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Time variability of methane extraction from hard coal deposits in the Upper Silesian Coal Basin (Poland) in relation to geological and mining conditions

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Keywords

coal mining, coal mine methane, degasification, methane management, Upper Silesian Coal Basin, Poland

Time Variability of Methane Extraction from Hard Coal Deposits in the Upper Silesian Coal Basin (Poland) in Relation to Geological and Mining Conditions

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Abstract

The extraction and economical use of methane from coal mines in the Upper Silesian Coal Basin, Poland (USCB) have shown a variable tendency in recent decades, with numerous fluctuations from year to year. In 2021, approximately 286 million m^3 of methane was collected from coal mines, which accounted for approximately 40% of the total emissions of this gas to mine workings. Due to the fact that the economical use of coal mine methane brings environmental, economic and work safety benefits, increasing its extraction is an urgent need. Trends in changes in the amount of mined methane in the entire USCB and in the deposits where the most methane was extracted in the last 25 years were analysed. The most important potential factors influencing the variability of coal mine gas extraction were taken into account, i.e. elements of the geological structure, coal extraction, methane emissions, mining and technical conditions, etc. The directions for using the collected methane and the main consumers were discussed. The aim is to indicate the most important problems faced by coal mining in terms of the capture and management of methane over the last 25 years and to outline possible solutions.

Keywords: Coal mining, Coal mine methane, Degasification, Methane management, Upper Silesian Coal Basin, Poland

1. Introduction

The Upper Silesian Coal Basin (USCB) is the main area of hard coal mining in Poland. Ensuring the continuity of supplies of this fuel requires mining at a greater depth, which is associated with the intensification of natural hazards, e.g. [1,2]. One of them is methane accompanying coal-bearing formations (coal bed methane), which on the one hand, causes an explosion and fire hazard, and on the other hand, can be considered an energy resource, e.g. [3]. Countries that are world leaders in coal mining, such as China, Russia, the USA and India, emit the most methane from mines. These four countries will be responsible for ca. 80% of global mine methane emissions by 2030 [4].

According to Polish law, coal bed methane is treated as an accompanying or main mineral commodity and is documented, including resource estimation. Every year, the Balance of Mineral Resources in Poland [5] lists the balance, off-balance resources and developed reserves of coal bed methane. In 2021, the balance resources of methane in the USCB amounted to 106.7 billion m^3 and developed reserves – of 11.2 billion m^3 and included methane deposits both within working coal mines and deposits outside coal mining (methane as an accompanying mineral commodity) and from the so-called virgin fields (methane as the main mineral commodity intended for borehole extraction). The most common form of methane extraction is underground degasification of mine workings (98.6% of the total methane extraction amounting to 286.6 million m^3 in 2021). The remaining part is borehole mining from old abandoned mines. Documentation of resources and

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extraction of coal mine methane (CMM) in Poland has been carried out for many years only within the USCB. There is a yearly change in the amount of gas extracted and lower production in relation to the total emission. Due to the fact that extraction of methane from mining coal deposits is of significant importance in terms of mining safety, and economic and environmental issues, the purpose of this study is to analyse the variability of CMM extraction and the total emissions to mine workings from USCB documented CMM deposits over the last 25 years with particular emphasis on the last 10-year period. The focus was only on methane collected as a result of the current underground degasification of working or abandoned mines due to the largest amount of this type of gas being extracted. The problem of CMM emission and extraction was raised by many, e.g. [1–3], however, this article attempts to approach the topic comprehensively by using a comparative analysis between the studied values, i.e. coal mining, methane emission and extraction, and the amount of gas used. It is meant to indicate the crucial factors influencing the amount of emission and methane drainage and the most important problems faced by coal mining in terms of methane collection and management, as well as possible solutions.

2. Source and scope of data

Data on the extraction of coal and drained methane as well as emissions with ventilation, were obtained from the annually published balance of mineral resources in Poland [5]. These data concerned only the deposits documented in terms of methane of coal seams as a mineral commodity accompanying hard coal. Ventilation methane emissions outside of documented methane deposits have not been taken into account, as the main focus has been on data provided by the Polish Geological Survey (PSG) for areas with calculated balance and developed methane reserves. Data from the period 1997–2021 for the entire USCB and 11 deposits of the basin from which the most methane was extracted were compiled. The data on the amount of methane captured from methane drainage was compared with the amount of coal extracted and the total methane emission to workings, that is, the sum of methane captured and emitted by ventilation shafts. The volume of methane extraction from a given mine was also compared with the extraction of this gas in the entire basin. Correlation coefficients were calculated for the compared values. In addition, data on the effectiveness of methane use, i.e. the ratio of methane used to the methane collected from drainage systems, has been compiled. These results were taken from the Reports on the state of natural and technical hazards in hard coal mines prepared by the Central Mining Institute in Katowice, Poland [6]. Due to the observed variability of the total emission and the amount of methane and coal extraction, the coefficients of variation for these values were calculated according to the formula

$$W = S/U \cdot 100\% \quad (1)$$

where, W – coefficient of variation, S – standard deviation, U – average methane emission or extraction or coal output. Information on the method of managing the captured gas and the directions of sale was also presented.

