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ECONOMIC EVALUATION OF COALBED METHANE EXPLOITATION; AN EXAMPLE FROM POLAND

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A b s t r a c t . The paper presents the methodology of economic evaluation of coalbed methane exploitation in coal mines. The methodology consists of seven phases, which analyse: gassy conditions of coal deposit, coal exploitation scope, ventilation conditions of underground workings, productivity of degasification system as well as economics of both coal exploitation and methane recovery. In the result of the analyses classification, of methane resources and their subdivision into economic reserves and potentially economic resources can be done on the ground of either economic findings or methane content figures. The analyses also show, that methane extraction is always economic, but it can be proved only, if profit resulted coal exploitation during degasification is taken into account.

K e y w o r d s : coalbed methane, reserves estimation, recovery economics.

INTRODUCTION

Typical process of mineral resource evaluation is similar worldwide and consists of three stages (United Nations..., 1997, Practical application..., 1999). These stages are: geological study, technical evaluation, and economic valorisation. Only the first two stages were commonly used in Poland during communist period, and even during the following few years. So, the most of evaluations were not adequate to free market conditions. Such situation was also observed with reference to coalbed methane economic potential assessments. To improve the situation, free-market rules have been adapted for estimating economics of methane extraction from coal mines and for classification of its resources. Methodology of the adaptation is presented in the paper based on real evaluations previously made by the authors for two coal mines, called here Mine A and Mine B.

PHASES OF ESTIMATING ECONOMICS OF METHANE EXPLOITATION AND CLASSIFICATION OF ITS RESOURCES

The adaptation of free-market rules for estimation of economics of methane extraction was realised in typical Polish document, called “project of deposit development” (PDD). According to geological and mining regulations (Rozporządzenie MOŚZNiL..., 1994), such a project should classify resources of methane into economic reserves and potentially economic resources, depending on the results of analyses of both technological possibility and economic viability of methane extraction, as well as on the findings of analyses of another factors influencing the extraction (legal conditions, environmental protection etc.). So, the classification made in PDD should consist of a few phases to fit both the regulations and free-market rules. The phases are as follows:

Technical analyses:

1) analysis of gassy conditions of deposit;

2) analysis of projected scope of coal exploitation;

3) analysis of ventilation conditions of planned longwall panels;

4) analysis of productivity of mine degasification system.

Economic analyses:

5) analysis of coal exploitation costs;

6) analysis of costs of and receipts from degasification.

