sciendo

Environmental & Socio-economic Studies

environ ses

DOI: 10.2478/environ-2019-0002

Environ. Socio.-econ. Stud., **2019, 7, 1: 12-23**

Review article

Methane emissions and demethanation of coal mines in the Upper Silesian Coal Basin between 1997 and 2016

Marcin Dreger, Sławomir Kędzior

Department of Applied Geology, Faculty of Earth Sciences, University of Silesia in Katowice, 60 Będzińska Str., 41-200 Sosnowiec, Poland
E–mail address (corresponding author): marcin.dreger@interia.pl
ORCID iD: Marcin Dreger: http://orcid.org/0000-0002-7250-2523; Sławomir Kędzior: http://orcid.org/0000-0001-6875-3015

ABSTRACT

Between 1997 and 2016 we observed important changes in hard coal extraction and methane emission in the Upper Silesian Coal Basin. Hard coal extraction in the near future will be very dangerous because it will be necessary to reach deeper methane-rich coal seams. Permanent monitoring of the volume of emitted and captured methane is necessary to combat the methane hazard. The predictability of gaseous hazards are important in order to keep underground work safe. We gathered and analysed data from three coal companies: Katowice Coal Holding, the Coal Company, Jastrzębie Coal Company and in the whole of the Upper Silesian Coal Basin for the last twenty years and this allowed us to notice changes and CH_4 trends in ventilation emission and demethanation. There is a decrease in the extraction of hard coal from year to year. At the same time there is an increase in the total methane emissions which forces actions aimed to effective contracting the methane hazard. Specifically, methane emission has been increasing for years, making hard coal extraction very dangerous. We observed increases in CH_4 vent emission and volume of methane coming from underground drainage systems. Much more methane is released during hard coal extraction at deeper mine levels. Throughout the entire research period the methane hazard increased. Therefore, the development of modern technologies for methane capturing should contribute to improvement of hazardous conditions for coal mining in the basin.

KEY WORDS: hard coal extraction, methane emissions, demethanation, ventilation air methane, Upper Silesian Coal Basin

ARTICLE HISTORY: received 30 August 2018; received in revised form 3 February 2019; accepted 11 February 2019

1. Introduction

Hard coal mining is a very complicated component of the extraction industry. Energy production in Poland is largely based on hard coal. Coal mines provide jobs for many people, however, coal extraction comes from seams that contain methane, which makes coal mining dangerous. To keep mining going and to hire many workers, companies have to reach the coal from deeper, and more dangerous, gassy seams. Many Upper Silesian coal mines extract coal from 1 000 meters below the ground level. In the near future the rest of these coal mines will have to reach the coal from deeper levels in order to keep the mines working. Every year, methane emission increases, so the possibility of a catastrophe increases too. Deeper coal seams are more methane rich (KOTARBA & NEY, 1995), so forecasting the volume of methane emissions is very important to keep underground work safe. Polish mines are being closed and hard coal extraction decreases every year. On the other hand, methane emission increases every year, and this trend is going to continue or grow. Demethanation of coal mines is very important nowadays for continued mine safety, because every Mg of extracted coal leads to CH_4 emission (KĘDZIOR, 2009).

In 2016 the Polish mining industry was reorganised. The coal mines, which belonged hitherto to two coal companies – the Coal Company (Kompania Węglowa) and Katowice Coal Holding (Katowicki Holding Węglowy) were incorporated into the newly established Polish Mining Group (PMG). In this way PMG became the largest mining company in Poland and Europe. Methane emissions from coal mines include methane emitted to the atmosphere together with ventilation air through ventilation shafts (ventilation air methane – VAM) and methane captured with underground methane drainage systems (degassing or demethanation). The purpose of the paper is to determine the variability of the volume of VAM and demethanation at the background of the amount of coal extracted in 1997-2016 both in three coal companies, i.e. Coal Company, Katowice Coal Holding and Jastrzębie Coal Company and in the entire Polish USCB.

2. Method

To show how hard coal extraction, methane emission levels and the amount of demethanation have changed, coal mines have been divided according to the previous division of USCB mines into three coal companies (Fig. 1). The largest was the Coal Company (CC) with the highest number of coal mines which included, Katowice Coal Holding (KCH) covering several coal mines from the Katowice region, and Jastrzębie Coal Company (JCC) consisting of five coal mines located in the vicinity of Jastrzębie in the south of the USCB (Fig. 1). As already mentioned, this division existed until 2016. Then, the mines of KCH and CC became a part of PMG.

