504 + 505, 506.

3.3. Selection of areas of deposits which can extend reserves of operating mines (up to the depth of 1,500 metres)

Undeveloped deposit Lędziny was selected as a potential deposit whose resources could be included in the reserves of operating mines, up to the depth of 1,500 metres. Lędziny deposit is located within the mining areas of Piast-Ziemowit Ruch Ziemowit coal mine and Mysłowice-Wesoła Ruch Wesoła coal mine. The anticipated economic resources of hard coal in Lędziny deposit documented up to the depth of 1,000 metres, in

Table 6. Final results of valorisation of undeveloped deposits.

Deposit	Total pts	Notes
Śmiłowice	29	Possible development of the deposit
Bzie-Dębina 1 - Zachód	28	Significant thickness of the overburden above the deposit – high costs of deposit development
Ćwiklice	27	The deposit adjacent to private Silesia coal mine
Pawłowice	26	Ongoing development works in Pawłowice 1 deposit (exploitation until approx. 2050)
Imielin Północ	25	Possible development of the deposit
Paruszowiec	25	Possible development of the deposit



(a) (b)

Fig. 4. Model of Paruszowiec deposit: (a) land surface; (b) the top of Carboniferous layer.

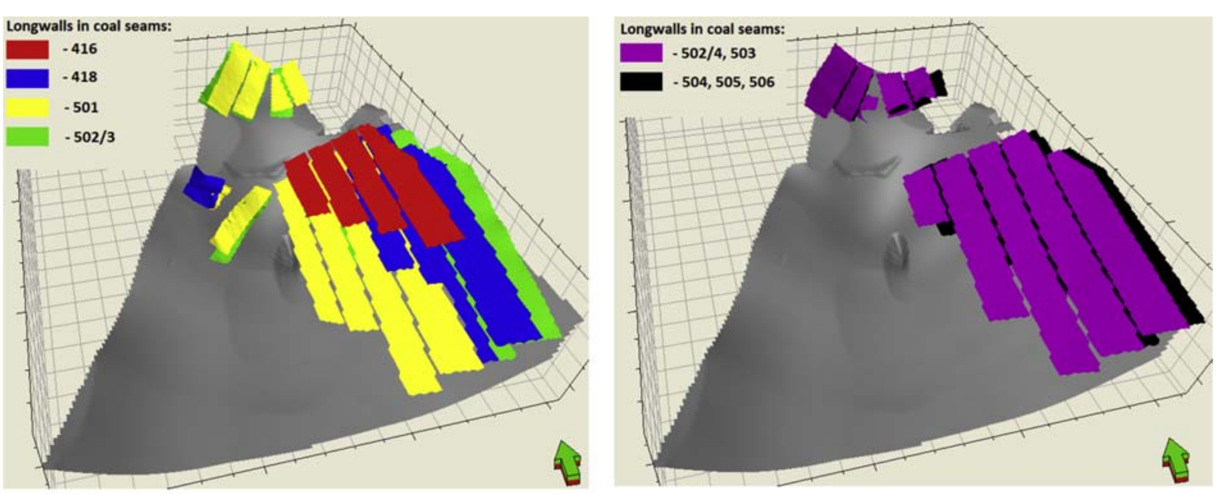
category C1, C2 are 140,586 thousand metric tons [16].

Coal reserves in Lędziny deposit at the depth 1,000-1,500 metres were estimated. The calculations employed a coal-bearing potential method in which the total thickness of over-1-metre-thick coal seams in a deposit, is calculated and then, on the basis, a map of isolines of total coal thickness in the vertical profile of the deposit is drawn, and anticipated economic resources at the depth of 1,000–1,500 metres are estimated.

At the first stage of works within Lędziny deposit, a 3D map (grid) of coal-bearing potential distribution was prepared by processing data collected in the data base. In the area of Lędziny deposit, to visualise it better the isoline, a coal-bearing potential map was interpolated (Fig. 6).

Then, the demanded parameters of the mineral were calculated: the surface area of the deposit, its volume; maximum, minimum and average coal-bearing potential in the area of coal deposit. The data, in text form, were exported to the database for reserve calculations.