3. General overview of coal mine methane in the USCB and environmental impact

The term coal mine methane (CMM) refers to the total methane emitted from deposits, mainly during and after the cessation of mining activities in mines [7]. Degasification is part of the total methane emissions to mine workings, which is the gas collection by methane drainage stations in mines with the highest category of methane hazard in order to carry it to the surface or to another safe place in the mine [8]. The collection of methane can be performed by means of underground drainage holes and through special mining excavations, the so-called overlying gangways. The gas reaching the methane drainage station is then used as fuel, while the surplus that has not been used up is released into the atmosphere as the so-called "blow-out", and in combination with the methane emitted with the ventilation air from the shafts represents the total amount of methane emitted to the atmosphere by the mine, e.g., [9,10]. For many years, studies have been underway on technologies for capturing methane from ventilation air (VAM), e.g. [11] and its use, but they are still expensive, and methane from this source is not used on a large scale so far. Due to the fact that methane is the second greenhouse gas after carbon dioxide, methane emissions from mines are harmful and contribute to the so-called greenhouse effect. Current estimates [12 and references therein] indicate that the radiation power of methane is 20–36 times greater than that of carbon dioxide, but its residence time in the atmosphere is much shorter–about 10–12 years. Taking into account the radiation power of methane and the fact that 1 tonne of methane combusted entails 2.75 tonnes of carbon dioxide emissions, combustion 1 tonne of methane equates to not emitting about

17–33 tonnes of CO_2. This means a reduction in greenhouse gas emissions per CO_2 equivalent by up to 80% in the case of generating 1 MWh of energy as a result of methane combustion for a cogeneration system [3]. Therefore, the full economic use of methane captured by mines is an urgent environmental need. In the USCB, out of 302.81 million m^3 of methane captured, about 187.93 million m^3 was used in 2020 [6], i.e. slightly over 62%. The remaining part was released into the atmosphere and together with the methane emitted by the ventilation shafts, it was 631.69 million m^3 [6]. Methane was collected in 2020 in 13 mines, most of them at the Knurów-Szczygłowice (57 million m^3), Brzeszcze (40 million m^3), Pniówek (34 million m^3) and Budryk (34 million m^3) mines. Brzeszcze and Pniówek mines were the most effective in using methane, respectively, 100 and 96% of the collected methane was used [6]. Degasification of the rock mass takes place in several stages. Initially it is degasification prior to exploitation (from dog headings), but due to low coal permeability and, in consequence, efficiency, it is used to a negligible extent. The *Geo-Metan* project, carried out by the Polish Geological Institute and PGNiG Company, was a promising variant of this degasification type consisting in test borehole degasification of coal seams from the surface. This project was discontinued in 2019. The majority of the drainage gas comes from mining excavations and goafs. In 2020, only 5.11 million m^3 of methane was extracted from dog headings (1.69% of the total gas obtained), 198.81 million m^3 (65.66%) from mining excavations and 98.89 million m^3 from goafs (32.66%) [6]. The gas obtained from the degasification of mine workings is a mixture of methane occurring naturally in coal deposits and ventilation air in various proportions. Usually, the methane content in the captured gas fluctuates in the range of 40–60% and is unstable, which limits the possibilities of economic use of the gas. The main direction of gas management is energy in the form of electricity, heat and cold generation in cogeneration systems. The energy generated in this way is used primarily by coal mines and thus partially compensate the costs incurred for the construction of methane drainage stations and the purchase of appropriate installations, because the main purpose of these activities is to ensure the safety of miners at work and the production of methane is only an additional activity. The sale of gas to external consumers is not common and concerns, among others, neighbouring power plants, recreation and sports facilities, schools and individual recipients. As a result, the methane obtained from the mines is not fully used, and more than 18% of the total gas emissions from USCB mines in 2020 came from the methane drainage installation. In view of the European Commission's plans to ban methane emissions to the atmosphere from methane drainage stations from 2025, increasing the amount of methane used becomes a necessity.

4. Results

As already mentioned, the data on the areas of documented methane deposits as accompanying commodities within active or abandoned mines, where continuous degasification of the rock mass is carried out, were taken into account. Of the 31 coal deposits from which methane is currently produced, 11 were selected with the highest amount of gas produced or stable production in the last 25 years (Fig. 1). Data on these deposits are presented in Tables 1 and 2.

In the period 1997–2021, the greatest amount of methane was extracted from the Brzeszcze, Pniówek and Krupiński fields. The total emission, including methane drainage and ventilation, was the highest in this period in the Pniówek, Budryk and Brzeszcze fields. The highest ratio of the amount of extracted methane to the total emission was in the Brzeszcze, Krupiński and Zofiówka deposits (Table 1). The coefficients of variation of methane extraction in the majority of the analysed deposits (8 out of 11 cases) exceed 40%, which makes the extraction variability large, i.e. the amount of gas extracted varies significantly from year to year. The coefficients of variation in coal extraction and total methane emissions are slightly lower (Table 2). The data in Table 2 show that the amount of obtained methane is most correlated with the total gas emission from documented deposits, but, in fact, it does not depend on the number of tonnes of extracted coal. The highest average effectiveness of methane use was recorded in the Brzeszcze, Pniówek, Zofiówka and Krupiński deposits (>65%, Table 1). In the 11 analysed deposits, along with the increase in the ratio of the amount of methane collected to the total emission, the effectiveness of methane use also increases (Fig. 2).