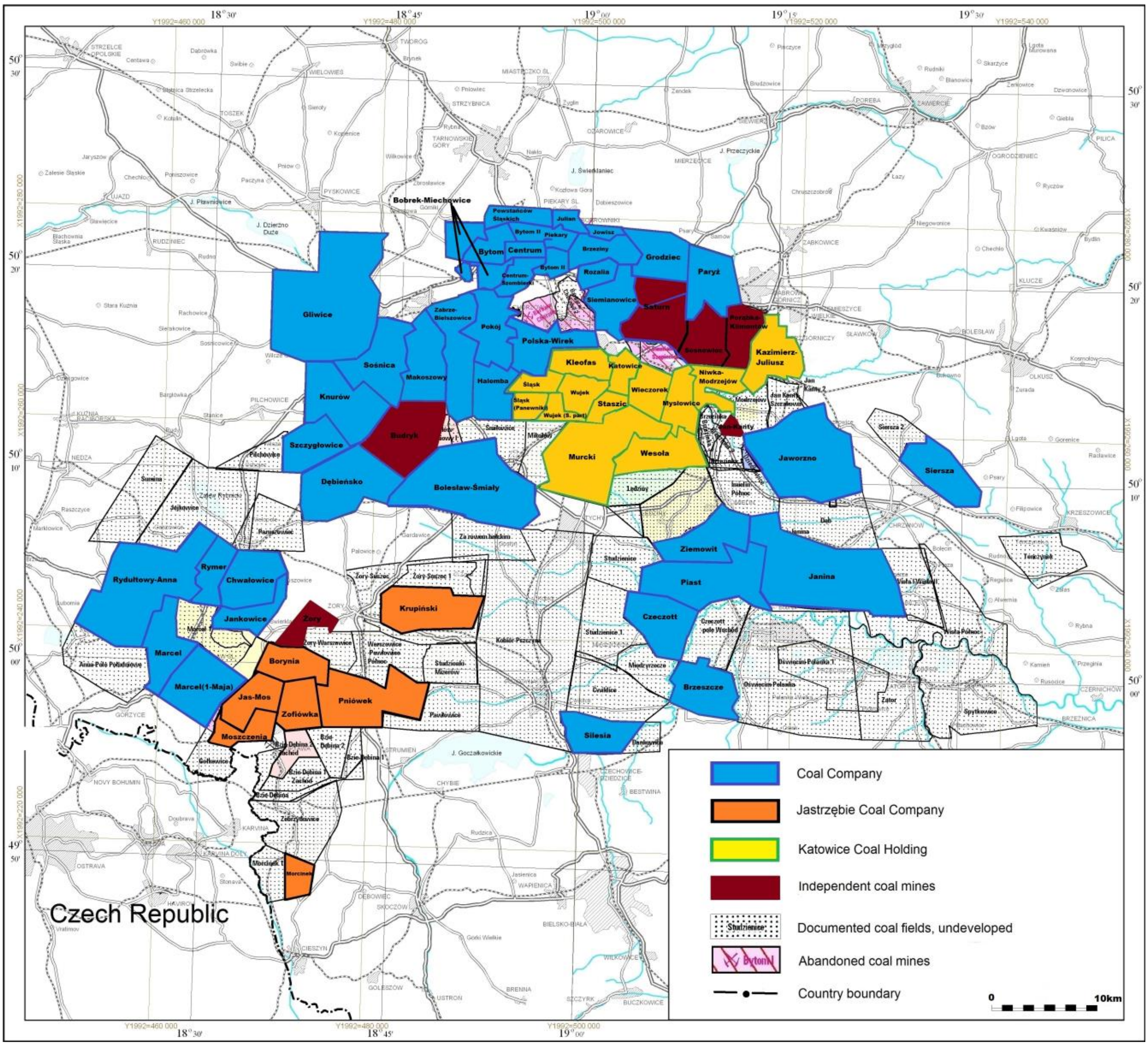

Fig. 1. Map of the coal companies and the arrangement of the coal deposits. in 1997
(modified after Polish Geological Institute – National Research Institute, 2017)

Most of the data, including amount of hard coal production, volume of methane emissions from the ventilation mine systems and amount of methane captured by demethanation mine stations, were obtained from the "*Annual report about basic, natural and technical threats in hard coal mining*" (Krause & Sebastian, 1997-2016). Based on the analysis of the most important data, such as hard coal extraction, absolute methane emissions, specific methane emissions and ventilation air methane emissions, figures, which show changes in these have been made. We can observe changes of hard coal extraction, methane emissions and demethanation in each coal company and the whole Upper Silesian Coal Basin, on graphs over the last twenty years. The period between 1997-2016 overlaps with the structural changes in Polish mining.

2.1. Outline of the geological structure and occurrence of methane

The Upper Silesian Coal Basin (USCB) is the largest coal basin in Poland and one of the largest in Europe. It covers an area of ca 7500 km^2 with boundaries within Poland and the Czech Republic, of which about 5600 km^2 are located in Poland.

The USCB belongs to the Palaeozoic platform unit that was consolidated during the Variscan and Caledonian orogenesis (Bukowy, 1972). It is a part of the Precambrian tectonic unit called the Brunnii-Upper Silesian Massif. The coal-bearing Upper Carboniferous strata filling the Upper Silesia depression is of the molasse type (Kotas, 1985).

The actual economic series consists of Upper Carboniferous deposits containing numerous coal seams lying among clastic rocks such as clays, siltstones and sandstones (Buła & Botor,1995; Wasilewska, 2007). In the profile of the Upper Carboniferous deposits about 400 coal seams and inserts were found, of which about 260 are of industrial value. The total thickness of balance coal seams (>0.6 m in thickness), up to a depth of 1000 m, is about 65 m in maximum, 20-30 m on average. The average thickness of individual balance seams varies within 0.7-3.0 m (e.g. Konstantynowicz, 1994).

The Carboniferous deposits lie relatively flat, dips in the coal seams do not exceed 10 degrees. The coal seams are cut by numerous faults in various systems, within which the seam dip increases. In addition to faults, folding structures are also present in the central and western part of the basin. In the latter there are depressions (thoughts), overthrusts and faults which complicate the tectonic structure of the USCB.

The coal rank varies both longitudinally and vertically. Vertical changes are in accordance with Hilt's rule where coal rank increases with depth. The lateral variations of coal rank arrangement are evident. The hard coal of the highest rank (the coking coal of 34-35 types and special coal) occurs in the south-western area of the USCB where the average ash content of that coal is equal to about 16%. Northern and eastern regions of the USCB are represented by coal of a lower rank (energetic hard coal of 31-33 types) with an average ash content of about 13%. Resources of hard coal in the USCB are estimated at 70 billion Mg in coal seams down to 1000 m deep. About 10-15% of coal has been exploited (Konopko, 2010; Kędzior, 2012; Gonet & Nagy, 2012).

In the USCB two main geological settings of vertical distribution of coal-bed methane can be distinguished (Kotas, 1994). These two settings are connected to the thickness and characteristics of the rocks covering the Carboniferous sub-surface (Fig. 2) (Kotas, 1994). Northern and middle-eastern regions of the USCB, where coal-bearing strata are covered by thin and permeable Triassic, Jurassic and Quaternary formations, are characterised by the occurrence of naturally degassed coal seams to a depth of 500-600m, with a methane content which does not exceed 4.5 $m^3/Mg\ c^{daf}$. Impermeable for gases Miocene clays, lying in the form of isolated patches in these USCB regions, are too thin (up to 100 m in thickness) to halt methane migration into the atmosphere in the geological past.

At greater depths than 500-600 m, methane content increases rapidly until it reaches the primary methane maximum where methane content exceeds 10 $m^3/Mg\ c^{daf}$. Deeper than the maximum, methane content tends to decrease.

Southern and south-western regions of the USCB are characterized by the presence of two maxima for the methane content. The first includes secondary accumulation of methane adsorbed in coal seams just under the impermeable and thick cover of the Miocene formation. The deeper lying primary methane maximum reaches the depth of the prospection limit, but deeper than 1500-2000 m the methane content decreases. Both methane maxima zones are separated by an interval of lower methane content (methane minimum) which can get thinner, or totally, vanish and thus in all of the Carboniferous profile the methane content is high (Kotas, 1994; Kędzior, 2012).

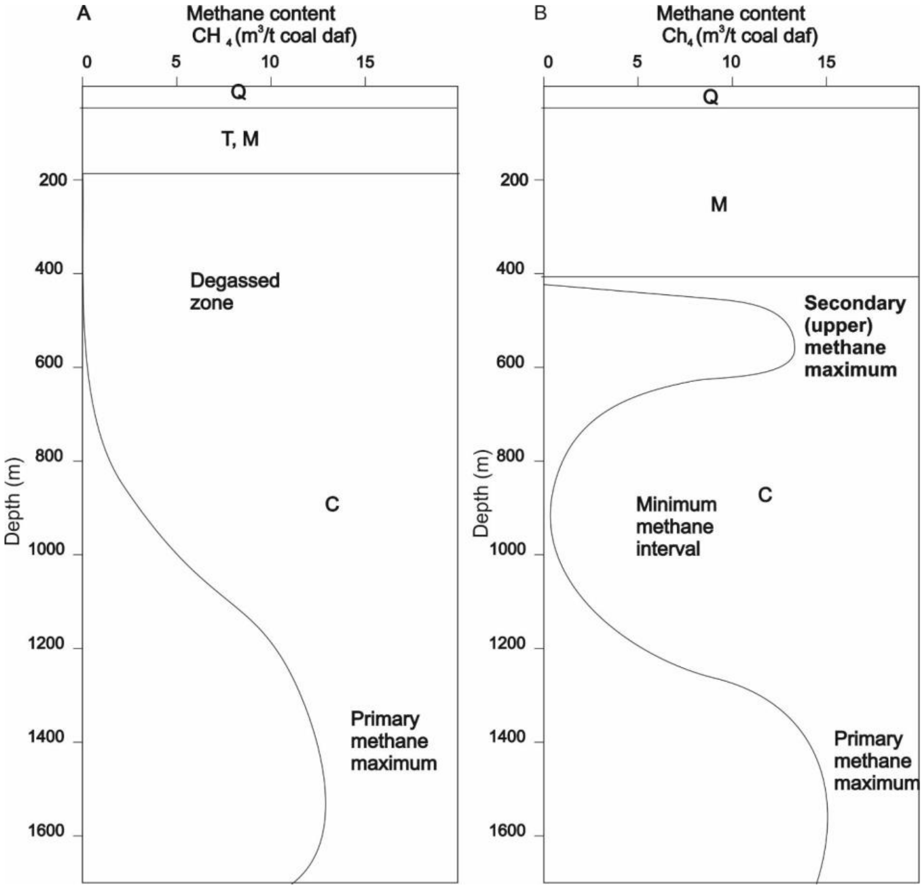

Fig. 2. Methane distribution in the northern (A) and southern (B) parts of the USCB (modified after Kędzior, 2012, 2015a; Kotas. 1994), Q – Quaternary, T – Triassic, M – Miocene, C – Carboniferous

