

Costs assesment of aerological hazards prevention exemplified by a coal mine company

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Abstract. A range of preventive works has been presented based on the example of one of the exploited longwalls and the costs borne by the coal mine have been exhibited. Further, the paper presents the costs of preventive aerological practices conducted for the improvement of work safety, borne by one of the coal mining companies. The paper also includes the calculation of cost indices. Based on these cost indices, an analysis of costs of the applied aerological preventive practices was conducted for the longwalls driven in years 2014-2015 by one of the coal mining companies.

1. Introduction

The exploitation of coal mine deposits in underground mines is becoming increasingly difficult and costly. The fixed and variable costs borne by the coal mines are mostly dependent on the amortization costs of machines and devices, the costs of materials and energy, remunerations, external services, taxes and fees as well as other prime costs [1, 2].

Conducting underground exploitation is inseparably linked to the occurrence of natural hazards. The group of aerological hazards includes methane hazard, spontaneous fire hazard, temperature hazard and coal dust explosion hazard. These hazards have a direct impact on the health and the life of the employees working in the mine. Due to the above, coal mines are obliged to conduct continuous preventive practices to limit the hazards occurring in the locations where the miners are working.

Preventive practices conducted against aerological hazards aimed at their limitation generate high costs, which are considered the variable costs of the conducted exploitation [3].

These hazards have a considerable impact on the total costs of a tonne of hard coal. The mean percentage of aerological preventive practices costs is within 4÷16.5% of the price of 1 Mg of coal [3]. As it may be noted, the necessity to conduct continuous preventive practices against aerological hazards to ensure functional safety [4] during exploitation is a cost that has a considerable impact on the price of coal.

The article includes the appraisal of costs of aerological prevention practices conducted in the coal mines of one of the coal mining companies [5]. The presented costs consider the aerological preventive practices applied for longwalls exploited in the years 2014-2015. The appraisal of the costs of the applied aerological preventive practices was based on the cost indices. The total costs borne within the applied



practices were prepared based on adequately drawn up universal tables summarizing the individual costs occurring during the performance of applicable preventive works.

2. An example of a longwall – preventive works and their costs

The longwall [5, 6] was driven using a longitudinal caving system. The length of the wall was 230 m and the face height was 2.0 m. The longwall panel length was 1280 m. The ventilation was conducted using the ‘Y’ method from the boundaries (figure 1). All aerological hazards occurred in the longwall: methane hazard – category 4, fire hazard – 2nd group of spontaneous ignition susceptibility of coal, 3rd critical level of climatic hazard and coal dust explosion hazard class B.

The preventive practices against the methane hazard encompassed mainly the removal of methane from the ventilating road as well as the additional sealing of the side wall in the heading 1a following the advance of the longwall using foams, filling of the heading 1 using foams and the use of jetflow air movers for providing air flow. The prevention against the fire hazard was mostly aimed at the additional sealing of the pillar between the heading 1a and the ventilating road. The preventive works pertaining to the climatic hazard consisted in the cooling of air using group system cooling units in the area of the heading 1. The preventive practices pertaining to the coal dust explosion encompassed standard measures, that is, dust barriers and dusting zones.

The longwall was characterized by a relatively high mean output of 1 715 Mg/day. The exploitation period of the longwall was 563 days and the total output reached 965 532 Mg.