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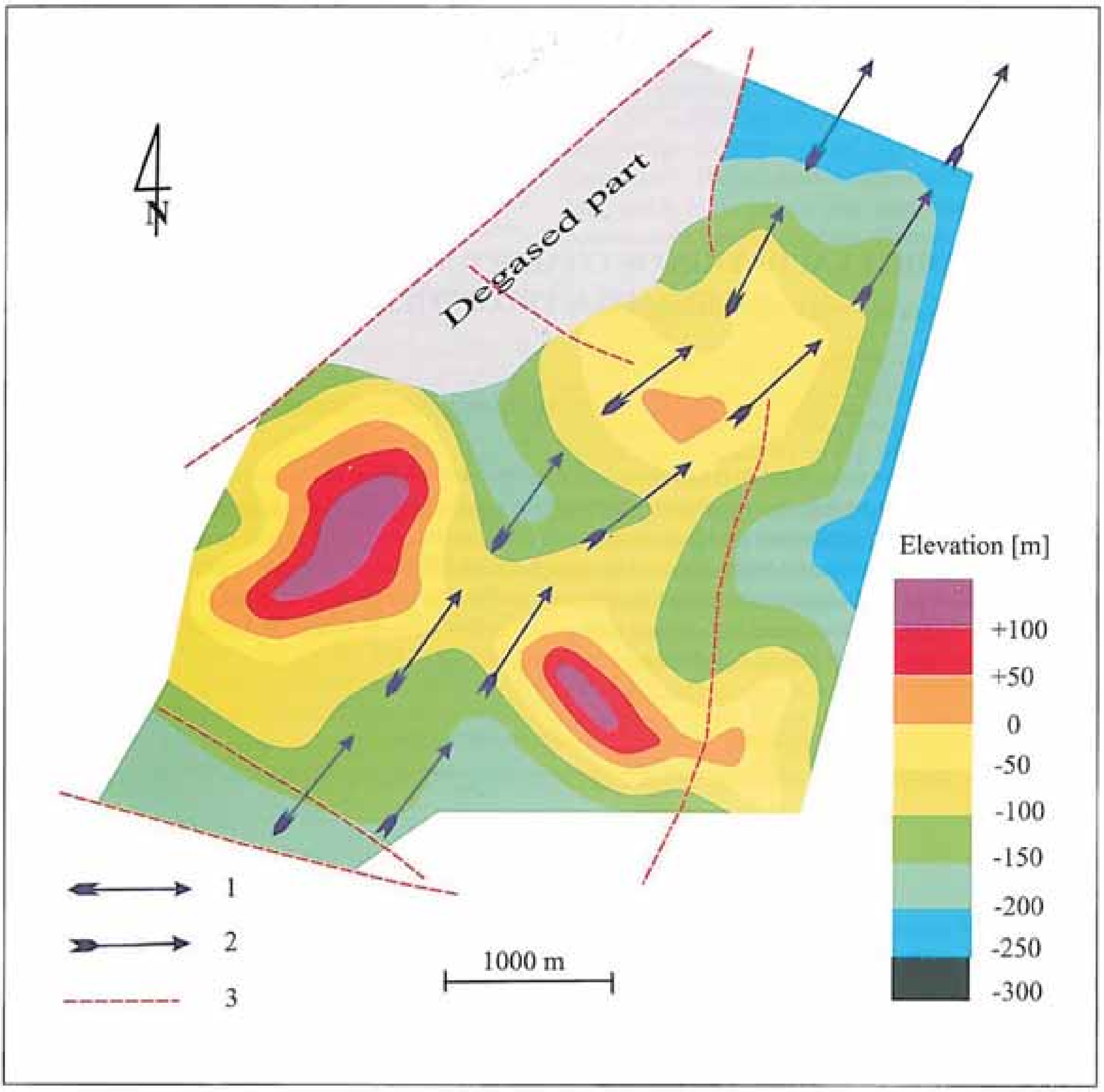

Fig. 1. An example of top surface map of the high methane content zone (G >4.5 m^3/Mg C^{daf}) in Mine A

1, *2* — course and direction of dip of main synclines (1) and anticlines (2), *3* — thrusts

Other analyses:

7) assessment of economic reserves.

Methodology of analysis of each phase is shortly described below.

Methodology of technical analyses

The first phase of classification, i.e. analysis of gassy conditions of deposit lies in finding the coal seams methane content which is high enough to degas coal obligatorily or to take degasification into account. This is made in terms of average as well as maximum methane content, because degasification of coal is possible if average methane content exceeds value of residual methane content (Grzybek, 1999). There is a duty in Poland to degas those parts of coal seams where maximum methane content is higher than 8 cubic meters per tonne of dry and ash free coal (m^3/Mg C^{daf}; Rozporządzenie MPiH..., 1995). It is important to notice here, that degasification is frequently taken into account, if the maximum methane content exceeds 4.5 m^3/Mg C^{daf}.

So, in practice the first phase consists, in bordering zones, of maximum methane content greater than 4.5 m^3/Mg C^{daf} and 8.0 m^3/Mg C^{daf}, as well as of finding values of residual methane content and calculating average methane contents at different depth levels of particular parts of coal mine. Methodology of those works was presented in details by Grzybek (1997), therefor, here only exemplary results of the works done for Mine A and Mine B are shown on Figure 1 and Table 1, respectively.

