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METHANE EMISSIONS AND HARD COAL PRODUCTION IN THE UPPER SILESIAN COAL BASIN IN RELATION TO THE GREENHOUSE EFFECT INCREASE IN POLAND IN 1994–2018

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Abstract: The Upper Silesian Coal Basin (USCB) is the largest coal basin in Poland and one of the largest in Europe. It is the most industrialised region in the country. The main natural source of energy is hard coal, which was produced by 65 mines in the early nineties. The USCB geology is very diverse and not homogeneous. Coal deposits situated in the central, southern, and western regions are mostly covered by impermeable Miocene deposits, which helped methane (CH_4) to accumulate in the past. Methane is one of the most dangerous natural hazards in Polish underground mining because it is an explosive gas. CH_4 is also the second strongest greenhouse gas after carbon dioxide, but its radiative power is 20–25 times stronger than the radiative power of CO_2. Polish coal mines release 470 thousand Mg (average) of CH_4 yearly and it contributes to the greenhouse effect increase. Year after year, Upper Silesian coal mines are going to extract hard coal from deeper seams where the methane content in coal seams is much higher. To keep workers safe, CH_4 needs to be captured and released to the open-air atmosphere or used in the power and heat production.

Keywords**:** *hard coal production, methane emissions, greenhouse effect, the Upper Silesia Coal Basin, Poland*

1. INTRODUCTION

Air pollution and the greenhouse effect increase are ones of the main problems in industrialised regions such as the Upper Silesian Coal Basin in Southern Poland. The Upper Silesian Coal Basin (USCB) is the largest coal basin in the country and one of

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the largest in Europe. USCB is located in Silesia and Małopolska provinces and it covers the territory of 5600 km^2 in Poland (Fig. 1). USCB is also located in the Czech Republic (area of 1900 km^2). This paper focuses only on the Polish part of the basin.

During hard coal exploitation, many cubic metres of CH_4 get released to coal workings, enlarging the danger and making coal production very difficult at the same time (Kotarba and Ney, 1995; Łukowicz and Krause, 2004). Methane (CH_4) is formed in parallel with hard coal formation processes, during coalification of plant materials. Difficult geological conditions (e.g., hermetic overburden) could have prevented methane from escaping in the geological past. (e.g., Szlązak, 2015). Methane occurs in coal seams in the form of free or adsorbed gas. Gas sorption depends on temperature, pressure, and the type of coal. Free methane fills voids, pores, and breaks in seams and surrounding rocks. In USCB methane occurs mainly as adsorbed methane (tied gas), bound with coal physically or chemically. During coal extraction, CH_4 is released into mine workings and the methane danger increases (Czapliński,1994; Karacan et al. 2011; Honysz, 2015).

Fig. 1. Position of the Upper Silesia Coal Basin

Most coal mine methane (CMM) needs to be directed to ventilation shafts and released to the atmospheric air – magnifying the greenhouse effect at the same time. The objective of the paper is to determine the greenhouse effect increase in the context of hard coal production processes (mainly methane emissions) in USCB and the entire territory of Poland. The period between 1994 and 2018 overlaps with a large decrease in the hard coal production, an increase in methane emissions, and important changes in regulations, heating technologies, and methods that coal is used in the heat production. The Polish government together with the European Union aim to reduce air pollution and the greenhouse effect increase.

Year after year, Polish mines need to produce coal from deeper and deeper seams to maintain profitability and keep mines working (Dreger and Kędzior 2019; Kędzior and Dreger, 2019; Dreger, 2020). Reaching deeper coal seams is associated with entering high methane zones where the methane content in one Mg of coal^{daf} (daf is a pure carbon substance, without moisture and ash) is much higher (Kędzior, 2009). It forces to struggle with CH_4 emissions in order to keep the work in the mine as safe as possible. Year after year the number of operating mines in the Polish part of USCB has been decreasing. At the beginning of the study (1994) 65 coal mines were active, but twenty-five years later, in the last year of the research (2018), the number of the mines decreased to 21 (Annual Report 1995–2018). These mines which still produce coal need to struggle with very hard conditions, such as gas hazard. Despite a decreasing number of working coal mines, the methane danger is not lower; on the contrary, the CH_4 hazard can increase every year as a result of complicated mining and geological conditions (Kędzior, Dreger, 2019).