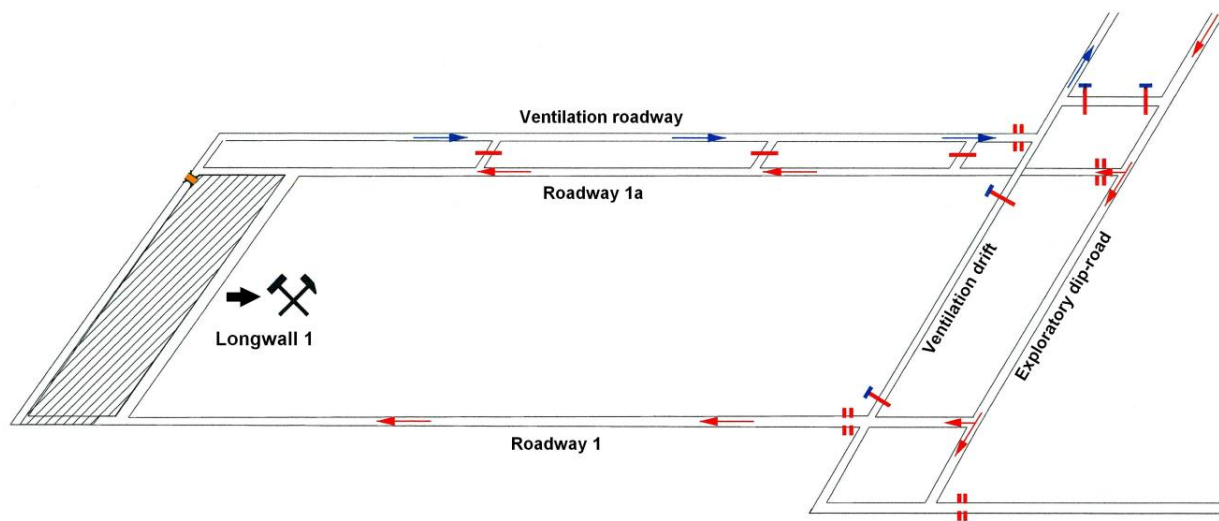


Figure 1. Layout of the longwall 1 [8].

The scope of works applied within the aerological preventive works in the longwall 1 including the unit costs has been presented in tables 1-4 [5, 7].

Table 1. List of costs of methane prevention practices for longwall 1 [5, 7].

No.	Name of the cost	Number/amount	Unit cost (zł)	Total cost (zł)
1.	Preparing drainage boreholes. Total No. of running meters of the drainage boreholes - 34 400 No. of boreholes - 316 No. of sets - 53	34 400	250 zł/1 running meter	8 600 000.00 zł
2.	Methane removal	19 months	94 210.00 zł/month	1 789 990.00 zł
3.	The performance of auxiliary ventilation devices (a – ventilating brattice lining material b – ventilating barriers, c – jetflow air movers, d – auxiliary fans, e – additional sealing of the caving with foams, f – insulating plugs etc.)	a- 0 b- 0 c- 2 pcs. d- 2 pcs. e- 359 895kg f- 14 pcs.	0 0 6 000 zł/piece 70 000 zł/piece 2.63 zł/kg 23 337 zł/piece	0 0 12 000.00 zł 140 000.00 zł 946 523.85 zł 326 718.00 zł
4.	Performance of a drainage roadway		Not applicable	
5.	Maintenance of the ventilation roadway in case of the Y-ventilation system	1 250 m	567.00 zł/1 running meter	708 750.00 zł
6.	Man-days related to preventing the methane hazard	11 403 man-days	547.19 zł/man-day	6 239 607.57 zł
7.	Energy costs WLE 1013B x 2 Huragan 120 jetflow air movers 2x – 19440 m ³ /d x2	520 days x2 550 days x2	114.24 zł 625.97 zł	118 809.60 zł 688 567.00 zł
8.	Total cost of the preventive practices			19 570 966.02 zł

Table 2. List of costs of fire prevention practices for longwall 1 [5, 7].

No.	Name of the cost	No./Amount	Unit cost (zł)	Total cost (zł)
1.	Use of chemical materials: - light foams - heavy foams, - anti-pyrogenic agents - polyurethane cements	0 dm ³ 9 000 dm ³ 0 dm ³ 1 300 dm ³	0 zł/dm ³ 5.40 zł/dm ³ 0 zł/dm ³ 7.48 zł/dm ³	- 48 600.00 zł - 9 724.00 zł
2.	Additional works for the application of chemical materials (boreholes, injection)	-	-	-
3.	Use of mineral materials: - mineral-cement binding materials, - cement, - sand	0 Mg 15 Mg 50 Mg	0 zł/kg 385.00 zł/Mg 22.96 zł/Mg	- 5 775.00 zł 1 148.00 zł
4.	Additional works for the application of mineral materials (boreholes, injection)	-	-	-
5.	Cuboid concrete blocks	2500 pcs.	3.22 zł/piece	8 050.00 zł
6.	Performance of packwalls (1 running meter)		None	
7.	Other construction materials		None	
8.	Laboratory tests of gas samples for early detection of spontaneous fires conducted by the	3.538 pcs.	23 zł/piece	81 374.00 zł

9.	mining facility Laboratory tests of gas samples for early detection of spontaneous fires conducted at an order	77 pcs.	215 zł/piece	16 555.00 zł
10.	Additional measurements (thermographic camera, pyrometer)	83	547.19	45 416.77 zł
11.	Use of inert gases – N ₂ or CO ₂			
12.	Inertization works		None	
13.	Lease or cost of use of inertization devices			
14.	Man-days related to preventing the fire hazard	450 man-days	362.33 zł/ man-day	163 048.50 zł
15.	Man-days of mine rescue workers working at preventive works	1 350 man-days	547.19 zł/ man-day	738 706.50 zł
16.	Use of water and other utilities	-	-	-
17.	Total cost of the preventive works			1 118 397.77 zł

Table 3. List of costs of climatic hazard prevention practices for longwall 1 [5, 7].