The second phase of classification, i.e. analysis of projected scope of coal exploitation, consists, of comparing position of planned longwall panels with findings of the first phase of classification. To make that comparison, each planned longwall panel is attributed to one of depth levels previously used

Table 1

An example of specification of maximum (G_{max}) and average (x) values of methane content for particular parts and depth levels of Mine B

Depth level [m]	Part of deposit													
	A		B		C		D		E		F		G	
	Methane content [m^3/Mg C^{daf}]													
	G_{max}	x	G_{max}	x	G_{max}	x	G_{max}	x	G_{max}	x	G_{max}	x	G_{max}	x
588	2.33	0.733	8.43	0.338	5.82	1.514	4.51	1.224	2.61	1.013	5.59	2.069	2.02	0.531
713	4.37	1.224	3.74	0.201	5.03	0.427	3.12	0.979	2.48	0.516	9.30	1.527	4.35	1.186
838	7.83	2.688	5.04	1.334	4.58	0.716	3.75	1.410	3.60	1.529	6.83	2.317	5.36	2.122
950	4.45	2.740	4.95	2.077	4.35	2.031	3.86	2.660	—	—	11.15	7.139	3.91	3.457
1034	—	—	—	—	—	—	—	—	—	—	9.99	8.546	5.66	2.807

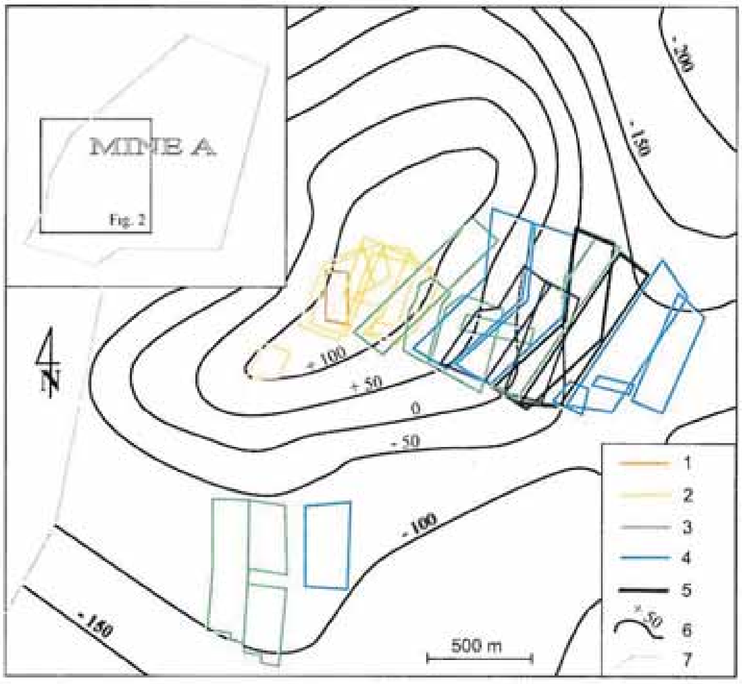

Fig. 2. An example of longwall panels attribution to chosen depth levels of single part of Mine A

1–5 — areas of planned coal exploitation; colours mark depth levels, acc. to elevation colour scale on Fig. 1; *6* — contour line of high methane content zone; *7* — boundary of mine

for calculations of average methane content (Fig. 2). Next it is tested if the panels occur in the space where both average and maximum methane content are greater than the residual methane content, and 4.5 m^3/Mg C^{daf}, respectively. In the result of testing none but these longwall panels, which occur at the depth levels of appropriate methane contents (i.e. "greater than ..."), are selected for further analyses.

An analysis of ventilation conditions of selected longwall panels makes **the third phase of classification**. The analysis is grounded on legal resolution, that for miners safety the maximum emission to longwall gangways cannot be higher than 10 m^3/min. If inflow of methane is higer than that value, either degasification of coal should be used or concentration of methane in ventilation air should be reduced by either gangways doubling or decreasing of coal output (Rozporządzenie MPiH..., 1995). So, during the analysis, emission for planned level of coal output is calculated in the first place for each longwall. Calculations are made in the way described in adequate instruction (Wytyczne..., 1978).