The Brzeszcze field is the most compatible with the extraction of methane in the entire USCB over the 25-year period (correlation coefficient 0.66; Table 2). In the years 2006–2008, the extraction of methane from this deposit accounted for approximately 30% of the total mine gas extraction in the USCB, which clearly influenced the amount of gas obtained in the entire basin.

Fig. 3 presents the total methane emission and extraction in the exampled three fields. The period

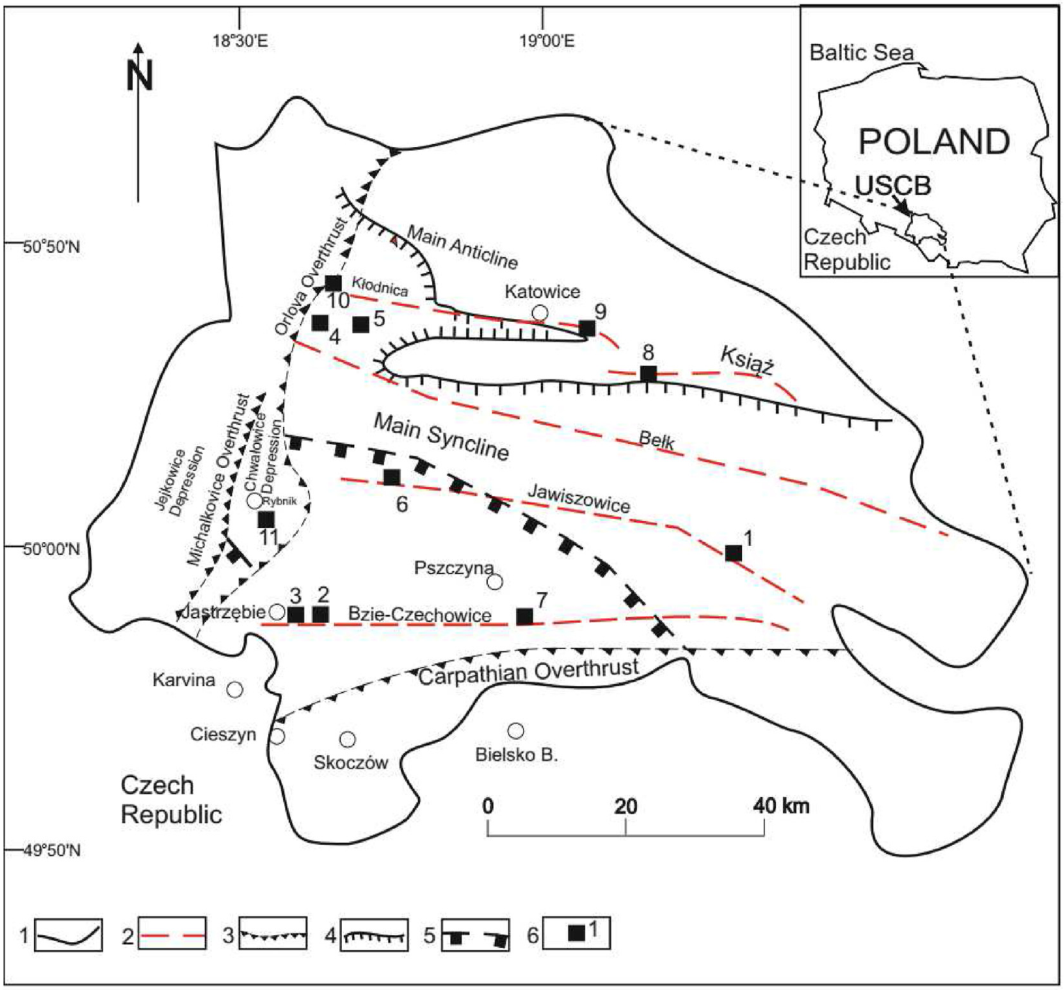

Fig. 1. Location of selected methane deposits in the Upper Silesian Coal Basin (USCB) sketch modified after [2]: 1 – basin boundary, 2 – fault, 3 – overthrust, 4 – range of continuous Miocene cover, 5 – range of methane accumulation directly below the Carboniferous roof, 6 – selected methane deposits (1 – Brzeszcze, 2 – Pniówek, 3 – Zofiówka, 4 – Szczygłowice, 5 – Budryk, 6 – Krupiński, 7 – Silesia, 8 – Wesoła, 9 – Staszic, 10 – Sośnica, 11 – Chwałowice).

Table 1. Total extraction of coal and coal mine methane as well as methane emissions from selected deposits and total USCB in 1997–2021 (own study after [5,6]).