No.	Name of the cost	No./Amount	Unit cost (zł)	Total cost (zł)
1.	Air conditioning devices	8 pcs.	90 000.00 zł	720 000.00 zł
3.	Auxiliary fans	0 pcs.	-	-
4.	Fans with air-ducts	8 pcs.	70 000.00 zł	560 000.00 zł
5.	Operation of the devices	2 252 man-days	374.50 zł	843 374.00 zł
6.	Insulation of headings	-	-	-
7.	Auxiliary materials	-	-	-
8.	Intensification of ventilation	-	-	-
9.	Man-days related to preventing climatic hazard	563 man-days	379.36 zł/ man-day	213 579.68 zł
10.	Energy costs			
	Air conditioning devices x8	450 x 8 days	720.00 zł	2 592 000.00 zł
	Fans for the air coolers x8	450 days	154.08 zł	554 688.00 zł
11.	Total cost of the preventive works			5 483 641.68 zł

Table 4. List of costs of coal dust explosion prevention practices for longwall 1 [5, 7].

No.	Name of the cost	No./Amount	Unit cost (zł)	Total cost (zł)
1.	Rock dust	342 Mg	146.34 zł/Mg	50 048.28 zł
2.	Containers for water curtains	-	-	-
3.	Wooden/steel structures for explosion-proof barriers	Wood – 120 m ³ Hooks – 1920 pcs.	643.40 zł/m ³ 2.15 zł/piece	77 208.00 zł 4 128.00 zł
4.	Monthly maintenance of protection zones against the propagation of the coal dust explosion in the region	18.5 months	17121 zł/month	316 738.50 zł
5.	Man-days related to the prevention of coal dust explosion hazard	3 378 man-days	379.36 zł/ man-day	1 281 478.08 zł
6.	Energy costs	-	-	-
7.	Total cost of the preventive works			1 729 600.86 zł

Table 5 presents the summary of aerological prevention costs borne during the exploitation of longwall 1.

Table 5. Summary of costs of methane prevention practices for longwall 1 [5, 7].

Cost of methane hazard prevention	19 570 966.02 zł
Cost of fire hazard prevention	1 118 397.77 zł
Cost of climatic hazard prevention	5 483 641.68 zł
Cost of dust hazard prevention	1 729 600.86 zł
Total cost of preventive ventilation practices in longwall No. 1	27 902 606.33 zł

3. Costs of prevention and cost indices

To assess the costs of aerological prevention, the following cost indices must be calculated:

- percentage of costs in proportion to the obtained revenue U_p , %,
- cost of prevention in conversion to 1 Mg of excavated coal K_{PMg} , zł/Mg.

Percentage of cost of prevention U_p was calculated based on the following formula:

$$U_p = \frac{K_p}{P_c} \cdot 100\%, (\%) \quad (1)$$

where:

K_p – total cost of preventive practices, zł,

P_c – total revenue, zł.

The total cost of the preventive works is the sum of the individual preventive ventilation practices costs.

The cost of prevention in conversion to 1 Mg of excavated coal K_{PMg} was calculated based on the following formula:

$$K_{PMg} = \frac{K_p}{W_c}, (\text{zł/Mg}) \quad (2)$$

where:

W_c – total output from the longwall, Mg.

The total cost of prevention in conversion to 1 Mg of the excavated coal K_{PMg} is the sum of the individual preventive practices costs in conversion to 1 Mg of the excavated coal.

To be able to compare the costs of the preventive works in relation to the coal price, a mean yearly price of 1 Mg of hard power coal was established. The price was calculated based on the coal price rate in line with the mean ARA prices [8] and – in the period in concern – it reached 70.42 USD. In line with the mean yearly exchange rate of USD in the years 2013-2015, which amounted to 3.46 zł [9], the price of 1 Mg of hard power coal was 243.65 zł/Mg.

18 longwalls exploited in the years 2013-2015 by one of the coal mining companies were subjected to the analysis [5]. The costs of the preventive practices and the costs as percentages have been exhibited in tables 6 and 7.