The Upper Silesian Coal Basin was divided into seven gassy regions to show and describe the lateral differentiation of CH_4 (Fig. 3). Four main faults divide the USCB into five almost latitudinal arranged gassy regions (from I to V). On the other side, two overthrusts (Michałkowice and Orłowa-Buguszowice) divide the western part of the USCB into two gassy regions which run nearly longitudinally (VI and VII). Every region is characterised by different gassy conditions and different accumulations of methane in the coal seams.

Northern and central regions (I, II and III) are mostly naturally degassed. Thanks to a lack, or small thickness, of Miocene cover in the Carboniferous overburden and permeable Triassic, Jurassic and Quaternary formations, CH_4 was liberated to the atmosphere from coal formations in the geological past That is why, the naturally degassed zone up to the depth of 500-600 m is evident here. The depth of the high-methane zone – indigenous (methane content up to 22 m^3/Mg c^{daf}) occurs from 600 to 1200 m under ground level. The most dangerous gassy conditions are found in regions IV and V. In the IV region, within primary high-methane zone, the methane content is from 6 m^3/Mg c^{daf} to above 18 m^3/Mg c^{daf} . In gassy region V both of the high-methane zones are particularly evident. Methane content varies from 10 to 22 m^3/Mg c^{daf}. A thick deposition of Miocene overburden and the presence of faults facilitated the migrating methane to accumulate within the uppermost part of the Carboniferous formation.

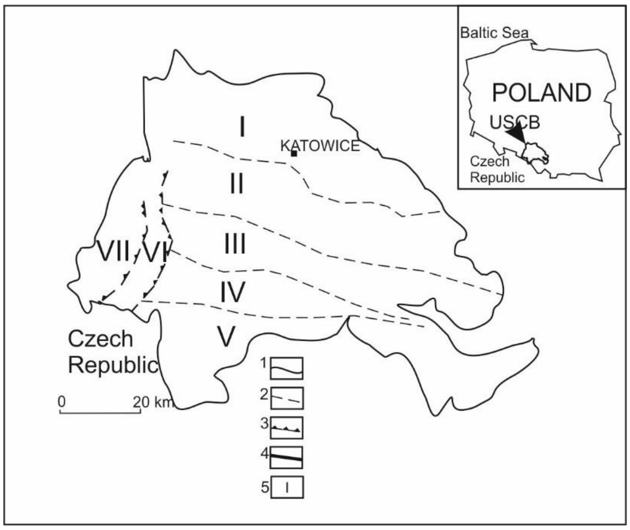

Fig. 3. Division of the USCB into seven gassy regions (modified after Kotarba et al., 1995)
1 – the USCB boundary, 2 – main faults, 3 – overthrusts, 4 – the regions boundaries, 5 – region number

The two western most USCB gassy regions (VI and VII) are poorer in methane than the IV and V regions. In the VI region a varied methane content can be observed laterally. More methane-rich seams are in the central part of the region. Closer to the border of the VI region (the region is limited by the Michałkowice and Orłowa-Buguszowice overthrusts) a decrease is observed in the methane content. It can be assumed, that permeable overthrusts are the active pathways for gasses and aided seams to degas. Region VII is characterised by various thicknesses of Miocene cover – from 0 to 1000 m. In this way an allochtonic high-methane zone cannot be noticed because some of the seams have been degassed in the past. The primary methane maximum occurs at depths greater than 600 m, where the methane content amounts to around 12 $m^3/Mg\ c^{daf}$ (KOTAS, 1994; KĘDZIOR, 2012).

3. Results

3.1. Hard coal production

The most important factor, describing every mine or corporation, is the amount of exploited coal. From the beginning of the study period (1997) coal production showed a decreasing tendency in the whole of the Upper Silesian Coal Basin. In the beginning of this period, all coal mines in Upper Silesia extracted more than 100 million Mg per year (Fig. 4). Between 2000 and 2006 coal production decreased slowly and the difference in extracted coal between 2000 and 2006 was equal to 9 million Mg. The coal extraction decreased gently and consistently. In 2016 Upper Silesian mines extracted 61.3 million Mg, which corresponded to just 45% of the production for 1997.

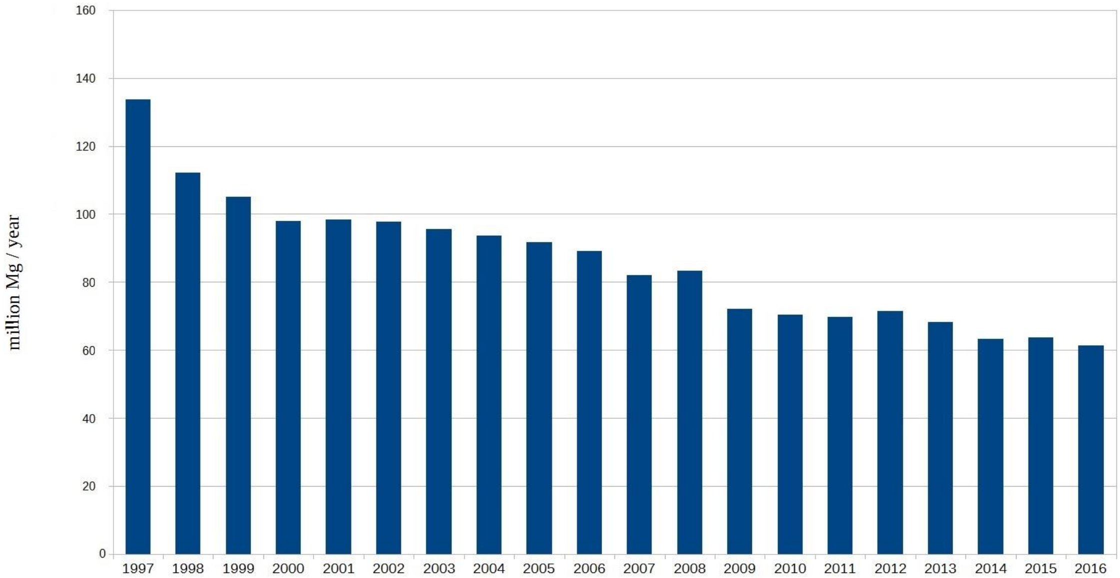

Fig. 4. Hard coal production in the Upper Silesia Coal Basin

The Coal Company (CC) united most of the Silesian coal mines. In this way, most of the coal has been extracted by CC during the studied period (Fig. 5). Due to the serious re-organisation of the mining sector and the process of mines closing, coal extraction decreased every year. In the first year (1997), CC mining participation was 65% of the whole USCB production (86.7 million Mg) but in the last year, it was just 38.5% (23.6 million Mg). The closure of two coal mines is one of the main reasons for the serious drop in coal extraction in the last years of this period. In 2011, the Silesia Coal Mine was separated from the CC and transformed into an individual coal corporation named "PG Silesia" ("Silesia Enterprise"). In 2016, "Brzeszcze" coal mine was joined into Coal Restructuring Company. One year later the new corporation was founded – new Brzeszcze Coal Mine which is a member of the "Tauron Wydobycie" Group.