The anticipated economic resources of hard coal in Lędziny deposit were calculated basing on the obtained numerical data and assuming averaged



(a) (b)

Fig. 5. Model of Paruszowiec deposit: (a) designed longwalls in seams 504, 505, 506; (b) planned exploitation in seam 502/4, 503.

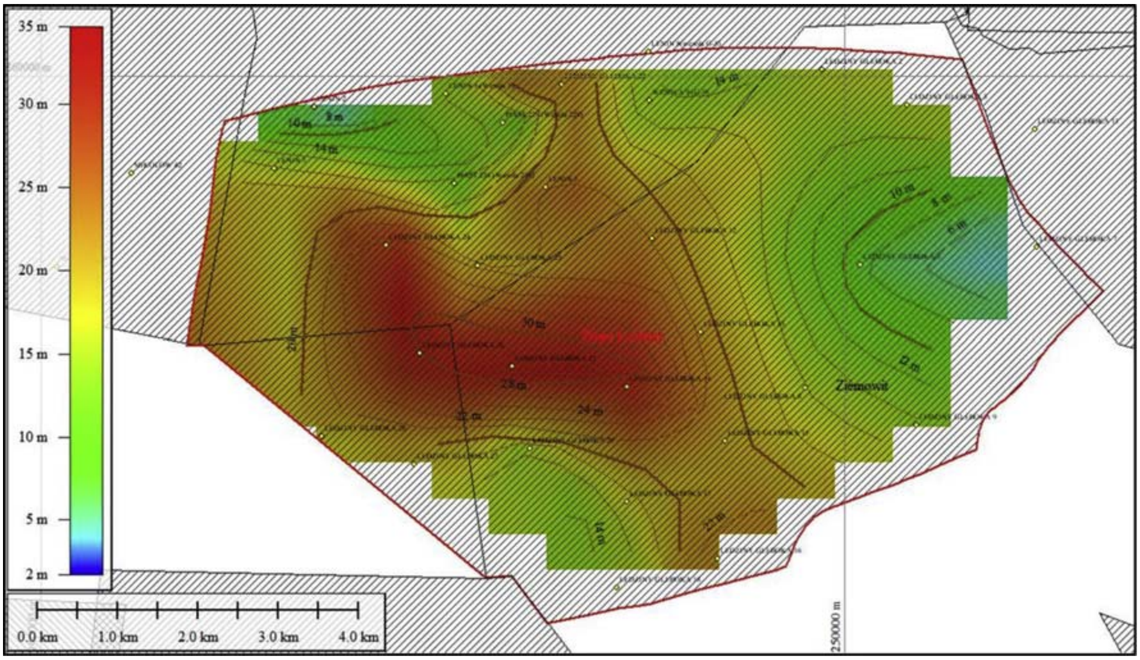


Fig. 6. Isoline coal-bearing potential map of Lędziny deposit.

unit weight of coal. Hard coal reserves were calculated for the depth of 1,000-1,500 metres, without dividing into more detailed reference levels. Finally, the value of anticipated economic resources in Lędziny deposit at the depth of 1,000-1,500 metres (Table 7) was obtained. The coal-bearing potential means the total thickness of over-1-metre-thick coal seams in coal deposit.

The calculated volume of coal reserves can be analysed in detail at further stages of work by (1) dividing into 100-metre-thick exploitation levels, (2) dividing into reserves within mining areas of operating coal mines and in areas kept in reserve or (3) selecting resources deposited within borders of local administrative units.

Table 7. Results of calculations of hard coal reserves in Lędziny deposit (a coal-bearing potential method).

Parameter	Volume	Unit
Surface area of coal deposit	47,668,186	m^2
Minimal coal-bearing potential in the area of coal deposit	4.2	m
Maximal coal-bearing potential in the area of coal deposit	33.4	m
Average coal-bearing potential in the area of coal deposit	~18.5	m
Volume of coal deposit (Surface area* Average coal-bearing potential)	881,956,671	m^3
Specific gravity of coal	1.3	t/m^3
Estimated anticipated economic resources, depth of 1,000 −1,500 metres	1,146,543.7	thousand tons

3.4. Selection of areas of deposits and the volume of deposits with a view to building new mines in the USCB area

Building new coal mines is a very complicated issue. It involves deep analysis of market offer and demand, substitution possibility of hard coal and economic evaluation. Regarding vastness of that issue, it can be considered in detail at situation on market and society, when new mines building will be necessary and admissible.