The highest costs of prevention of natural hazards related to ventilation are generated by preventive works linked to the limitation of the methane hazard. As shown in table 6, the lowest methane hazard prevention cost was 1 127 998.96 zł, while the highest reached as much as 23 080 212.22 zł. The span is thus considerable. Most of all, this is related to the range of the preventive works, especially the methane

removal from the rock mass. As it may be noted, no active methane prevention was conducted in case of 5 longwalls. The mean cost of the conducted methane prevention within the company was 5 528 116.48 zł.

Prevention against spontaneous fire hazard was conducted in case of all of the analyzed longwalls. The preventive works related to fire hazard are characterized by much lower costs, although longwalls exist in which the costs are also considerable. To exemplify this, the mean cost of preventive works in case of the analyzed longwalls was 2 677 879.64 zł. Only in case of 5 longwalls the costs of prevention exceeded the mean value. In case of two longwalls it was several-fold higher than the mean value and it amounted to 7 475 712.70 zł and 11 749 548.56 zł, respectively. The costs in case of the rest of the longwalls fell within the range of 167 963.73 zł – 4 858 262.01 zł. In that range, this resulted in a mean cost of prevention of 1 811 035.77 zł. It is also worth to note the individual costs borne within the fire prevention practices presented in the earlier example. The highest costs within these prevention works are the costs of the man-days. In the presented example, as much as 80.6% of the costs spent on prevention of fire hazard were spent on the man-days of the mining plant's rescue workers performing their duties in the form of preventive works and the man-days of the ventilation division's employees. The division of costs of fire prevention works in case of other analyzed longwalls is similar.

Preventive works related to climatic conditions were conducted only in 8 regions of the analysed longwalls. Their costs varied largely from 613 673.51 zł up to as much as 12 055 022.10 zł. The highest unit costs in case of prevention related to climatic conditions are denoted mostly by the costs of machines, air conditioning and auxiliary devices as well as the costs of the electric energy used to power the machines and devices.

From among all the costs borne for the preventive works conducted in relation to natural hazards in the range of ventilation, the lowest costs were related to the prevention of coal dust explosion hazard. It is one of the hazards with regard to which the prevention is obligatory [10]. The mean cost of the preventive works related to dust explosion hazard was 523 578.56 zł, although in case of two regions the costs amounted to 1 335 881.01 and 1 729 600.86 zł, respectively.

Figure 2 presents the costs of preventive works related to ventilation. As it may be noted, the highest cost of the conducted prevention is related to the methane hazard, while the lowest cost is related to the coal dust explosion hazard.

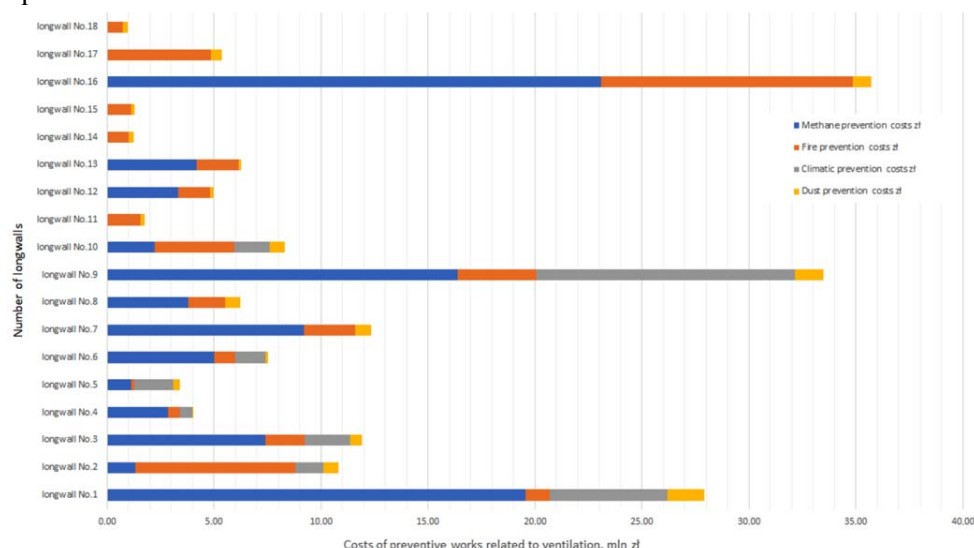


Figure 2. Costs of the aerological preventive practices in case of the analyzed longwalls.

Table 6. Costs of aerological preventive practices.