Methane disposal is necessary for the underground production to be as safe as possible. Methane accompanying coal bearing formations can cause ignition and explosion. When the concentration of methane in the air mixture is between 5 and 15% with the oxygen content above 12%, a single spark or open fire can initiate an explosion. Ignition of the mixture occurs at temperatures above 650 °C, but explosion temperature is up to 1875 °C (e.g., Kozłowski and Grębski, 1982; Karacan et al. 2011; Honysz, 2015).
A methane explosion is very difficult to contain, because it spreads quickly due to a small cross-section of the wall; therefore, there are many fatalities and serious injuries in the Polish mining history (Borynia Mine – 6 deaths, 17 injured; Śląsk Mine – 20 deaths, 34 injured, Mysłowice-Wesoła Mine – 5 deaths, 25 injured) (Honysz, 2015; State Mining Authority 2019). To protect workers, mining industries have to keep the mining atmosphere free of methane by extracting used mining air outside the mine by underground ventilation systems directly to the atmosphere, or by draining coal seams by drillings and collecting the collected gas for internal mining processes (Kozłowski and Grębski, 1982).

Hard coal is the main natural source of energy produced in USCB. From the chemical point of view, coal substance can be divided into three groups: organic substances, non-organic (mineral) substances, and water. Hard coal flammable substances are built of hydrocarbons and organic compounds (sulphur, oxygen, and nitrogen) (Lorenz 1999). Out of all elements forming hard coal, only carbon (C), hydrogen (H), sulphur (S), and nitrogen (N) are flammable. Therefore, the final products of oxidation of flammable elements are CO_2, H_2O (steam), SO_2, and SO_3. All these products are very harmful to natural environment and atmospheric air (Lorenz, 2005). Environment and air can be contaminated, but these deleterious processes take place in coal power plants or in home furnaces. Underground coal extraction processes themselves do not pollute the air. Rail and wheeled transport can cause dust pollution, noise, and shakes, but it does not have a significant effect on the environment. Coal-bearing formations do not consist of coal only. Rocks like sandstone, claystone, or shale form coal-bearing formations together with coal as the fossil fuel. After underground extraction, useless material such as gangue or coal waste needs to be deposited somewhere. The easiest way, used in USCB for years, is to deposit useless material as close to the mine as possible (transport limitation), creating dumps. High dumps with regular shapes (cones, cuboids) covering a considerable area can be unattractive visually and can be a big dust issuer when they are not properly developed (e.g., afforestation) (Uberman and Ostręga, 2004). Underground coal production is not flawless. Water coming from mining and technological processes can contaminate surface water, which leads to soil pollution and lack of arable lands (Bednorz, 2011). It should be clearly emphasised that combustion products such as CO_2, dust caused by heavy transport, and dumps are created after coal extraction. Hard coal production itself does not affect air pollution.

Table 1. Characteristics of the most common greenhouse gases
(after United States Environmental Protection Agency 2006, modified)

	CO_2	CH_4	CFC-11	CFC-12	N_2O	SF_6
Existence in the atmosphere (years)	50–200	10	65	130	150	3200
Global warming potential	1	20-25	4600	10600	310	23900
Concentration in the atmosphere in year ~1800	280 ppm	0.8 ppm	0	0	288 ppb	0
Concentration in the atmosphere in 1990	353 ppm	1.72 ppm	280 ppt	484 ppt	310 ppb	–
Concentration in the atmosphere in 1998	365 ppm	1.75 ppm	–	–	314 ppb	4.2 ppm
Annually concentration increase in 1990s	1.5 ppm	0.007 ppm	9.5 ppt	–	0.8 ppb	0.24 ppm
Annually concentration increase in 1990s in %	0.5	0.9	4	–	0.25	6
Estimated influence on greenhouse effect in %	50	19	17		4	–