No.	Deposit	Coal extraction (C) (thousand tonnes)	Methane extracted (D) (million m^3)	Total methane emissions (E) (million m^3)	D/E (%)	Effectiveness of methane use (%)[a]
1	Brzeszcze	38,051	1135.66	1452.67	78.18	99.62
2	Pniówek	78,553	980.87	2061.29	47.59	87.22
3	Zofiówka	53,012	808.95	1162.54	69.58	91.05
4	Szczygłowice	53,089	244.35	636.67	38.38	34.18 (2009)
5	Budryk	65,155	556.25	1599.42	34.78	58.64 (2003)
6	Krupiński	42,016	893.59	1149.12	77.76	66.53
7	Silesia	22,927	410.98	709.17	57.95	64.62[b]
8	Wesoła	71,727	350.44	832.11	42.11	57.31
9	Staszic	72,498	264.97	773.29	34.27	53.43
10	Sośnica	28,421	326.4	664.02	49.16	44.17 (2009)
11	Chwałowice	28,030	96.07	216.56	44.36	49.90 (2011)
	Total USCB	1,885,640	7674.33	16,006.01		

[a] The average for 1997–2021 or for the period from the beginning of methane use after 1997 (initial year in brackets, after [5]).
[b] For 1997–2011, the average effectiveness is 99.33%, and for 2012–2021 is 22.55% [6].

Table 2. Variation and correlation coefficients of the coal (C) and methane (D) extraction, and methane emissions (E) in selected deposits and total USCB in 1997–2021 for values from individual years (own study after [5]).

No.	Deposit	Variation coefficient (%)			Correlation coefficient		
		C	D	E	D/C[a]	D/D_{USCB}[b]	D/E[a]
1	Brzeszcze	42.09	65.85	33.77	0.32	0.66	0.88
2	Pniówek	11.86	16.51	42.48	0.02	0.1	0.78
3	Zofiówka	23.47	63.88	22.01	0.73	0.28	0.74
4	Szczygłowice	18.01	75.07	48.81	−0.48	−0.01	0.77
5	Budryk	19.56	56.17	55.17	0.14	0.41	0.89
6	Krupiński	51.31	59.11	60.44	0.38	0.67	0.99
7	Silesia	54.17	67.34	36.46	0.13	0.46	0.78
8	Wesoła	29.03	34.3	68.09	−0.56	−0.01	0.73
9	Staszic	20.98	44.07	22.67	−0.56	−0.01	0.73
10	Sośnica	27.89	28.14	16.02	−0.56	−0.01	0.73
11	Chwałowice	6.69	70.15	47.04	−0.2	0.07	0.66
	Total USCB	29.97	31.07	28.25	−0.45	–	0.83

[a] Concerns data from particular years in 1997–2021.
[b] Concerns the methane extraction in a given deposit to methane extraction in the USCB in 1997–2021.

covers the last 10 years because, at that time, in all analysed deposits, advanced methane drainage was already carried out, and the captured methane was used. The trends in time changes of both methane degasification and emission within the studied deposits are similar, but they differ between the deposits. In the Brzeszcze and Pniówek deposits, first the downward and then the upward trend is observed (Fig. 3a). The situation is the opposite in the case of the Budryk field, where the upward trend changes to the decreasing one (Fig. 3b). In the Wesoła, Staszic and Sośnica fields, the trend is similar to the Budryk field, but the changes are less pronounced (Fig. 3c). For the entire basin (Fig. 4), 2016 was the culmination year, followed by a decrease in emissions and methane production from all USCB fields, lasting until 2021, i.e. until the end of the research period.

5. Discussion

5.1. Geological and mining conditions

The growing trend of methane emissions to mine workings, despite the decline in coal extraction in the USCB (Fig. 4), is the result of the constantly increasing depth of mining, at which greater gas content in coal seams and greater gas pressure in the seam cause increased gas desorption from the seams and thus increasing emissions, e.g. [2]. This

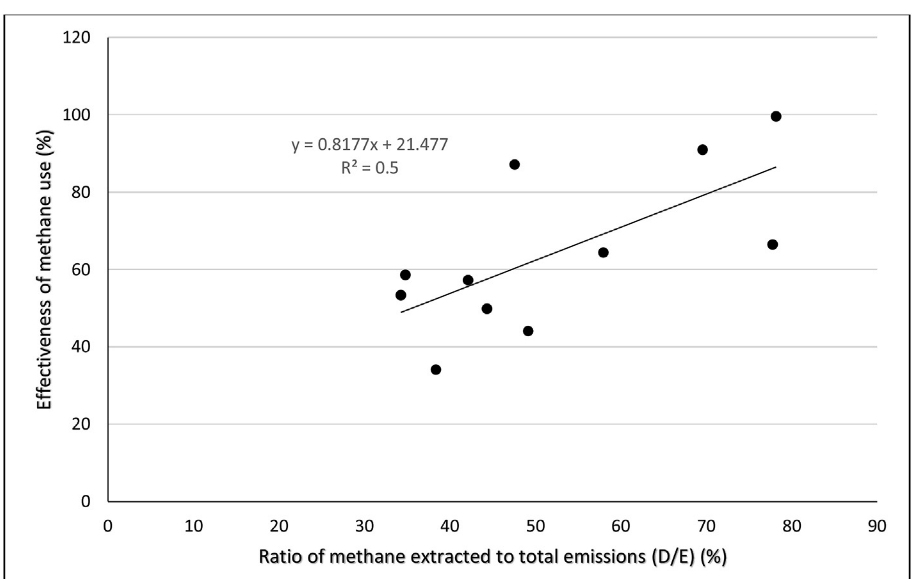

Fig. 2. Ratio of methane extracted to total methane emissions against the effectiveness of methane used (own study after [6]).