	Total output W_C (Mg)	Total revenue P_C (zł)	Methane prevention		Fire prevention		Climatic prevention		Dust prevention		Total cost of the preventive works	
			costs K_{PM} (zł)		costs K_{PP} (zł)		costs K_{PK} (zł)		costs K_{PPL} (zł)		K_P (zł)	
longwall No.1	965 532	235 251 871.80	19 570 966.02		1 118 397.77		5 483 641.68		1 729 600.86		27 902 606.33	
longwall No.2	558 018	135 961 085.70	1 326 128.40		7 475 712.70		1 303 146.42		718 274.54		10 823 262.06	
longwall No.3	1 303 819	317 675 499.35	7 388 397.34		1 840 149.90		2 120 459.40		582 193.60		11 931 200.24	
longwall No.4	155 343	37 849 321.95	2 865 640.23		521 430.96		613 673.51		35 069.70		4 035 814.40	
longwall No.5	682 836	166 372 991.40	1 127 998.96		167 963.73		1 808 183.04		287 664.80		3 391 810.53	
longwall No.6	414 661	101 032 152.65	4 997 091.93		1 004 621.95		1 400 759.92		120 034.40		7 522 508.20	
longwall No.7	389 392	94 875 360.80	9 212 301.90		2 399 711.70		Not used		750 630.02		12 362 643.62	
longwall No.8	548 225	133 575 021.25	3 794 635.40		1 737 317.00		Not used		683 330.16		6 215 282.56	
longwall No.9	561 807	136 884 275.55	16 377 089.90		3 694 356.77		12 055 022.10		1 335 881.01		33 462 349.78	
longwall No.10	822 958	200 513 716.70	2 227 132.50		3 707 806.58		1 654 043.78		710 428.75		8 299 411.61	
longwall No.11	346 417	84 404 502.05	Not used		1 573 923.75		Not used		177 868.78		1 751 792.53	
longwall No.12	758 683	184 853 112.95	3 344 598.59		1 487 906.10		Not used		127 050.21		4 959 554.90	
longwall No.13	578 793	141 022 914.45	4 193 903.32		1 957 206.60		Not used		127 050.21		6 278 160.13	
longwall No.14	1 518 280	369 928 922.00	Not used		1 005 440.00		Not used		241 025.85		1 246 465.85	
longwall No.15	333 550	81 269 457.50	Not used		1 151 312.45		Not used		149 835.78		1 301 148.23	
longwall No.16	1 237 743	301 576 081.95	23 080 212.22		11 749 548.56		Not used		884 925.33		35 714 686.11	
longwall No.17	487 795	118 851 251.75	Not used		4 858 262.01		Not used		526 839.26		5 385 101.27	
longwall No.18	106 802	26 022 307.30	Not used		750 765.04		Not used		236 710.73		987 475.77	
Mean	653 925	159 328 880.39	5 528 116.48		2 677 879.64		1 468 829.44		523 578.56		10 198 404.12	
Total	11 770 654	2 867 919 847.10	99 506 096.71		48 201 833.57		26 438 929.85		9 424 413.99		183 571 274.12	

Table 7. Cost indices of the aerological preventive practices.