Contribution in anthropogenic emission in %	–	–	100	100	–	100

The presence of such gases as carbon dioxide in the atmosphere makes temperatures rise due to a limited heat outflow, with its relatively free inflow. This mechanism, which forms amounts of outflows and inflows, is called *the greenhouse effect*. Not so long ago, the greenhouse effect intensification was identified with increasing concentrations of CO_2 in the atmosphere (Kożuchowski and Przybylak, 1995). Many other gases besides CO_2 were found in subsequent studies to absorb long-wave radiation of Earth and atmosphere. Consequently, it contributes to an increase of Earth's temperature. The most commonly known greenhouse gases (besides CO_2) are: methane (CH_4), which is the most important gas included in the study and tackled in this paper, ozone (O_3), nitrous oxides (NO, NO_2, N_2O), sulphur dioxide (SO_2), ammonia (NH_3), carbon oxide (CO), and freons CFC-11($CFCL_3$ and CFC-12 (CF_2CL_2) (Kożuchowski and Przybylak, 1995; Kundziewicz, 2013). Short characteristics of the gases are presented below in Table 1.

Poland as a signatory of the UN Framework Convention On Climate Change (1994) and Kyoto Protocol (2002) works for the limitation of climate changes, including greenhouse gases emissions to the atmosphere.

The convention requires than industrialised countries help developing countries to reduce greenhouse gases emissions. It also points out that wealthy nations which have built their opulence and prosperity thanks to fossil fuels are responsible for large CO_2 emissions. The main assumption of the Protocol is to decrease the volume of emitted greenhouse gases (5.2 % on average) in time. Not all greenhouse gases are covered by the limitation; in fact, only six of them are: carbon dioxide(CO_2), methane (CH_4), nitrous oxide (N_2O), industrial gases (HFC,PFC), and sulphur hexafluoride (SF_6) (*Kyoto Protocol*). To achieve the assumption of a reduction in the global gases emission, each of the 15 members of the European Union (as of 1997) and Bulgaria, the Czech Republic, Estonia, Lithuania, Latvia, Malta, Romania, Slovakia, and Slovenia agreed to reduce emissions by at least 8%, the USA by 7%, Poland, Canada, Hungary, and Japan by 6%, and Croatia by 5%. All of these countries needed to limit the emissions in the 2008–2012 period in reference to the base year (every country sets the limit individually, but it is around 1990). New Zealand, Russia, and Ukraine can keep their emissions at the same level as in 1990, but Iceland, Norway, and Australia can increase their emissions (by 10, 1, and 8%, respectively) (Kundziewicz, 2013; *Kyoto Protocol*). It is worth mentioning that the USA has indicated its intention not to ratify the Kyoto Protocol (*Kyoto Protocol*). Asian countries do not reduce greenhouse gases emission due to their dynamic economic development and an increasing energy demand in the Asian region (Teluk, 2008).

During the Climate Change Conference which took place in Paris in 2015 over 190 countries signed a global commitment called the Paris agreement. The main assumption was to limit the global temperature growth to 1.5–2 °C. The agreement is binding when at least 55 countries which produce 55% of greenhouse gases sign the agreement and take steps to fulfil the promises (*Paris Agreement*).

During *COP 24* in Katowice in 2018 political and technical decisions concerning the Paris Agreement were clarified. The European Union is responsible for just over a dozen percent of greenhouse gases emissions. The main issuers are USA, China, and India. These three countries are not obligated by any regulation to working on the reduction of greenhouse gases (Kundziewicz, 2013). Without a global agreement and commitment, the reduction in greenhouse gases emissions may fail.

1.1. OUTLINE OF THE GEOLOGICAL STRUCTURE AND METHANE OCCURRENCE

The geological structure of USCB is very diverse. Northern parts of the basin are not covered by the Miocene overburden (apart from local patches); hence, coal deposits were naturally degassed in the geological past (Mesozoic, Cenozoic, and the modern era). In some areas outcrops of older rock formations (permeable Triassic, Jurassic, and Quaternary deposits) cover Carboniferous coal-bearing deposits. Carboniferous formations are shallowly deposited (e.g., Grzybek and Kędzior, 2005; Kędzior, 2012).