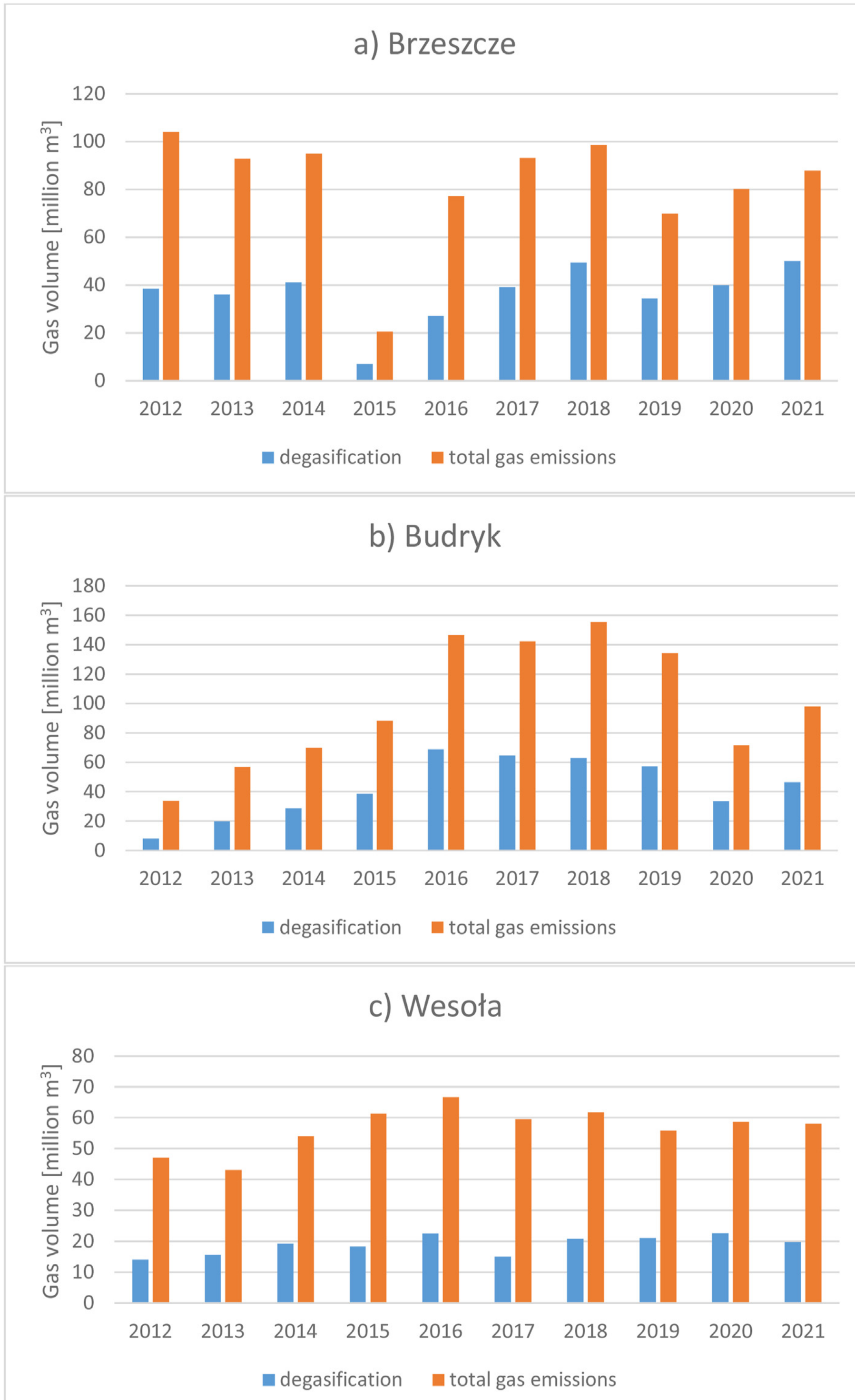

Fig. 3. Emission and extraction of methane in exampled deposits in 2012−2021 (own study after [5]).

phenomenon is favoured by the decreasing sorption capacity of coal with increasing temperature and coalification degree of the seams, e.g. [13], and because these values increase with depth, it is a significant factor contributing to gas emissions and gas-geodynamic phenomena in mines after reaching a large depth of exploitation (>1000 m). A good example is the Budryk mine, launched in 1994, which initially had no gas problems and showed low methane emissions, but after 1997 there was a sharp