On the base of results of those calculations and in the same manner, for each longwall panel characterized by emission higher than 10 m^3/min, there is evaluated "permissible" coal output for which the emission is equal or very close to this limit. Exemplary results of such evaluation made for Mine B and summed for particular coal seams are shown on Table 2. The table shows also calculated differences between planned and

Table 2

Specification of differences in emission and coal output of longwall panels between exploitation with versus without use of degasification; an example from Mine B

Part of deposit*	Number of coal seam*	Planned coal output [t/d]	Emission for planned coal output [m^3/min]	"Permissible" coal output [t/d]	Emission for permissible coal output [m^3/min]	Difference in coal production [t/d]	Planned period of exploitation [month]	Difference in coal production during exploitation [t]
A	361/1	1800	10.83	1600	9.96	200	12	50,400
	362/3	1800	11.33	1400	9.74	400	12	100,800
	363/1	2000	11.93	1500	9.76	500	11	115,500
	403/2	2200	12.30	1600	9.90	600	9	113,400
	406/3	2400	12.38	1700	9.65	700	24	352,800
	407/1-2	2600	11.61	2100	9.88	500	9	94,500
B	407/1-2	4500	15.22	2600	9.98	1900	12	478,800
D	362/2-3	3000	10.18	2900	9.96	100	12	25,200
	404/1	3000	10.42	2800	9.87	200	29	121,800
F	403/1	2200	12.54	1500	9.76	700	16	411,600
	404/1	3200	13.20	2200	9.71	1000	6	126,000
	405/1 (west)	4000	10.62	3700	9.96	300	13	81,900
	405/1 (east)	4000	13.89	2800	9.87	1200	23	579,600

* these parts and coal seams only, where coal exploitation is planned

permissible coal output. Because use of coal degasification decreases emission measured in gangways and thus makes possible to realize coal output planned, the differences should be considered as a profit from degasification.

The fourth phase of classification is constituted by analysis of degasification system productivity. The analysis consists of estimating efficiency of methane capturing by degasification system and of methane volume possible to capture.

In Polish coal mines mostly a cross-measured holes technique is utilized for coal formation degasification. Its efficiency depends on a lot of factors and probably has never been investigated. Therefore, estimation of it is grounded on personal communications with personnel of the most gassy mines. According to findings of the communications, quotients of captured to liberated volumes of methane observed within particular longwall panels oscillate between 50 and 57%. So, the average quotient can be assumed as equal to 53.5% (comp. to 40–45% reported by Mills and Stevenson, 1991 — see: Pilcher *et al.*, 1991).

To calculate methane volume possible to capture, the total volume liberated to gangways of longwall panel should be assessed first. For this purpose, there is usually used Stufken's model, which shows percentage of methane liberation from coal as a function of vertical distance between coal seams exploited and influenced by the exploitation (Fig. 3). However, other models can be utilized, too. Assuming that coals are regularly distributed in the space from 120 m above to 60 m below exploited seam, it can be found, according to Stuffken's model, that out of total methane reserves, contained in coals influenced by exploitation of single seam (dashed line on Fig. 3), only 51 per cent can be liberated (line 3 on Fig. 3). A product of this value and the quotient 53.5% makes 27 per cent. Therefore,

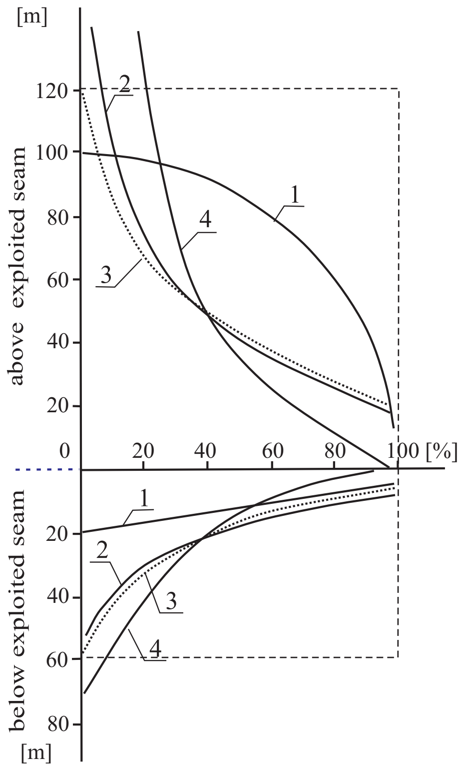

Fig. 3. The graph showing different models of percentage of methane liberation from coal (horizontal axis; %) as a function of vertical distance (vertical axis; m) between coal exploited (positioned at 0 m) and influenced by the exploitation (any other distance)