Southern and southwestern areas of the basin are almost entirely covered by a thick and continuous Miocene cover consisting of clays, sandstones, and silt ranging from 200 to a maximum of over 1000 m. These impermeable deposits helped methane and other gasses to accumulate in coal-bearing units in the past. Therefore, deep hard coal exploitation (coal seams are deeper deposited than seams in the middle and in the northern parts of the basin) in conjunction with many fault zones (which helped CH_4 to migrate) is very complicated. Western areas of USCB are covered by the Miocene overburden (clays and silts) of various thicknesses – ranging from 0 to a maximum of over 1000 meters, but in some locations outcrops of coal-bearing strata are found (e.g., Grzybek and Kędzior, 2005).

In USCB two main geological settings of vertical distribution of coal bed methane (CBM) are distinguished (Kotas, 1994). These settings are closely connected with deposits covering the Carboniferous coal-bearing strata (Fig. 2). Northern and central areas of the basin where Carboniferous deposits appear as outcrops or are covered by thin and permeable Miocene and older formations are characterised by the occurrence of naturally degassed coal seams to the depth of 600 meters with the methane content lower than 4.5 m^3/Mg $coal^{daf}$. As the depth increases, the methane content grows rapidly – reaching the primary methane maximum when the CH_4 content exceeds 10 m^3/Mg $coal^{daf}$. The methane content slowly decreases at levels lower than the level of the methane maximum.

Southern regions, where the geological structure is characterised by impermeable Miocene deposits covering the coal bearing strata, consist of two maxima of the methane content. The first includes the secondary accumulation of CH_4 adsorbed in coal seams immediately below a thick and impermeable Miocene cover (400–600 m). A deeper maximum of the primary methane content occurs below 1300 m, but deeper than 1600 m the methane content tends to decrease. An interval of a lower CH_4 content (methane minimum zone) separates these two maxima (Kotas, 1994; Kędzior, 2012). The number of operating coal mines in USCB were changing during the study period. At the beginning of the research, in the early 1990s, 65 mines were producing coal. Over the years the coal mines were abandoned or merged into one big enterprise. As a result of the restructuring processes the number of coal mines was decreasing, to reach 21 in 2018 (*Annual Report 1995–2018*). The mines producing coal in northern and south-western parts of the basin were closed as a result of the depletion of shallow-lying and easily-extracted coal reserves. Natural and technical conditions were also a big difficulty preventing further coal production (Kędzior and Dreger, 2019). A dropping number of coal mines and the need to reach deeper coal seams in order to maintain profitability are some of the reasons for diminishing coal production every year in USCB (Dreger and Kędzior, 2019).