Moreover, when the areas to build new hard coal mines are selected, environmental and social aspects play a significant role. In many cases, social approval of the planned mineral extraction from a deposit plays a significant role when an investor decides to realize a mining project. One of the tools which enables initial estimation of deposits with a view to a social conflict associated with environmental issues is the mathematical multicriteria method AHP (Analytic Hierarchy Process) [24,25]. Basing on the analysis of 15 deposits, conducted with multicriteria method AHP [26], the area which can be considered to be least vulnerable to a social and environmental conflict, is a fragment of

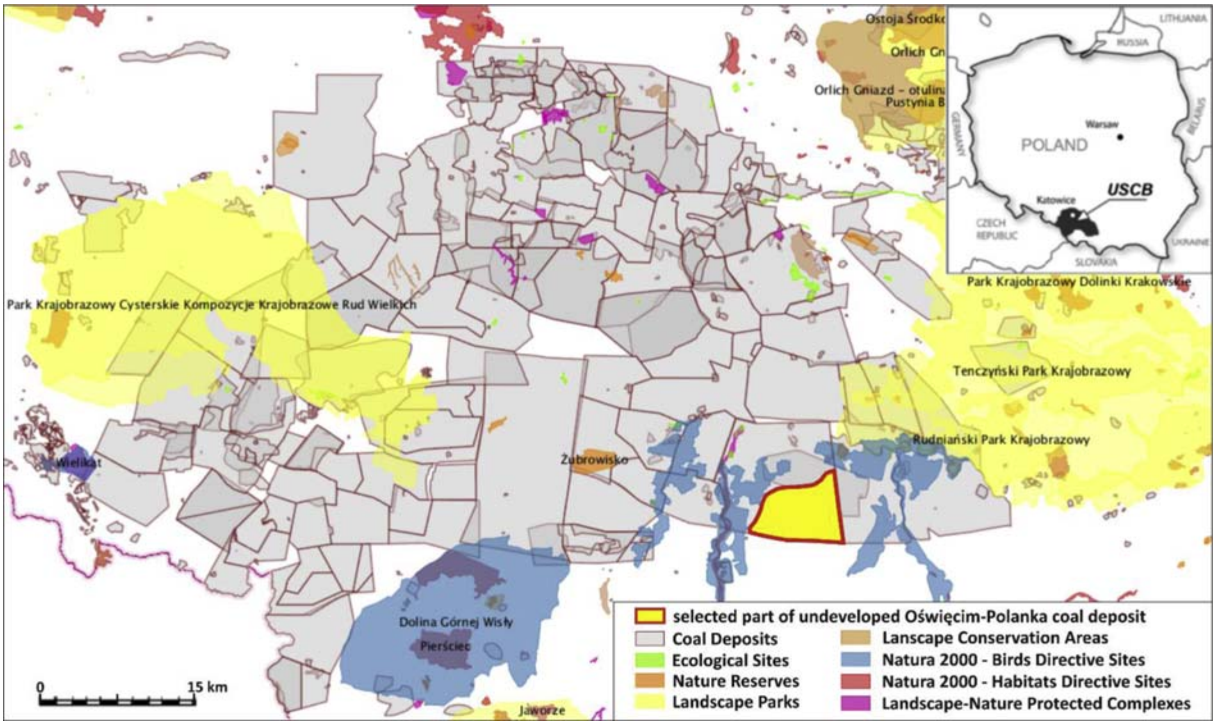


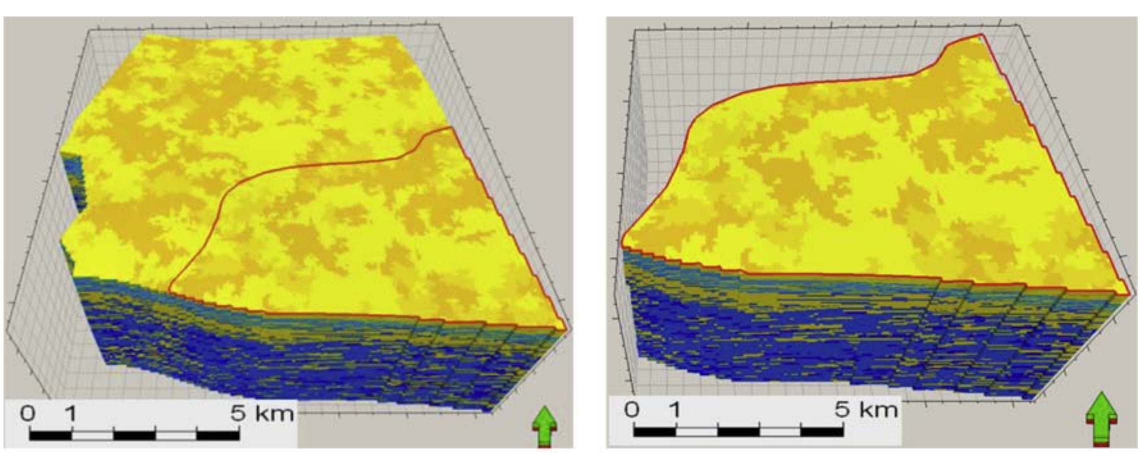
Fig. 7. Location of a part of Oświęcim-Polanka deposit considered [20].

undeveloped Oświęcim-Polanka deposit (Fig. 7). The map below presents clearly that there is no conflict between the selected area and the forms of the environmental protection in the area.

As it has been already mentioned, the area which can be considered to be the least vulnerable to a social and environmental conflict is a fragment of undeveloped Oświęcim-Polanka deposit. However, when the deposit is treated as a whole, it turns out to be an area particularly vulnerable to a social and environmental conflict.

For the needs of the analysis, a part of the deposit of the lowest influence of social and environmental conditions was separated out from earlier developed model (Fig. 8).

One of the ways of developing a deposit is driving underground roadways connecting coal seams with the surface [27,28]. Fig. 9. presents an example of



(a) (b)

Fig. 8. 3D model of Oświęcim-Polanka deposit (a) and the selected part of the deposit which is the least vulnerable to a social and environmental conflict (b).