	Cost percentage of methane prevention	Cost percentage of fire prevention	Cost percentage of climatic prevention	Cost percentage of dust prevention	Total percentage of the prevention costs	Cost of methane prevention per 1 Mg of the output	Cost of fire prevention per 1 Mg of the output	Cost of climatic prevention per 1 Mg of the output	Cost of dust prevention per 1 Mg of the output	K_{PMgPy} (zł)	K_{PMg} (zł)	Total cost of prevention per 1 Mg of output
	U_{PMe} (%)	U_{PPo} (%)	U_{PKI} (%)	U_{PPy} (%)	U_P (%)	K_{PMgMe} (zł)	K_{PMgPo} (zł)	K_{PMgKI} (zł)	K_{PMgPy} (zł)	K_{PMg} (zł)	K_{PMg} (zł)	Total cost of prevention per 1 Mg of output
longwall No.1	8.32	0.48	2.33	0.74	11.86	20.27	1.16	5.68	1.79	28.90		
longwall No.2	0.98	5.50	0.96	0.53	7.96	2.38	13.40	2.34	1.29	19.40		
longwall No.3	2.33	0.58	0.67	0.18	3.76	5.67	1.41	1.63	0.45	9.15		
longwall No.4	7.57	1.38	1.62	0.09	10.66	18.45	3.36	3.95	0.23	25.98		
longwall No.5	0.68	0.10	1.09	0.17	2.04	1.65	0.25	2.65	0.42	4.97		
longwall No.6	4.95	0.99	1.39	0.12	7.45	12.05	2.42	3.38	0.29	18.14		
longwall No.7	9.71	2.53	0.00	0.79	13.03	23.66	6.16	0.00	1.93	31.75		
longwall No.8	2.84	1.30	0.00	0.51	4.65	6.92	3.17	0.00	1.25	11.34		
longwall No.9	11.96	2.70	8.81	0.98	24.45	29.15	6.58	21.46	2.38	59.56		
longwall No.10	1.11	1.85	0.82	0.35	4.14	2.71	4.51	2.01	0.86	10.08		
longwall No.11	0.00	1.86	0.00	0.21	2.08	0.00	4.54	0.00	0.51	5.06		
longwall No.12	1.81	0.80	0.00	0.07	2.68	4.41	1.96	0.00	0.17	6.54		
longwall No.13	2.97	1.39	0.00	0.09	4.45	7.25	3.38	0.00	0.22	10.85		
longwall No.14	0.00	0.27	0.00	0.07	0.34	0.00	0.66	0.00	0.16	0.82		
longwall No.15	0.00	1.42	0.00	0.18	1.60	0.00	3.45	0.00	0.45	3.90		
longwall No.16	7.65	3.90	0.00	0.29	11.84	18.65	9.49	0.00	0.71	28.85		
longwall No.17	0.00	4.09	0.00	0.44	4.53	0.00	9.96	0.00	1.08	11.04		
longwall No.18	0.00	2.89	0.00	0.91	3.79	0.00	7.03	0.00	2.22	9.25		
average	3.49	1.89	0.98	0.37	6.74	8.51	4.60	2.39	0.91	16.42		

The total cost of the conducted preventive works is relatively variable. Depending on the occurring natural hazards and the necessary scope of preventive works, the cost may be considerable. This may be observed while comparing the costs of the preventive works with the total revenue obtained from the longwalls (figure 3).

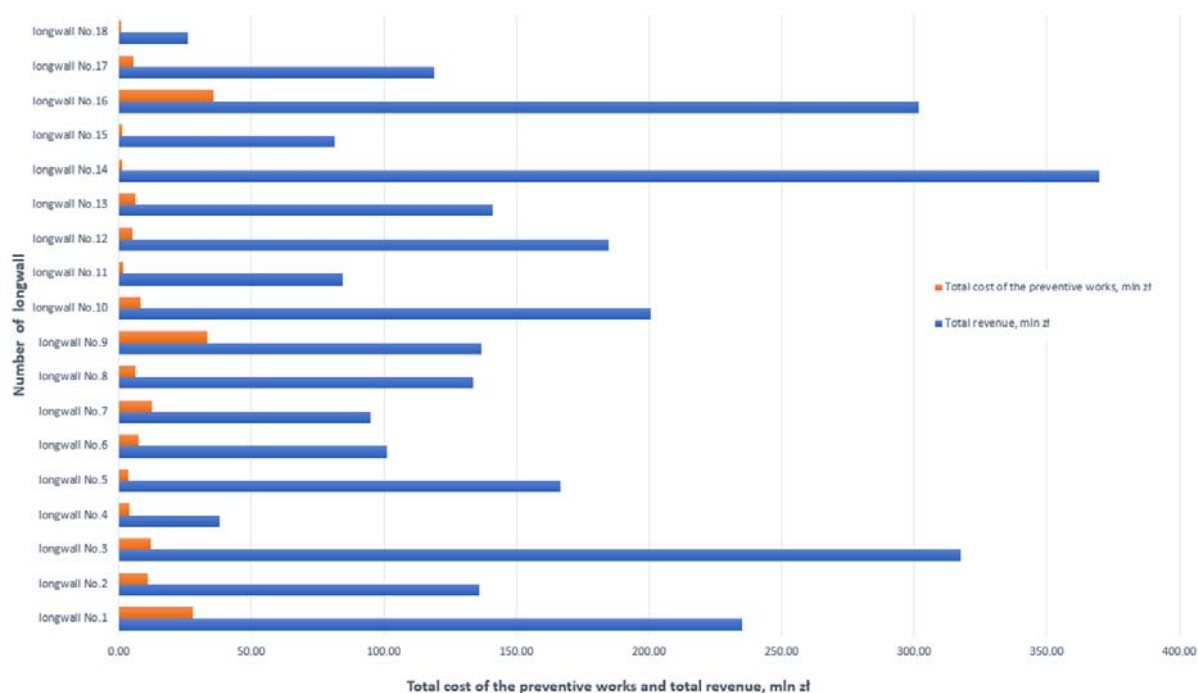


Figure 3. A comparison of the total cost of the aerological preventive practices and the total revenue in case of the analyzed longwalls.