Coal output for the Jastrzębie Coal Company (JCC) was stable and oscillated around 13 million Mg (Fig. 5). But in the first three years of the period a big drop was noticed. The hard coal production decreased to less than 12 million Mg in 2007 and 2009. Knurów–Szczygłowice Coal Mine was joined into JCC in 2014. This coal mine helped to increase the company production to more than 16 million Mg in 2016. In the last year studied (2016) Jastrzębie Coal Company extracted only 300 thousands Mg less than in the best year (1997).

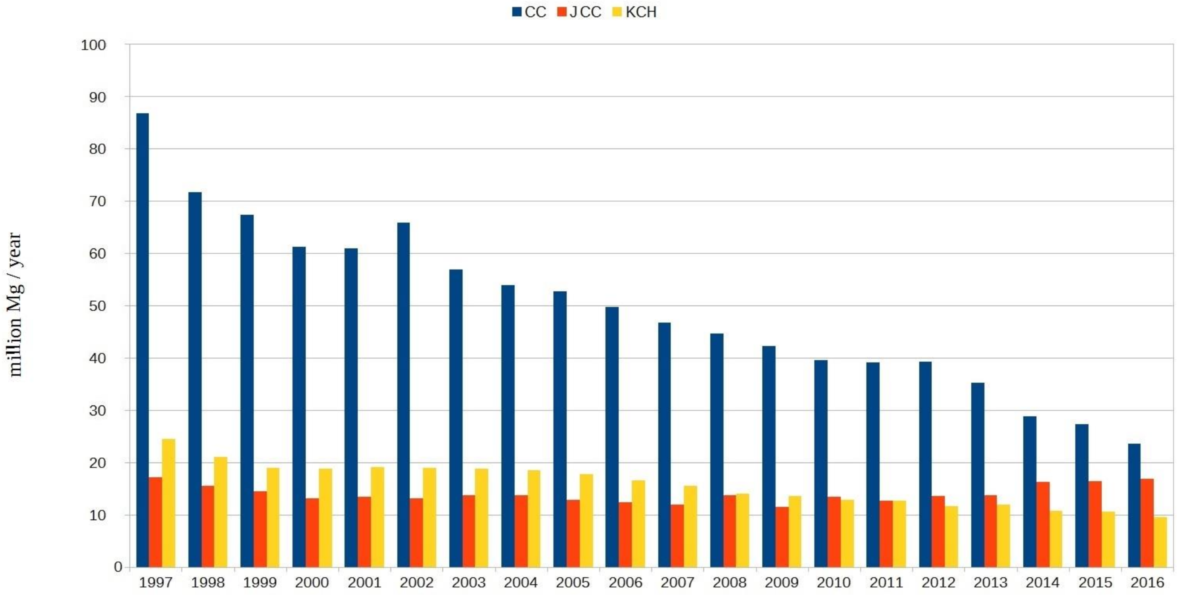

Fig. 5. Hard coal production of the coal companies

Katowice Coal Holding (KCH) was the most stable coal corporation in the USCB. The reorganisations processes weren't needed in KCH, so hard coal production is studied from a similar number of mines. Coal production exceeding 20 million Mg was noticed only in 1997 and 1998. It was the most effective period in KCH history. A constant fall of coal output was noticed to the end of 2008, when 15 million Mg of coal were extracted. A bigger drop of coal output was clearly noticed in 2006, when only 9.5 million Mg of coal were produced. Coal production in 2016 was about 61% lower than in the beginning of the study period.

3.2. Absolute methane emission

Absolute methane emission is the sum of the ventilation air methane and the methane coming from mine demethanation. Deeper and deeper coal extraction that has reached the primary methane maximum means a higher methane danger (GRZYBEK & KĘDZIOR, 2005). The changes in total absolute methane emission from 1997 to 2016 are shown in Figures 6 and 7.

Absolute methane emission for all mines in the Upper Silesian Coal Basin have grown (Fig. 6) with a gentle drop in the period 2009-2012. Over 933 million m^3 of methane were yearly liberated in mine excavations in the last two years (2015-2016). This was a 22% growth in relation to the beginning of the study (760 million m^3 in 1997). In the last twenty years, 16 584 million m^3 of CH_4 has been released from Upper Silesian coal mines.

More than 2 750 million m^3 of methane were liberated during the period 2014-2016, which constituted a 16.6% share of the twenty years of the study term. The periodic changes of the total methane emission from the whole USCB and each of the three Polish coal companies differ.

The Coal Company's (CC) methane emissions had been consistently growing from 321 million m^3 in 1999 to 402.3 million m^3 in 2007 (Fig. 7). After that period methane emissions dropped with partial rises in 2009 and 2012. The decrease in coal extraction affected lower methane liberation in the last few years. One of the reasons for this is the separation of two large coal mines from CC. An extremely low methane emissions (153 million m^3 of CH_4) could be observed in 2016. This constituted a 49% drop compared with the beginning of the studied period (1997).

The absolute methane emission of the Jastrzębie Coal Company (JCC) can be divided into two similar stages including the first stable methane liberation, and subsequent decreases and a quick rise (Fig. 7). Methane emissions were less than 300 million m^3 in the first two analysed years. Next, a drop to 242 million m^3 in 2002 was observed. From that period to 2008 methane emissions had still been rising, to an amount of 386 million m^3 of liberated CH_4 in 2008. In the next three years methane emissions were at the level of 330 million m^3. In the last four years there was a noticeable increase in the emission of methane was up to 483 million m^3 in 2016. Possible reasons for the rise in methane emissions is the difficult geological-mining conditions in the extraction region, such as differences in the Miocene cover thickness, variable Carboniferous lithology and methane content growth in deeper parts of the deposits (GRZYBEK & KĘDZIOR, 2005). In the JCC the CH_4 emissions increased by 60% in the 2012-2016 period.