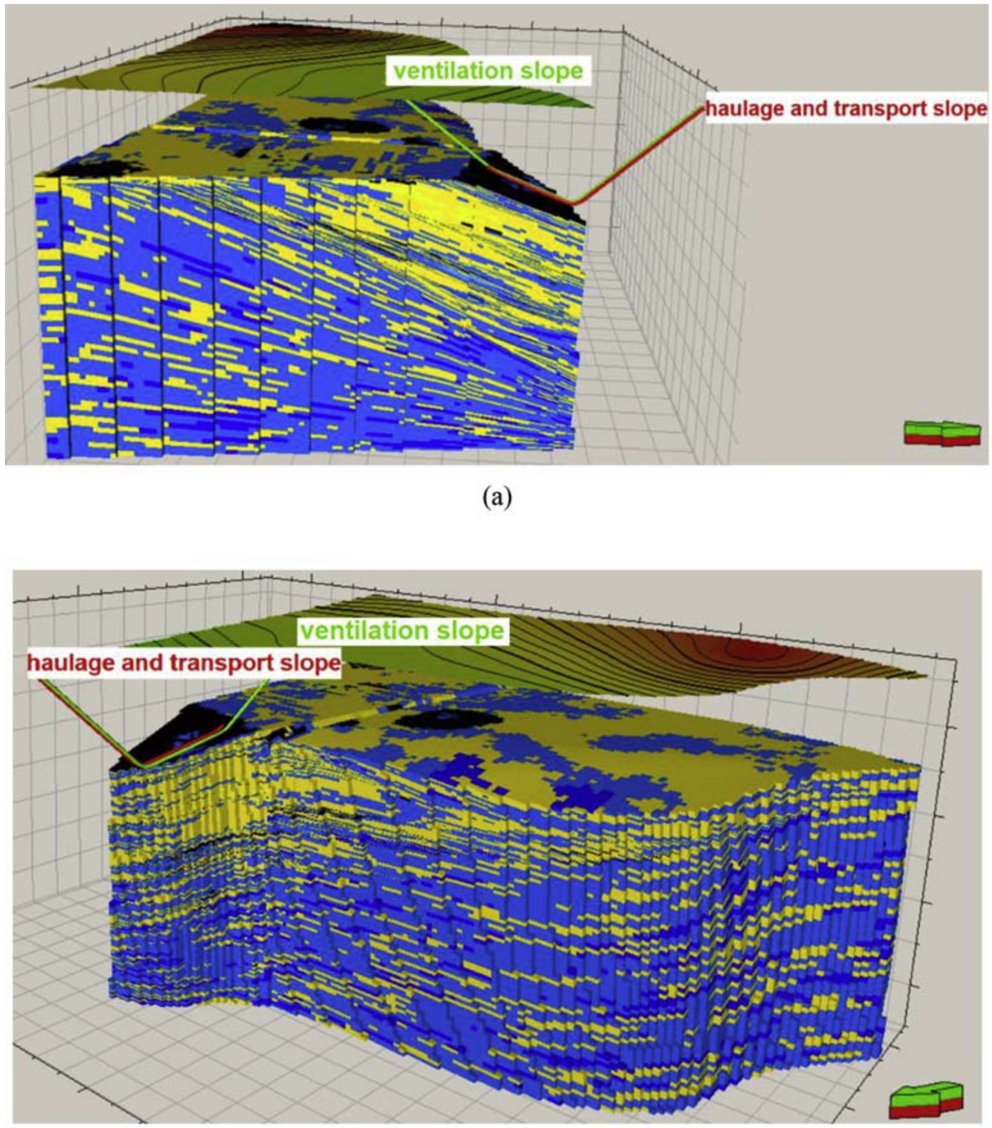


Fig. 9. Model of developing a part of the deposit: (a) E view; (b) N—W view.

a deposit development with three inclines: ventilation, extraction and transport/haulage. The designed mine working was placed in the 3D geological deposit model which is a useful tool for designing spatial deposit management [29-31].

The anticipated economic resources of Oświęcim-Polanka deposit are: 2,142.426 million metric tons [16], while for the part of Oświęcim-Polanka deposit, selected as a potential area for building a new coal mine, the anticipated economic resources of hard coal are 924.391 million metric tons.

4. Conclusions

Estimations of undeveloped deposits, as objects qualifying for prospective development, are a complex issue. Within the framework of this study, evaluation of hard coal deposits was established on criterions choice and their score determination. On the basis of obtained the final score and after consultations with experts in the field of hard coal mining, there were selected the following areas of undeveloped deposits which can extend the coal reserve base located in the direct vicinity of operating hard coal mines: Śmiłowice deposit with the amount of 737.620 Mt (million metric tons) of anticipated economic resources, Imielin Północ deposit with the amount of 766.228 Mt and Paruszowiec deposit — 486.337 Mt. Undeveloped deposit Lędziny was selected as a potential deposit whose resources could be included in the reserves of operating mines, up to the depth of 1,500 metres.

Anticipated economic resources of a selected Lędziny deposit which can extend hard coal reserve base of coal mines at the depth 1,000-1,500 m amounts to 1,146.544 million metric tons.

Additionally, there were determined areas of the deposits and hard coal reserves were estimated with a view to building new mines. For Oświęcim-Polanka deposit, there was built a 3D geological model with estimated the amount of 924.391 Mt (million metric tons) of anticipated economic resources of coal. The developed 3D geological models of selected hard coal deposits can be applied to plan deposit development and its rational management. Three dimensional geological model enables effective interpretation of the geological conditions of coal deposit, which may support the mine designing stage. It can also support planning mining operations and protecting the surface against mining subsidence. 3D geological model of a deposit is a tool of growing significance and it is more and more commonly used in rational deposit management.

Conflicts of interest

None declared.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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