1–4 — the models from P. Schultze (1), K. Winter (2), J. Stuffken (3) and K. Patteisky (4); dashed line represents all methane above and below coal seam exploited (after Kozłowski and Grębski, 1982)

Table 3

Evaluation of total methane reserves in coals influenced by exploitation of single coal seam; an example from Mine B

Number of coal seam	Distance to seam exploited [m]	Thicknees of coal seam [m]	Average methane content [m^3/Mg C^{daf}]	Degasification coefficient of previous exploitation	Coefficient for pure coal substance calculation	Methane reserves [m^3]
357/1	116.2	1.3	1.22	0.15	0.826	164.34
NA	112.3	0.4	1.22	0.10	0.826	54.20
358/1	105.4	1.4	1.22	0.05	0.826	198.11
358/2	93.6	0.6	1.22	0.00	0.826	0.00
358/3	90.7	1.7	1.22	0.00	0.826	0.00
359/1	74.7	1.8	1.22	0.00	0.826	0.00
359/2	62.4	1.6	1.22	0.00	0.826	0.00
359/3	51.5	1.7	1.22	0.25	0.826	16,728.50
360/1	17.7	2.5	1.22	0.00	0.826	0.00
361/1	0.0	1.9	2.69	0.50	0.826	362,304.82
361/2	–9.7	0.8	2.69	0.70	0.826	161,470.67
361/3	–20.4	1.0	2.69	0.85	0.826	136,244.99
362/1	–32.0	1.0	2.69	0.95	0.826	88,438.61
362/2	–33.4	0.8	2.69	0.95	0.826	55,264.72
362/3	–46.4	2.0	2.69	1.00	0.826	66,246.10
NA	–57.8	0.4	2.69	1.00	0.826	3,232.22
Total reserves of methane [m^3]						900,347.39

NA — not applicable

only 27 per cent can be captured from the above total methane reserves. An example of assessment of total reserves contained in coals influenced by exploitation of single coal seam of Mine B is given in Table 3, while a specification of total and possible to capture reserves within all coal seams of this mine in Table 4.

Table 4

Total and possible to capture reserves of methane calculated for all coal seams planned for exploitation in Mine B

Part of deposit	Depth level [m]	Number of coal seam	Methane reserves [m^3] Total	Methane reserves [m^3] Possible to capture
A	838	361/1	900,347.39	243,093.80
		362/3	3,293,330.63	889,199.27
		363/1	1,517,276.57	409,664.67
	950	403/2	2,414,286.53	651,857.36
		406/3	3,075,294.16	830,329.42
		407/1-2	2,540,793.98	686,014.37
B	1034	407/1-2	16,122,837.08	4,353,166.01
D	838	362/2-3, 404/1	8,289,671.00	8,289,671.00
F	950	403/1	8,372,099.94	2,260,466.98
		404/1	8,659,948.03	2,338,185.97
		405/1 (west)	12,486,724.02	3,371,415.49
	1034	405/1 (east)	3,907,568.97	1,055,043.62
Total			71,580,178.30	25,378,107.97

Methodology of economic analyses

The fifth phase of classification is created by analysis of coal exploitation costs. The analysis is carried out from the cash flow point of view and comprises expected permanent costs planned by PDD for coal deposit. The permanent costs of Mine B are shown against a background of expected prices of coal sale (Tab. 5). Because permanent costs are not dependent on tonnage of coal production, it should be taken into account that with no degasification, the average permanent cost per tonne of decreased (the permissible) coal output is higher than per tonne of scheduled coal output. In other words, use of degasification decreases the permanent unit cost of coal production and in this way makes possible to have bigger profit from each tonne of sold coal. So, the difference between permanent unit costs of permissible and scheduled coal output should be considered as a profit from degasification. To calculate receipts from the

Table 5

Planned costs of coal production and expected prices of coal sale for years 1999–2010; an example from Mine B