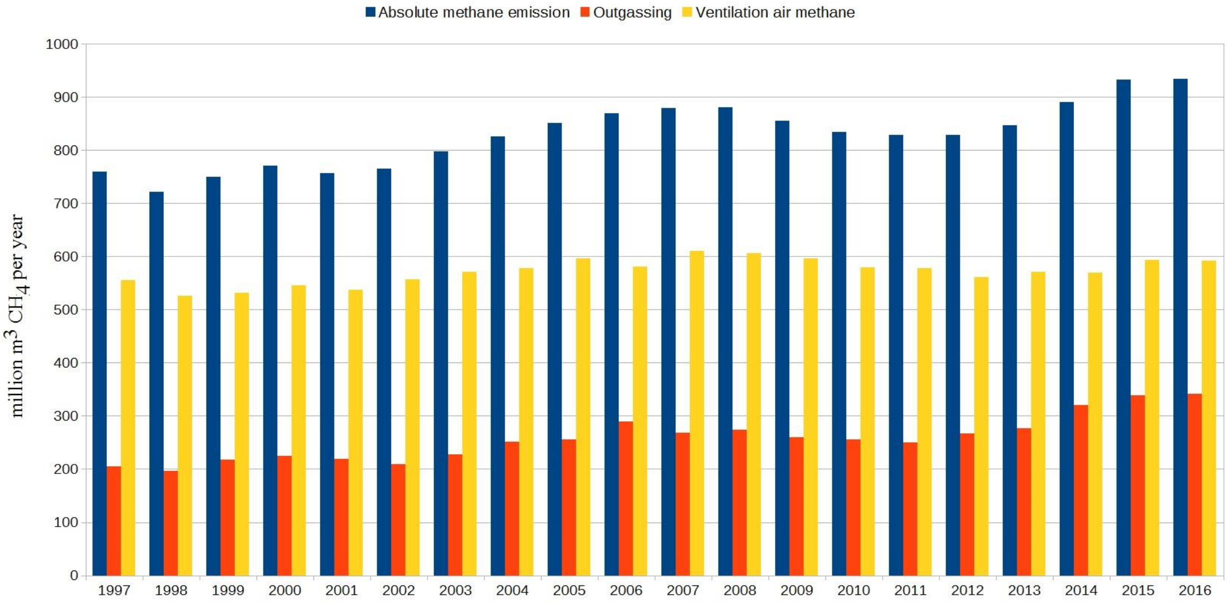

Fig. 6. Absolute methane emissions, ventilation air methane content and mine degassing in USCB

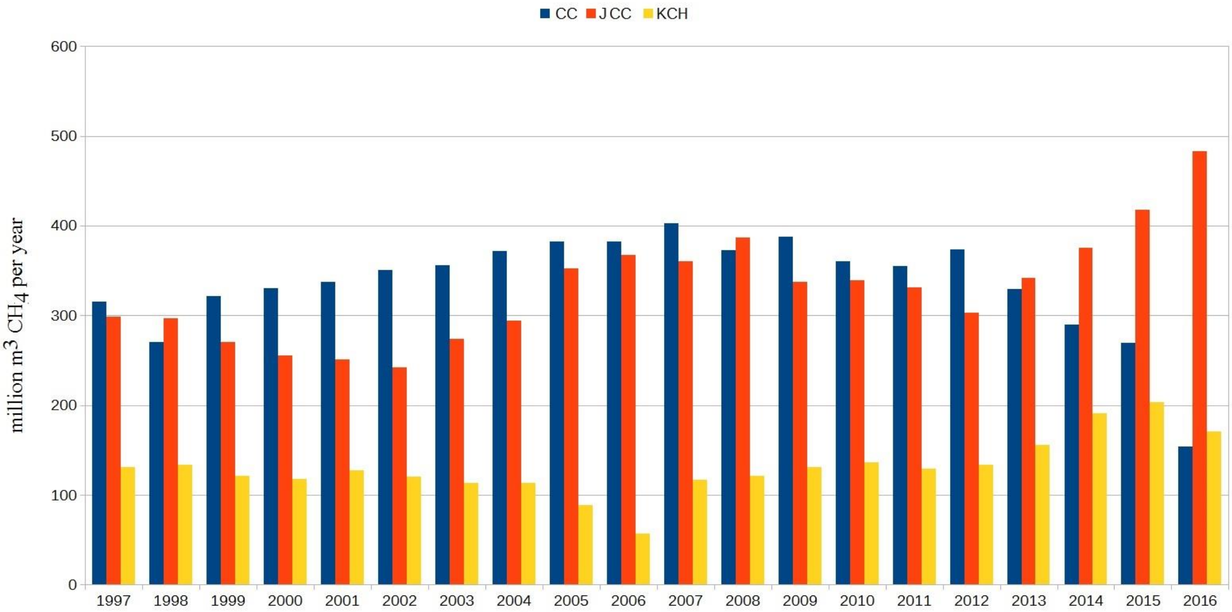

Fig. 7. Absolute methane emissions for the coal companies studied

Katowice Coal Holding (KCH) was the most stable corporation in the whole of the Upper Silesia Coal Basin from the point of view of coal extraction and methane emissions. Before 2013 the methane emissions fluctuated between 110–130 million m^3 per year. In 2005-2006 the methane emissions dropped under the level of 100 million m^3 per year. The highest methane emissions were noticed in 2015, when more than 200 million m^3 of methane were liberated. In the last four years of this research, the fast growth of methane emissions was evident due to the hard geological-mining conditions. Hard coal exploitation from deeper parts of the deposits was connected to the increase in methane content at depths of 600-1200 m. Shallower parts of the deposits were naturally degassed in the past by faults facilitating methane migration and the lack of hermetic Miocene cover in the northern part of the USCB (Kędzior, 2015b; Kotas,1994).

3.3. Specific methane emission

Specific methane emission describes how much methane volume is emitted to mine workings with every extracted Mg of hard coal. It is a very important index, because it shows a real methane danger. Within the last twenty years coal production had been decreasing (Fig. 4) while methane emission had been gently rising (but with periodic drops) (Fig. 6). Many of USCB mines extracted coal from deeper than 1 000 m. In this way, mines reached the primary methane maximum in the profile, with methane content in lower lying coal seams higher than in upper lying seams (Kędzior, 2012).

Specific methane emission increased three times throughout the studied period (Fig. 8), from 5.7 m^3 CH_4/t in 1997 to 15.2 m^3 CH_4/t in 2016. This means that in 2017 for each extracted Mg of hard coal, specific methane emission was tripled – in reference to 1997. From the beginning of the studied period to 2009 the specific methane emission had been constantly growing with slight fluctuations. There was a four-year stagnation period (2009-2012) with an average of 11.8 m^3 methane emitted per one Mg of coal. The period of the last four years (2013-2016) was characterised by a rapid increase in the specific methane emission from 12.44 to over 15 m^3CH_4/t.