One of the cost indicators for a given prevention practice is its share in the total revenue. While analyzing the shares of the costs (table 7, figure 4) the highest costs concern the methane hazard prevention, amounting to a mean percentage of 3.49%, although longwalls exist for which the value varies around 10%.

In case of the fire hazard, the mean share of the costs reached 1.89%. The span of the cost fractions was wide and varied in the range of 0.10 to 5.50%. In case of the thermal hazard, the percentage of the prevention costs varied in the range of 0.67-8.81%. The lowest portion of the costs was exhibited in case of coal dust explosion hazard prevention. The mean percentage was 0.37%, while the portion of the costs in the total revenue varied between 0.07 to 0.98%.

The cost of a given prevention practice per 1 Mg of output is a significant indicator (table 7, figure 5). The mean cost of methane hazard prevention was 8.51 zł per a tonne of output. The lowest cost thereof was 1.65 zł/1 Mg while the highest reached 29.15 zł/1 Mg. In case of the fire hazard prevention, the mean cost was 4.60 zł/1 Mg, while the costs of prevention per 1 Mg of output varied in the range of 0.25-13.40 zł/1 Mg. The necessity to exercise the prevention of thermal hazard requires high costs to be borne. In case of the analyzed longwalls, the range of the costs of the thermal prevention per 1 Mg of output varied in the range from 1.63 zł/1 Mg up to 21.46 zł/1 Mg. The prevention against coal dust explosion was the most “even” in terms of the costs. Its mean cost was 0.91 zł/1 Mg in the range of 0.16-2.38 zł/1 Mg.

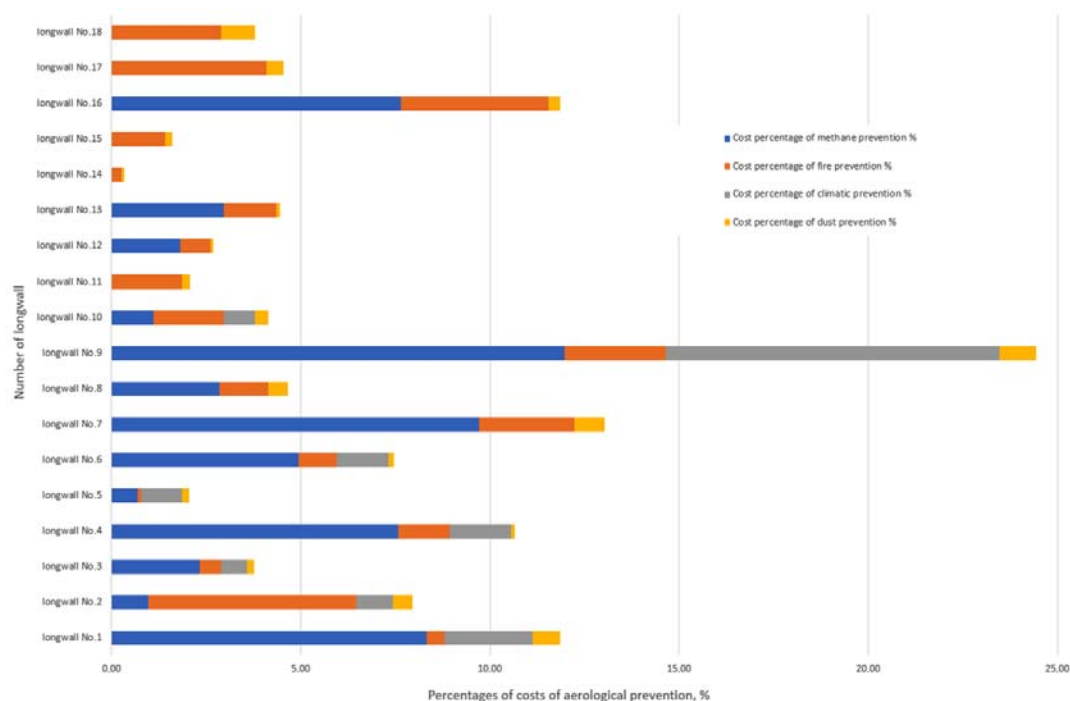


Figure 4. Percentages of costs of aerological prevention practices in the total revenue in case of the analyzed longwalls.