Year	Coal output planned [1x10^3 t/year]	Price [PLN/t]	Total costs		Permanent costs			Difference in permanent cost [PLN/t]
			[1x10^3 PLN]	[PLN/t]	[1x10^3 PLN]	for coal output planned [PLN/t]	for “permissible” coal output [PLN/t]	
1999	2,824.5	137.58	392,718.5	139.04	333,799.4	118.18	121.43	3.25
2000	2,761.0	147.91	376,876.5	136.50	320,358.8	116.03	117.73	1.70
2001	2,761.0	149.72	377,345.9	136.67	320,745.4	116.17	120.86	4.69
2002	2,635.5	150.37	356,583.1	135.30	303,108.9	115.01	128.41	13.40
2003	2,635.5	150.37	363,330.0	137.86	308,827.9	117.18	124.21	7.03
2004	2,635.5	150.37	367,230.6	139.34	312,148.6	118.44	122.34	3.90
2005	2,510.0	150.37	357,775.4	142.54	304,111.6	121.16	121.16	0.00
2006	2,510.0	150.37	356,972.2	142.22	303,433.9	120.89	132.90	12.01
2007	2,510.,0	150.37	355,165.0	141.50	301,902.8	120.28	128.10	7.82
2008	2,510.0	150.37	355,165.0	141.50	301,902.8	120.28	131.02	10.74
2009	2,510.0	150.37	355,165.0	141.50	301,902.8	120.28	157.42	37.14
2010	2,510.0	150.37	355,165.0	141.50	301,902.8	120.28	170.89	50.61

PLN — Polish zloty

Table 6

Differences between planned and permissible coal output shown for particular years of 1999–2010 period; an example from Mine B

Part of deposit*	Coal seam*	Differences in the year [1x10^3 t]												
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
A	361/1	50.4												50.4
	362/3			33.6	67.2									100.8
	363/1					31.5	84.0							115.5
	403/2											113.4		113.4
	406/3				117.6	117.6					29.4	88.2		352.8
	407/1-2											31.5	63.0	94.5
B	407/1-2												478.8	478.8
D	362/2-3		18.9	6.3										25.2
	404/1	25.2	21.0	42.0	33.6									121.8
F	403/1									102.9	176.4	132.3		411.6
	404/1												126.0	126.0
	405/1 (west)			25.2	56.7									81.9
	405/1 (east)								226.8	50.4		226.8	75.6	579.6
Total		75.6	39.9	107.1	275.1	149.1	84.0		226.8	153.3	205.8	592.2	743.4	2,652.3

* these parts and coal seams only, where coal exploitation is planned

profit analysed for each year permissible coal output should be multiplied by the above difference.

Supplementary to this phase, differences between planned and permissible coal output shown on Table 2 should be recalculated for each year of production (Tab. 6), and next multiplied by scheduled price of coal sale, to evaluate receipt from additional (above the permissible) coal production.

The sixth phase of classification consists of analysis of degasification costs and receipts. To assess the costs of degasification, a scheme of degasification system (Fig. 4) should be

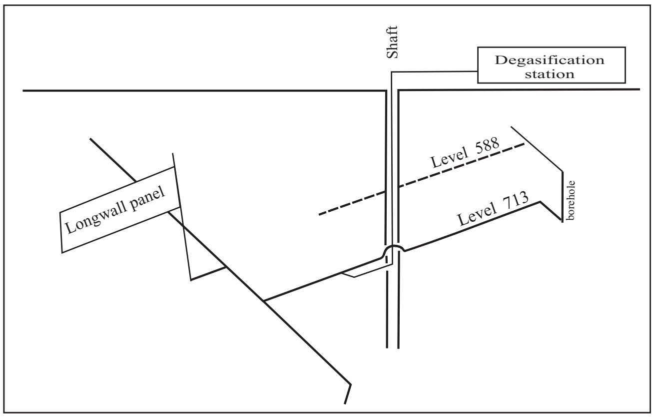

Fig. 4. A scheme of in mine degasification system

Table 7

Average parameters for calculations of degasification costs; an example from Mine B

Part of deposit	Number of coal seam	Length of gangways in longwall panels [m]	Planned length of boreholes [m]	Pipelines installation and dismantling [m]
A	361/1	700	2,838	1,400
	362/3	850	3,612	1,700
	363/1	800	3,354	1,600
	403/2	750	3,096	1,500
	406/3	1,720	7,224	3,440
	407/1-2	1,780	7,482	3,560
B	407/1-2	3,400	14,448	6,800
D	362/2-3	870	3,612	1,740
	404/1	2,800	11,868	5,600
F	403/1	1,900	7,998	3,800
	404/1	1,910	7,998	3,820
	405/1 (west)	2,580	11,094	5,160
	405/1 (east)	980	4,128	1,960