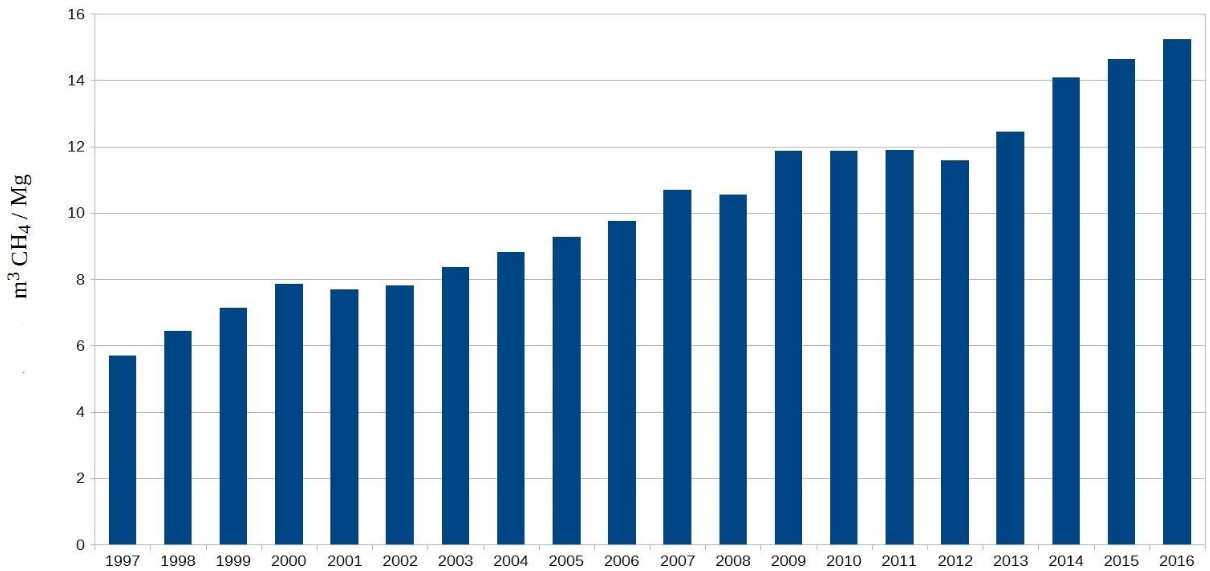

Fig. 8. Specific methane emission at USCB

3.4. Degassing

The underground mining degassing system is one of the methods to keep mining work safe. Mine degassing leads to the drainage of as many coal-bed gases as possible to outside the mine, or to the place of the ventilation network, where these gases are no longer a danger for the working miners. Furthermore, the collected gas can be used economically in the mining processes, or sold to outside customers (Kozłowski & Grębski, 1982; Szlązak, 2015).

The most effective period for degassing was 2014-2016 when in total 1 billion m^3 of methane was collected by the Upper Silesian coal mines (Fig. 6). Except for the period of the last 36 months, the degassing was at a stable level – 200-250 million m^3 per year, with slight periodic fluctuations. Within the whole studied period 5151 million m^3 of methane was collected from the USCB coal mines, which constituted 31% of the absolute methane emissions.

Constant degassing, which amounted to over 100 million m^3 per year, took place in the Coal Company in 2005-2009 (Fig. 9). Before 2009 there was a constant growth of degassing, but in the next years this trend was diminished with a growth in the 2012 period (124 million m^3).

The Coal Company degassing was very similar to the degassing noticed in the whole USCB. The contribution of degassing is 27% of the absolute methane emissions.

The hard coal mines belonging to the Jastrzębie Coal Company noticed decrease in degassing during the first six years of the research period (1997-2002)– from 111 million m^3 to 86.6 million m^3 of methane per year. Degassing in the next years was characterised by 100 million m^3 of captured CH_4 per year. In 2013-2016 demethanation of the JCC mines increased. The same trend was evident for the absolute methane emission, 530 million m^3 of methane was captured during the degassing of the JCC coal mines during the last 36 month period, which was 37% of the absolute methane emissions.

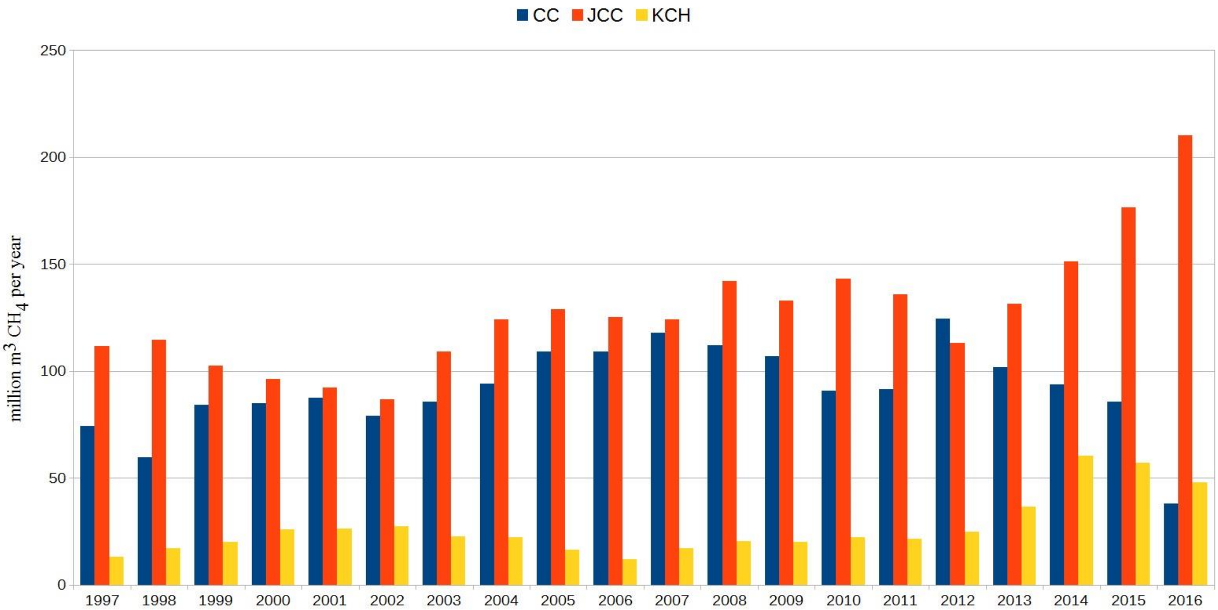

Fig. 9. Amounts of degassing by coal companies

The Katowice Coal Holding used only 20% of the captured methane for heating and power producing processes. This was the lowest ratio in the USCB. In the first six years the quantity of captured methane gradually increased, from 13.2 to 27.3 million m^3. Then, the fall in degassing was noticed, up to 12 million m^3 in 2006. A gentle, but constant growth in demethanation (degassing) took place in the next 72 months. The largest amounts of captured CH_4 in 2014 amounted to 60 million m^3. Building new and expanding the existing mine demethanation stations improved the degassing systems in the coal mines in the USCB and increased the quantity of collected gas.

3.5. Ventilation air methane

The underground ventilation systems of the coal mines and methane captured by mining demethanation are the two main solutions to keeping the mining atmosphere safe. One of the disadvantages of releasing hundreds of millions of m^3 of CH_4 to the atmosphere is enlarging the greenhouse effect.

The Upper Silesian Coal Basin is characterised by the stable release of ventilation air methane from coal mines amounting to more than 500 million m^3 per year (Fig. 6). The level of 600 million m^3 of gas removed by underground ventilation systems was slightly exceeded, or was very close to doing it, in 2005, 2007-2009 and 2015-2016.

The Coal Company emitted 284 million m^3 of CH_4 in 2007. It was the biggest ventilation air methane emission during the research period (1997-2016). Before 2009, the emission of ventilation air methane was still rising, but after 2009 there was a sudden and constant decrease. The level of under 200 million m^3 of methane released per year was reached in the period 2013-2015. One year later the amount of ventilation air methane was the lowest in the studied period – 115 million m^3 of CH_4, which constituted just 40% of the highest ventilation outcome in 2007 (Fig. 10).

The amounts of methane emitted, by underground ventilation systems, in the JCC were completely different when compared with other companies. The first period (1997-2004) was characterised by 160-185 million m^3 of methane emitted per year. After that there was a four-year increase. Each year 220 million m^3 of CH_4 was emitted from the JCC's mines. In the third period (2014-2016) there was an increase in the ventilation air methane emission from 224 million m^3 in 2014 to 272 million m^3 in 2016. The Jastrzębie Coal Company extracts hard coal in complicated and very dangerous gassy conditions. At the southern part of the JCC's deposits the Miocene cover is thicker than in the northern part (Kotas, 1994) and constitutes a hermetic screen for gases. Thus, almost all the Carboniferous profile is methane rich and therefore the JCC's mines are the leaders in degassing and releasing ventilation methane to the atmosphere.