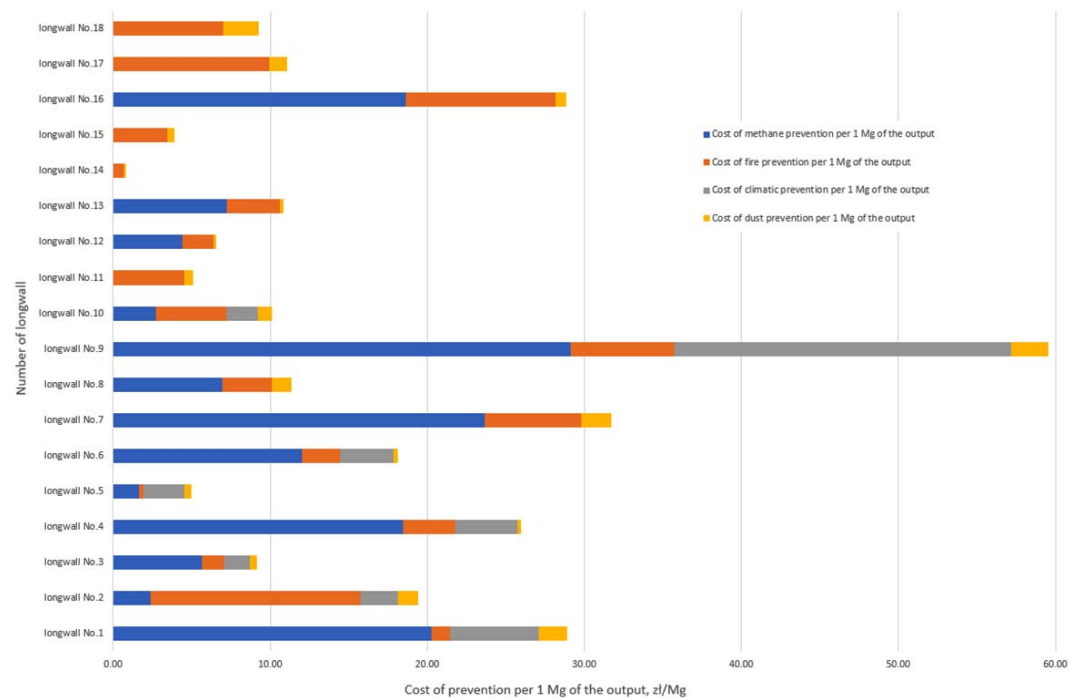


Figure 5. Costs of aerological prevention practices per 1 Mg of output for the analyzed longwalls.

4. Summary

The performed analysis of costs of preventive works exhibits that the highest costs are borne due to fighting the methane hazard. The large majority of the analyzed longwalls, namely 72.2% required the application of methane hazard prevention. The costs of methane prevention constitute as much as 51.8% of the total costs borne by the coal mines for the prevention of aerological hazards. The mean cost of methane hazard prevention amounted to 8.51 zł/1 Mg of output. One may note, however, that often the costs of methane prevention exceed 20.00 zł/1 Mg (maximum of 29.15 zł/1 Mg).

The prevention works that were most often conducted were the works in the scope of spontaneous fire prevention. In case of all the analyzed longwalls, active prevention of fire hazard was conducted. The mean cost of the fire prevention was 4.60 zł/1 Mg.

In case of coal dust explosion hazard prevention, due to its obligatory character, the costs of application are lower as compared to other prevention practices. This is related to the to the legally required algorithm of conduct imposed by means of the mining provisions. The mean cost of prevention amounted to 0.91 zł/1 Mg of output.

Thermal hazard prevention, although costly, was not often applied in case of the analyzed longwalls. Active prevention of thermal hazard was conducted only in 8 of the 18 analyzed longwalls.

The total participation of the costs of preventive works in the revenue of the analyzed longwalls was 6.74%, while the total mean cost of prevention practices was 16.42 zł/1 Mg of output.

The share of the prevention practices costs related to ventilation increases gradually. This is not only related to the significant decrease in the price of coal, but also the necessity to exploit seams at a gradual and slow increase of the impact of natural hazards and the increasingly difficult geological and mining conditions. If the low prices are maintained at a stable level for a longer period, a situation may occur when the costs of preventing the hazards related to ventilation shall be so high that the exploitation of coal will prove unprofitable.

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