Table 8

Unit costs and receipts from coal seams degasification for 1998

Specification	Unit of measure	Unit cost/receipts [PLN]
Drainage borehole drilling	m	113.56
Pipeline installation or dismantling	m	64.70
Operational cost of degasification	year	602,000
Average price of methane sale	$1x10^3$ m^3	118.96

PLN — Polish zloty

verified first, to find need for such investments as installation and dismantling underground pipelines and drilling drainage boreholes. During verification it is usually assumed that:

— pipelines length is equal to the length of gangways, but should be doubled to take into account as well installation as dismantling;

— per each 60 m of gangway, three drainage boreholes are drilled;

— average depth of single borehole is equal to 86 m.

An example of such findings from Mine B is shown in Table 7. Next, the findings should be multiplied by adequate investment and operational costs (Tab. 8) to evaluate total costs of degasification for each year of planned methane production.

In the same way, receipts from methane sale should also be calculated, taking into account 100 per cent of methane reserves possible to capture and price of methane sale. Then all costs and receipts calculated during fifth and sixth phases of classification can be compared for each year of methane production to assess final profit from degasification of coal deposit. The results of profit assessment made for Mine B are presented in Table 9 in terms of current value of money. For final analysis they have to be recalculated into discounted values, of course.

Assessment of economic reserves

The last, **seventh phase of classification** is constituted by establishment of economic reserves of methane as well as classification of its resources into economic reserves and potentially economic resources. Establishment of economic reserves is simple because on the ground of analyses previously presented these reserves of methane are obviously economic, as possible to capture.

Classification of resources is somewhat less possible because there is a need to find potentially economic resources

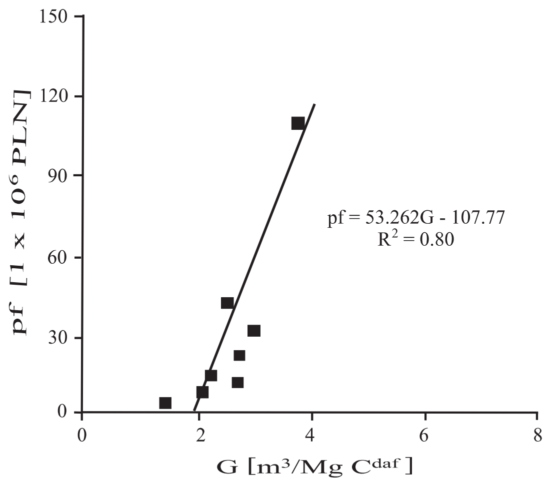

Fig. 5. Profit (pf, $1x10^6$ PLN) dependence on average value of methane content (G, m^3/Mg C^{daf}) of coal exploited; an example from Mine B