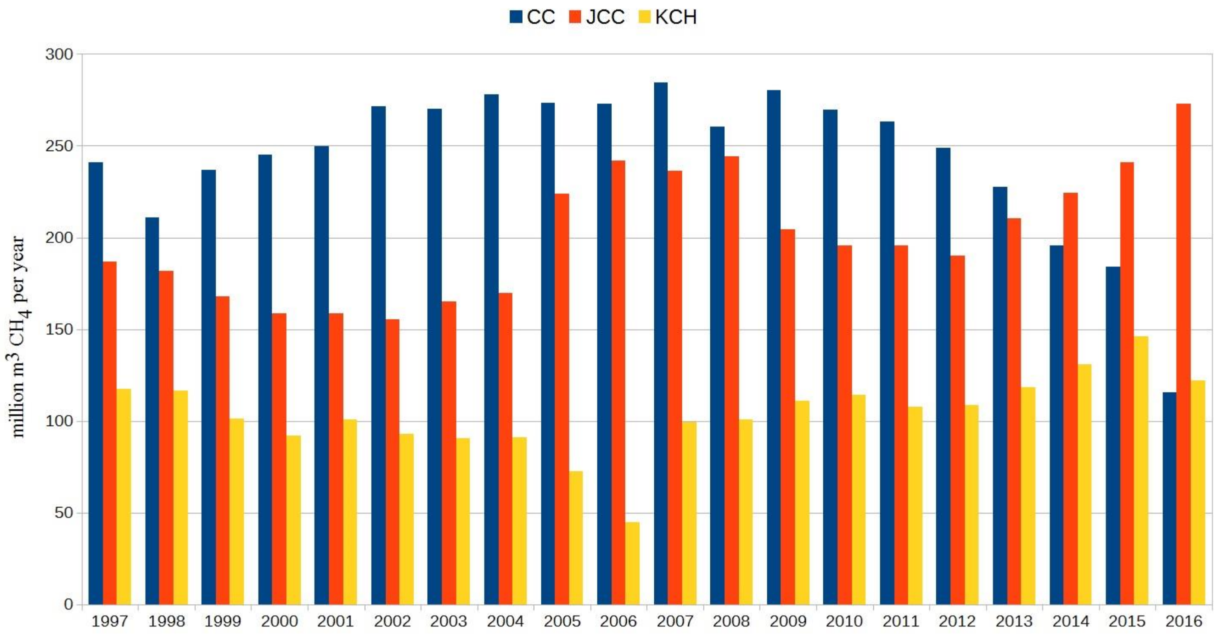

Fig. 10. Ventilation air methane inform the coal companies

The first period (1997-1998) for the Katowice Coal Holding was characterised by 117 million m^3 of methane emitted in 1997 and 116.4 million m^3 in 1998. The emission of ventilation air methane gently dropped in the next years but in 2002–2004 stagnation was evident. Two years later the lowest amount of methane – just 45 million m^3 was emitted from KCH coal mines. It's important to note that at the same time (2016) the absolute methane emission, ventilation air methane and demethanation for the whole of the Katowice Coal Holding were at the lowest during the study term. From 2006 to 2015 ventilation methane emission rose to the level of 146 million m^3 of emitted methane. Throughout the 20 years KCH emitted 2080 million m^3 of methane to the atmosphere, which was equal to the four-year (2013-2016) emission period for all the mines in the whole of the Upper Silesia Coal Basin.

3.6. Specific ventilation air methane (VAM) emission

Specific VAM emission describes how much methane is liberated to the atmosphere from ventilation shafts with each Mg of hard coal extracted. Specific VAM emission values are really similar to the specific methane emission. These two figures are closely connected (Fig. 8 and 11). Rises and falls in the specific methane emission are almost in the same periods as for the specific VAM emission. At the beginning of the studied period (1997) coal mines in USCB released 4.15 m^3 of methane with each extracted Mg of hard coal (Fig. 11). In the following years the specific VAM emission rose. Thus, seven years later (2004) the level of 6 m^3 gas, were liberated out of the mines per excavation of one Mg of hard coal were exceeded. The first of two gentle falls took place in 2008, where the specific VAM decreased by a value 0.15 m^3CH_4 per Mg (7.43 m^3CH_4 in 2007 and 7.27 m^3CH_4 in 2008). But in 2009 the specific VAM emission value rose to 8.27 m^3 of CH_4 released per one extracted Mg of hard coal. The same trend was noticed for the specific methane emission with a gentle drop from 10.7 m^3 of emitted CH_4 in 2007 to 10.56 m^3 in 2008 (Fig. 6). In 2009 there was a quick rise to 11.88 m^3 CH_4. After that period values in both figures increased until a second gentle drop in 2012. Specific VAM emission decreased from 8.30 m^3CH_4 in 2011 to 7.86 m^3 in 2012. One year later (2013) there was a return in the upward trend with 8.39 m^3 methane released per one Mg of hard coal. In the last year of the studied period the specific VAM emission was 9.65 m^3CH_4/Mg. In this way, in 2016, Polish coal mines released to the atmosphere over two times more methane per one Mg of hard coal than at the beginning of the study period (4.15 m^3 in 1997 and 9.65 m^3 in 2016).

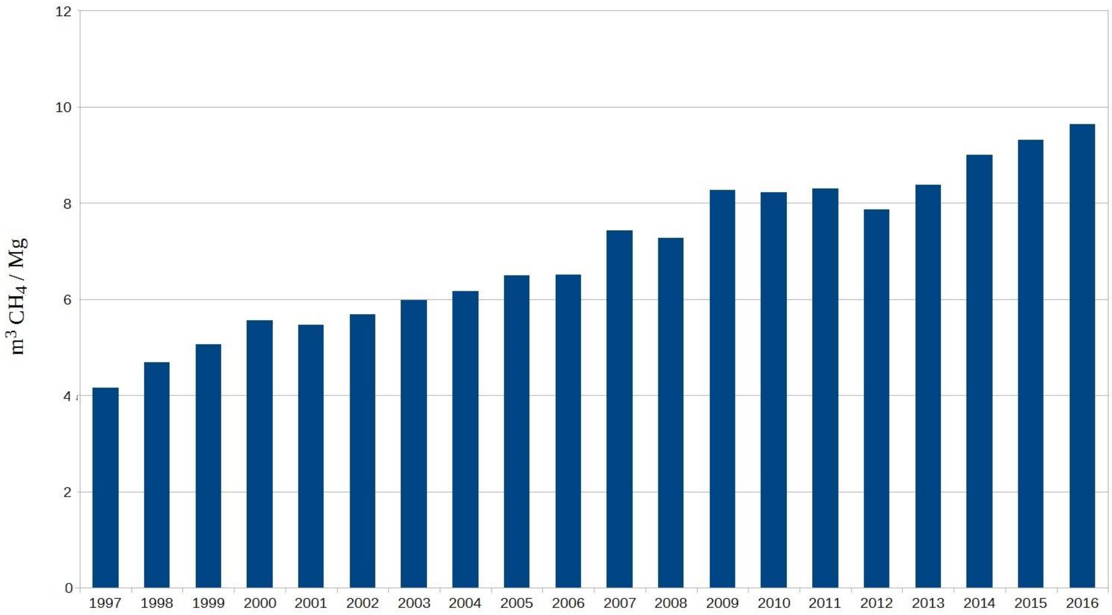

Fig. 11. Specific ventilation air methane (VAM) emission in the USCB

4. Conclusions

Within the twenty year study period (1997-2016) hard coal production in the USCB decreased from over 100 million Mg in 1997 to just 61.3 million Mg in 2016. The vast majority of coal mines working during these years were characterized by a serious methane hazard. To keep mines productive, coal seams deeper than 1 000 m below ground level are operated now or will be operated in the near future. That means that coal is extracted from the depth corresponding to the primary methane interval (>500-600 m), in which the coal seams are methane-rich and therefore the increase in methane emissions is currently evident and will be observed in the future.