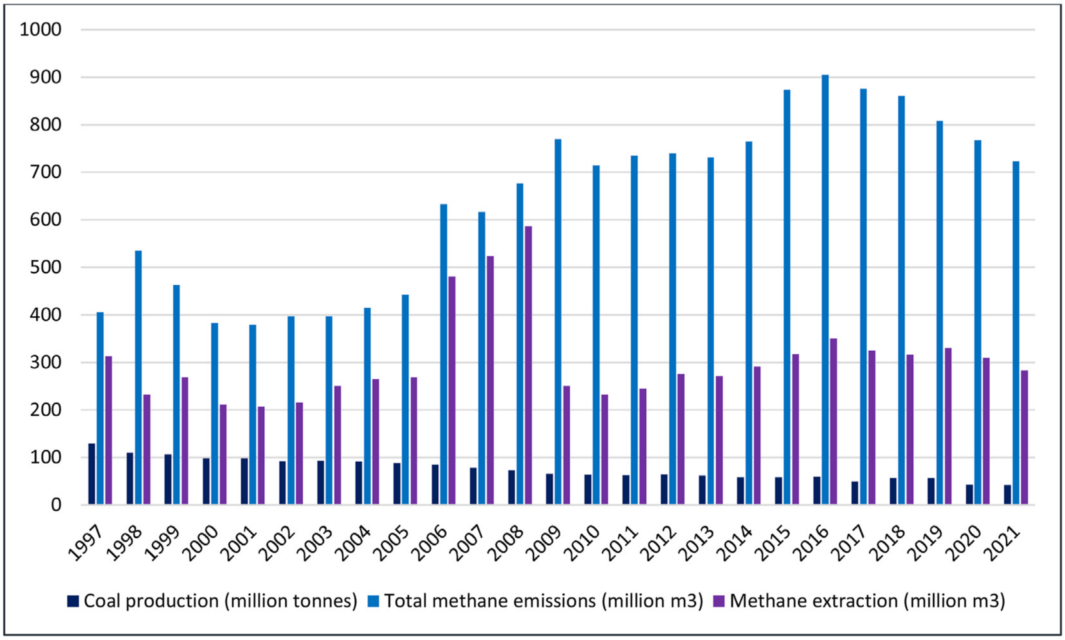

Fig. 4. Changes in coal production, total methane emissions and methane extraction in the USCB 1997–2021 (own study after [5]).

increase in emissions after the depth of mining reached the high-methane zone [12]. Data from the analysed deposits indicate that in the last decade (2012–2021), there has been some stabilisation of methane emissions and in some deposits, even a decrease. The probable reason may be that some mines (e.g. Pniówek or Zofiówka) have reached the depth of maximum gas content in the seams, below which the amount of methane in the deposits decreases (Fig. 5). On the other hand, it is difficult to say whether this is a permanent trend or just a temporary change.

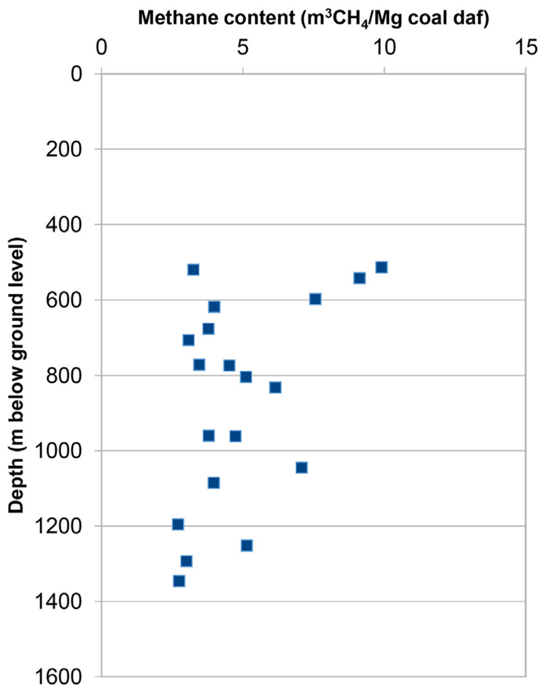

Fig. 5. Depth distribution of the methane content in coal seams in one of the coal deposits in the southern part of the USCB (modified after mining reports). Below the depth of 1000 m, a decrease in methane content is evident.

Geological factors influencing the gas-bearing capacity of coal seams, such as the thickness and lithological nature of the Miocene overburden, the parameters of porosity and permeability of the rocks surrounding the coal seams and fault tectonics, also control the volume of methane emissions from the deposits. This issue was discussed in the works of [2 and 12]. It was observed that higher emissions are characteristic of those deposits that are adjacent to the regional faults of the USCB (e.g. the Brzeszcze and Krupiński deposits to the Jawiszowice dislocation, Pniówek, Zofiówka and Silesia to the Bzie-Czechowice fault, Fig. 1) or are strongly tectonically involved (e.g. the Budryk field). The increased emissions can be explained by gas migration through fissures and faults to mine workings or goafs. On the other side, in the vicinity of faults originated in the compression regime (which are barriers to gases flow), methane is cumulated in the rocks (seams) in greater quantity, which causes greater emission to the mine workings. This issue has been confirmed by numerous national, e.g. [1,14] and global studies, e.g. [7,15].