R — correlation coefficient

Table 9

Calculations of profit from coal seams degasification; an example from Mine B

Year	No. of coal seam	Methane production [1x10^3 m^3]	Costs of: [1x10^3 PLN]				Receipts from: [1x10^3 PLN]				Profit [1x10^3 PLN]
			drainage boreholes	pipelines	operational costs	total	sale of methane	sale of additional coal	difference in permanent costs	total	
1999	361/1	243.1	396.6	88.8			28.9	6,934.0			
	404/1	846.4	343.1	73.5			100.7	3,467.0			
	Total	1,089.5	739.7	162.3	602.0	1,504.0	129.6	10,401.0	8,933.9	19,464.5	17,960.5
2000	362/2-3	1,995.5	378.5	82.8			237.4	2,795.5			
	404/1	539.1	285.9	61.3			64.1	3,106.1			
	Total	2,534.6	664.4	144.1	602.0	1,410.5	301.5	5,901.6	4,625.9	10,829.0	9,418.5
2001	362/3	296.4	168.2	35.9			35.3	5,030.6			
	362/2-3	665.2	126.2	27.6			79.1	943.2			
	404/1	2,475.4	571.8	122.5			294.5	6,288.2			
	405/1	1,037.4	477.0	100.7			123.4	3,772.9			
	Total	4,474.4	1,343.2	286.7	602.0	2,231.9	532.3	16,034.9	12,446.8	29,014.0	26,782.1
2002	362/3	592.8	336.5	71.9			70.5	10,104.9			
	406/3	276.8	336.5	72.7			32.9	17,683.5			
	404/1	1,768.1	457.5	98.0			210.3	5,052.4			
	405/1	2,334.0	1,073.2	226.6			277.7	8,526.0			
	Total	4,971.7	2,203.7	469.2	602.0	3,274.9	591.4	41,366.8	31,629.4	73,587.6	70,312.7
2003	363/1	111.7	127.8	27.7			13.3	4,736.7			
	406/3	276.8	336.5	72.7			32.9	17,683.5			
	Total	388.5	464.3	100.4	602.0	1,166.7	46.2	22,420.2	17,479.4	39,945.8	38,779.1
2004	363/1	298.0	340.8	101.5	602.0	1,044.3	35.4	12,631.1	9,950.8	22,617.3	21,573.0
2005	–	–	–	–	602.0	602.0	–	–	–	–	–602.0
2006	405/1	412.8	225.7	48.7	602.0	876.4	49.1	34,103.9	27,421.2	61,574.2	60,697.8
2007	403/1	565.1	279.4	60.3			67.2	15,473.1			
	405/1	91.8	50.2	10.8			10.9	7,578.6			
	Total	656.9	329.6	71.1	602.0	1,002.7	78.1	23,051.7	18,429.4	41,559.2	40,556.5
2008	406/3	69.2	84.1	18.2			8.2	4,420.9			
	403/1	968.8	479.0	103.3			115.2	26,525.3			
	Total	1,038.0	563.1	121.5	602.0	1,286.6	123.4	30,946.2	24,747.1	55,816.7	54,530.1
2009	403/2	651.9	432.6	95.2			77.6	17,052.0			
	406/3	207.5	252.3	54.6			24.7	13,262.6			
	407/1-2	228.7	348.5	75.3			27.2	4,736.7			
	403/1	726.6	359.2	77.5			86.4	19,894.0			
	405/1	412.8	225.7	48.7			49.1	34,103.9			
	Total	2,227.5	1,618.3	351.3	602.0	2,571.6	265.0	89,049.2	71,227.1	160,541.3	157,969.7
2010	407/1-2	457.3	697.0	150.6			54.4	9,473.3			
	407/1-2	4,353.2	2,018.8	431.4			517.9	71,997.2			
	404/1	2,338.2	1,117.6	242.3			278.2	18,946.6			
	405/1	137.6	75.2	16.2			16.4	11,368.0			
	Total	7,286.3	3,908.6	840.5	602.0	5,351.1	866.9	111,785.1	89,407.6	202,059.6	196,708.5

PLN — Polish zloty

not only for analysed period of time but also for the further future. So, it has been stated, that for this purpose there should be found such value of average methane content of coal seams, planned to exploitation during the analysed period of time, for which evaluated profit from the seams degasification is equal to zero. Then, the value can be compared to average methane contents of coal seams located at those depth levels and in those parts of mine which are considered to be exploited not during the analysed period of time but in the further future. As a result of the comparison, all methane contained in coal seams located at such depth levels and parts, which are characterized by higher average methane contents than the one previously found, can be assumed as potentially economic resource. Such evaluation is usually made with use of correlation and regression analyses of profit dependence on average methane content, as it is shown on the example from Mine B presented on Figure 5. All data from longwall panels previously verified are used for the analysis.

CONCLUSIONS

The paper presents the methodology for economic evaluation of coalbed methane exploitation in coal mines as well as for classification of methane resources. The methodology consists of one analytical, two economic, and four technical phases. Evaluation made in the paper shows that extraction of methane is economic only if benefits from coal exploitation resulted from degasification are taken into account. The same result has also been found during evaluations made by the authors for other coal mines. Additionally, the methodology makes possible to classify resources of methane into economic and potentially economic. The classification can be made on the base of both economic findings and average methane content.

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