Over the study period the absolute methane emission for the whole USCB had been constantly increasing, with the exception of one gentle drop in the 2009-2012. Over 933 million m^3 of methane were yearly liberated from mine excavations during the last two years of the study (2015-2016). Hard coal production dropped and absolute methane emission rose, with an increase in specific methane emission every year. Throughout the studied period (1997-2016) the specific methane emission increased three times – from 5.7 m^3CH_4/t in 1997 to 15.2 m^3 CH_4/t in 2016. To keep workers and mines safe, methane was captured by underground systems and used in the internal processes of the mines, such as heating or power production.

The Coal Company united most coal mines in the USCB, which were located in all the gassy regions. Thus the absolute methane emission and ventilation air methane emission figures were the highest for the whole of the studied period – with the exception of the last four years, when restructuring processes took place and the Jastrzębie Coal Company became the four-year leader, emitting the most CH_4.

The Jastrzębie Coal Company's mines are located in the central-southern and southern parts of the USCB. Here mining and geological conditions are very complex and favourable for methane accumulation. Captured methane can be used for heating and power processes. For this reason JCC's mines captured the most methane during the last twenty years of the study.

The Katowice Coal Holding united the lowest number of coal mines in the USCB. The KCC' mines were located in the central and northern regions of USCB, so geological and methane conditions are not as dangerous as in rest of the coal basin. Therefore degassing, absolute methane emission and ventilation air methane emission figures were significantly lower than those for CC and JCC's.

By reaching deeper coal seams, highly rich in methane, Polish mines will struggle with very dangerous gassy conditions. Figures relating to specific methane emission have shown that every year more methane is emitted for each single extracted Mg of hard coal. Specific methane emission is closely connected with specific VAM emission and shows that for every extracted Mg of hard coal, the amount of liberated methane increases every year.

From 1997 to 2016 the methane hazard increased but by increasing degassing and use of modern technology this should keep mines safe.

References

Bukowy S. 1972. Budowa podłoża karbonu Górnośląskiego Zagłębia Węglowego. *Karbon Górnośląskiego Zagłębia Węglowego. Prace IG*, 61: 23–59.

Buła Z., Botor D. 1995. Zarys budowy geologicznej i warunki geotermiczne utworów węglonośnych górnego karbonu w Górnośląskim Zagłębiu Węglowym. [in:] R. Ney, M. Kotarba (eds.) *Opracowanie modeli oraz bilansu generowania i akumulacji gazów w serii węglonośnej Górnośląskiego Zagłębia Węglowego*. Wydawnictwo Centrum PPGSMiE PAN, Kraków: 25–41.

Gonet A., Nagy S. 2012. *Technologia wydobycia metanu z pokładów węgla*. Akademia Górniczo-Hutnicza, Kraków.

Grzybek I., Kędzior S. 2005. Zróżnicowanie warunków gazowych Górnośląskiego Zagłębia Węglowego, a możliwości migracji metanu ze zlikwidowanych kopalń węgla kamiennego. *Zeszyty Naukowe Politechniki Śląskiej*, 268: 55–66.

Kędzior S. 2009. Problem emisji i ujmowania metanu kopalnianego na przykładzie wybranych czynnych kopalń południowej części Górnośląskiego Zagłębia Węglowego. *Górnictwo Odkrywkowe*, 2–3: 79–83.

Kędzior S. 2012. *Przystropowa strefa gazonośna w utworach karbonu południowej części Górnośląskiego Zagłębia Węglowego: występowanie, parametry zbiornikowe węgla oraz możliwości pozyskania metanu*. Wydawnictwo Uniwersytetu Śląskiego, Katowice.

Kędzior S. 2015a. Methane contents and coal-rank variability in the Upper Silesian Coal Basin, Poland. *International Journal of Coal Geology*, 139, 152–164.

Kędzior S. 2015b. Emission and commercial utilization of coal mine methane in the Upper Silesian Coal Basin illustrated by the example of Katowice Coal Holding Company. *Environmental & Socio-economic Studies*, 3, 1: 1–10.

Konopko W. 2010. *Warunki bezpiecznej eksploatacji pokładów węgla zagrożonych metanem, tąpaniami i pożarami endogenicznymi.* Główny Instytut Górnictwa, Katowice.

Konstantynowicz E. 1994. *Geologia złóż kopalin. Kopaliny energetyczne*. Wydawnictwo Uniwersytetu Śląskiego, Katowice.

Kotarba M., Ney R. 1995. Węglowodory w utworach węglonośnych górnego karbonu Górnośląskiego Zagłębia Węglowego. [in:] R. Ney, M. Kotarba (eds.) *Opracowanie modeli oraz bilansu generowania i akumulacji gazów w serii węglonośnej Górnośląskiego Zagłębia Węglowego.* Wydawnictwo Centrum PPGSMiE PAN, Kraków: 7–24.

Kotarba M., Pękała Z., Daniel J., Więcław D., Smolarski L., 1995. Rozkład głębokościowy zawartości metanu i węglowodorów wyższych w utworach węglonośnych górnego karbonu Górnośląskiego Zagłębia Węglowego. [in:] R. Ney, M. Kotarba (eds.) *Opracowanie modeli oraz bilansu generowania i akumulacji gazów w serii węglonośnej Górnośląskiego Zagłębia Węglowego*. Wydawnictwo Centrum PPGSMiE PAN, Kraków: 175–180.

Kotas A. 1985. Uwagi o ewolucji strukturalnej GZW. Tektonika GZW, *Materiały Konferencyjne. Tektonika GZW.* Uniwersytet Śląski, Sosnowiec: 17–46.

Kotas A. 1994. Coalbed methane potential of the Upper Silesian Coal Basin, Poland. *Prace Państwowego Instytutu Geologicznego*, 142.

Kozłowski B., Grębski Z. 1982. *Odmetanowanie górotworu w kopalniach.* Wydawnictwo Śląsk, Katowice.

Krause E., Sebastian S. 1997–2016. *Raporty roczne o stanie podstawowych zagrożeń naturalnych i technicznych w górnictwie węgla kamiennego*. GIG, Katowice.

Szlązak N. 2015. *Odmetanowanie górotworu w kopalniach węgla kamiennego,* Wydawnictwo AGH, Kraków.

Wasilewska M. 2007. *Struktura zmienności parametrów złóż węgla kamiennego w wybranych kopalniach Górnośląskiego Zagłębia Węglowego.* PhD Dissertation. Akademia Górniczo-Hutnicza, Kraków.