In addition, barren rocks, especially sandstones, in which methane is accumulated, may be a source of gas migration to mine workings or may constitute independent accumulations of free methane in the uppermost parts of the coal bearing series, which are the subject of well-exploitation (e.g. Silesia and Marcel mines) [2].

Apart from natural conditions, the intensity of emissions is also influenced by mining factors consisting in the concentration of coal extraction, i.e. increasing the extraction from a single longwall. This entails an increase in the length, height and rate of the wall advance, which causes the relaxation of the rock mass and, consequently, increased gas emission. This issue is discussed in more detail in the publications of, inter alia Krause and Pokryszka [16], and Krause and Smoliński [17] as well as partially of Kędzior and Dreger [2]. It should be mentioned that the source of gas migration occurs not only within the currently mined seam but mainly in the lower and higher seams, e.g. [18], barren rocks (sandstones) and in old goafs. This is confirmed by the specific methane emission, i.e. the emission per tonne of extracted coal. It is much greater than the methane content in the coal seam. In USCB mines, the specific methane emissions are at least several times higher than the measured methane-bearing capacity of the seam. In Australian coal mines, specific methane emissions are four times higher than the methane content in coal [19], and in the USA even more [7]. The variability of methane emissions in deposits related to the above-mentioned natural and mining factors can be considered the primary cause of the variability of gas collection to the methane drainage station due to the high correlation between the total gas emission and degasification, and the coincidence of the variability trends of both these quantities.

5.2. Technical conditions and management of the extracted gas

Table 3 summarises the amount and directions of methane use from the analysed deposits.

Management of the gas captured by methane drainage stations brings both economic and environmental benefits (see section 3). Therefore, modern methane drainage stations with cogeneration systems for the combustion of captured gas have been installed for some time. At the Brzeszcze mine, after a downtime in 2015 caused by economic difficulties and a decrease in methane emissions, a renewed increase in gas emissions is observed (Fig. 3a). In 2021, a modern methane drainage station and two cogeneration installations were commissioned here, and the annual amount of gas obtained increased to 50 million m^3, and 100% effectiveness was achieved, as well as 57% of the total gas emissions are managed. Cogeneration stations process approximately 20 million m^3 of pure

Table 3. Directions of development and CMM consumers in the USCB ([6] and own study).

Deposit	Gas used in 2020 (million m^3)	Effectiveness of gas use (%)	How the gas is used	Gas consumers
Brzeszcze	39.94	100	Heat and power production	Brzeszcze Mine internal demand
Pniówek	32.68	95.81	Heat, cooling and power production	PGNiG Termika Pniówek Mine, Pawłowice community
Zofiówka	11.65	95.18	Heat and power production	PGNiG Termika Zofiówka Mine, Houses and factories in Jastrzębie-Zdrój
Szczygłowice	14.02[a]	24.52[a]	Power production	Szczygłowice Mine internal demand and transfer to other JSW SA mines
Budryk	24.42	72.21	Heat and cold production	Budryk Mine internal demand and heat producer ZPC Żory − transfer to Budryk Mine, schools, housing
Krupiński	11.58	99.06	Heat and power production	PGNiG Termika
Silesia	3.67	22.30	Heat production	PG Silesia Mine internal demand
Wesoła	13.97	61.87	Heat production	EDF Dalkia Polska Energia (former ZEC), local heat plant
Staszic	10.60[b]	77.83[b]	Heat production	EDF Dalkia Polska Energia − methane transfer to neighbouring mines
Sośnica	2.91	15.90	Heat and power production	Sośnica Mine internal demand
Chwałowice 1	5.63[c]	29.52[c]	Transfer to Jankowice Mine methane station	Jankowice heat plant

[a] Data refer to the Knurów-Szczygłowice coal mine, which operates Knurów and Szczygłowice deposits.
[b] Data refer to the Murcki-Staszic coal mine, which operates Murcki and Staszic deposits.
[c] Data refer to the Jankowice and Chwałowice coal mines − methane from Chwałowice 1 deposit is transferred by gas pipeline to Jankowice methane station.

methane, which allows for the production of over 80,000 MWh of electricity and 250,000 GJ of heat per year [20]. Similar solutions are in place at the Pniówek mine, where the production of mine methane is stable at the level of approximately 40 million m^3 of methane per year. A similar situation occurred at the Zofiówka and Budryk mines. In the latter, after installing modern devices for gas intake and combustion in 2015 (an oil boiler with a dual-fuel burner with a capacity of 4 MW), it was possible to increase production to approximately 70 million m^3 in 2016. The decline in the extraction of gas at the Krupiński mine is due to its closure in 2016. However, it did not cause the complete cessation of gas extraction, and over a dozen million m^3 of gas is obtained annually by SRK S.A. as part of its liquidation activities. Significant investments have been made in the Wesoła and Staszic mines, where approximately 20 million m^3 of gas has been produced annually for several years. However, the effectiveness of gas use in these mines, amounting to 65–72% (in 2020), is lower. As can be seen from the above, the installation of new methane drainage stations with new solutions for the combustion of the captured gas and the generation of heat and electricity on site or ensuring its sale to external consumers positively affects both the amount of gas obtained and the effectiveness of use. The expansion of the existing methane drainage stations is therefore an urgent need due to the increasing depth of coal extraction and the amount of gas emissions. The capture and use of methane have a positive effect on mining safety, reducing the risk of mining disasters involving methane, the natural environment in the form of lower methane emissions to the atmosphere and the economic issues of mining, i.e. generating own energy and reducing the need to purchase it from external companies.

A special case here is the Silesia mine, which until 2011 showed almost 100% effectiveness in the use of methane, then there was a decrease to approximately 20% in 2012–2021 (Table 1). The reason could be ownership changes (purchase of the mine by a private entrepreneur) and the cessation of gas sales to external consumers (e.g. Czechowice Refinery) and the current use of gas solely for own needs (Table 3).

5.3. Barriers and brakes for the use of gas from coal deposits

In addition to the benefits of using gas from methane drainage from mines, the Polish coal mining industry has been facing problems with sales and, consequently, full use of gas, which have remained unchanged for years. The most important of them is the aforementioned gas composition, in which methane is only 40–60% and, in addition, it is unstable, which limits the use of this gas for non-energy purposes and eliminates the possibility of transmission in the gas network, because it does not meet the requirements for the composition of pipeline gas. A solution to this problem could be either to separate the methane from the air in a cryogenic or chemical manner or to mix the mine gas with the high-methane gas. The first method seems too costly, while the second, once used, is today too technologically and economically troublesome. Another issue is the uneven demand for energy from mined gas throughout the year, higher in winter and lower in summer. This can be remedied by establishing underground gas storage facilities. However, gas storage requires a favourable geological environment; well-sealed and, in the case of USCB deposits, with strongly fractured rock mass, this issue seems uncertain, and numerous studies and tests are necessary. In recent years, the mentality of the mining industry seems to be changing for the better, which has so far perceived mine methane as a necessary evil and a troublesome mineral commodity that requires the fastest possible removal and release of gas into the atmosphere and thus getting rid of the problem. However, the current legal and financial solutions do not fully encourage mines to intensify efforts to increase the utilization rate of collected gas and its more stable production. A serious obstacle is the lack of legal positioning of gas from mines among the ecologically privileged (renewable) mineral, which could facilitate obtaining funds for projects related to the purchase of gas combustion installations and electricity production in the form of grants or loans on favourable terms. However, a legislative convenience is the lack of the need to apply for a mining licence for an entrepreneur responsible for the mine closure and only during the time of mine liquidation. This privilege is currently used by SRK in the case of the liquidated Krupiński mine. It should be remembered that we will deal with the emission of mine methane at least as long as the coal is extracted. Later, however, the problem will be methane emission from abandoned mines, an example is the Krupiński mine, and, i.e. the Anna mine described by [21]. Therefore, efforts to eliminate methane emissions from underground methane drainage systems should be intensified, primarily in order to avoid surprises related to the need to pay high emission fees in accordance with the CO_2 equivalent, which the European Commission intends to introduce, or possible penalties for prohibited methane emissions from methane drainage stations from 2025.

6. Conclusions

The amount of gas produced from methane drainage in most of the deposits analysed is very variable from year to year. The coefficient of variation exceeds 40%. This amount, in fact, does not depend on the number of tonnes of coal extracted, but it is most correlated with the total gas emissions from individual mines, as indicated by correlation coefficients exceeding 0.65. Trends in changes in extracted gas over time are consistent with trends in total gas emissions within individual fields but differ between fields. In the period 1997−2021, the greatest amount of methane was extracted from the Brzeszcze, Pniówek, Krupiński and Zofiówka fields. In these fields, the effectiveness of gas use was also the highest (80−100%). The amount of emitted and used gas is controlled by natural (geological) factors expressed, inter alia, by the presence of faults as gas migration pathways or sealing screens and mining-related ones, which are manifested by the concentration of coal extraction, as well as the occurrence of higher and lower lying coal seams, and the presence of old goafs accumulating gas. These factors overlap with technical and managing conditions, i.e. the commissioning of methane drainage stations and the possibility of using gas (for the mines' own needs and sales to external consumers). The expansion of the existing methane drainage stations and commissioning new ones is an urgent need due to the increasing depth of coal extraction and the amount of gas emitted. Some inconveniences, such as low methane content in the captured gas and the inability to gas store in the period of reduced demand, make it difficult to achieve the expected level of gas use, however, collecting and full use of mine methane will positively affect mining safety, the natural environment and the economy of mining. Considering the plans of the European Commission to monitor methane emissions to the atmosphere and ban gas discharges from methane drainage stations from 2025, increasing the effectiveness of using the collected methane to 100% is an urgent need.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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Conflict of interest

The authors declare no conflict of interest.

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