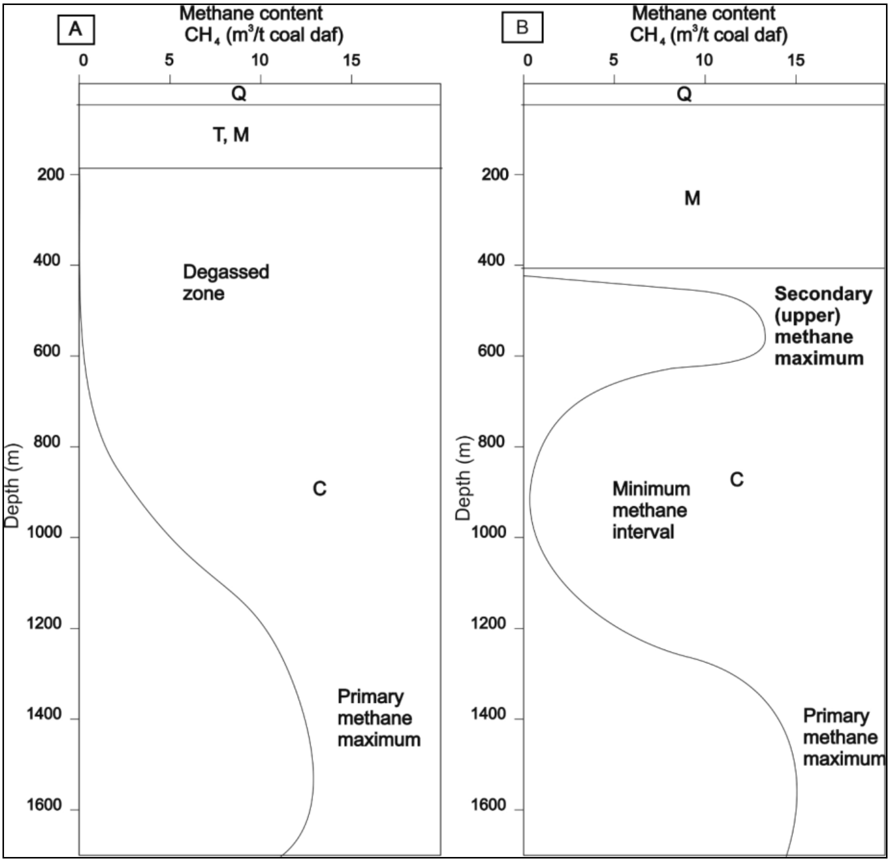

Fig. 2. Methane distribution in the northern (A) and southern (B) region of USCB (Kędzior, 2012)
Q – Quaternary, M – Miocene, T – Triassic, C – Carboniferous

At the beginning of the research (1994-1997) hard coal production in USCB exceeded 120 million Mg yearly. In the remaining period of the study (1998-2018) USCB mines were producing less coal every year. The decreasing trend was stable and coal production dropped from 112 million Mg in 1998 to 52 million Mg in 2018, which was just 39% of the production in relation to the highest coal extraction over the analysed years, when 133 million Mg of coal was extracted in 1996 and 1997 (*Annual Report 1995–2018*). Restructuring processes, increasing difficulties of extraction (thermal, methane hazards), concentration of production, exploitation of shallow-lying coal seams located mainly in the northern part of the basin contributed to the reduction of the hard coal production year after year. On the other hand, in order to maintain profitability and keep thousands of workplaces safe, coal enterprises need to reach deeper coal seams, where the methane content in coal is higher. In the modern era and in the future, the methane hazard is going to be the main natural danger which coal companies need to face (Dreger and Kędzior, 2019).

2. METHOD AND RESULTS

In order to investigate and demonstrate how methane emissions and coal production in USCB coal mines affect the greenhouse effect increase, figures such as coal production, emissions of CO, CO_2, CH_4, NO_x , SO_x were taken into account.

All essential data were obtained from:

- Resources, Use, Pollution and Protection of Waters (in: Environment, Central Statistical Office, 2005–2020)
- A national inventory report 2020 – inventory of greenhouse gases in Poland from 1988 to 2018 (Institute of Environmental Protection – National Research Institute, 2020)
- Annual report about basic, natural and technical threats in hard coal mining (*Annual Report 1995–2018*).

Based on the analysis of the most important data, figures which show changes and the percentage share of the responsibility for the greenhouse gases emission have been developed.

2.1. GREENHOUSE GASES EMISSION IN POLAND

In order to describe how much greenhouse gases was emitted to the Polish atmosphere, all the greenhouse gases were summed up. Every gas has a different weight and volume; for these reasons all the collected gases (CO_2, CH_4, N_2O, HFC, PFC, SF_6, and NF_3) were calculated as CO_2 equivalent [eq]. The biggest emission was noticed at the beginning of the study (1994–1997) (Fig. 3). Heavy industry and rapid economic growth caused big emissions, exceeding 430 million Mg of emitted greenhouse gases yearly, with the highest emissions in 1996 (453 million Mg of CO_2 equivalent) (Institute of Environmental Protection – National Research Institute, 2020). In the next five-year period (1998–2002) the biggest decrease in the greenhouse gases production was observed. Government programmes and actions for the efficient energy use contributed to the fact that the emission of carbon dioxide, methane, nitric oxides, and other gases was rapidly dropping to the lowest volume in the entire research period – 380 million Mg of CO_2 eq in 2002. Subsequent years (2003–2007) were marked by the economic recovery, which translated into a gentle but constant increase of gases emission into atmospheric air. From 2008 to 2014 the emission was slowly decreasing to 383 million Mg of CO_2 eq in 2014, but over the last four years of the study (2015–2018) a constant rise in the emission was observed. From 386 million Mg (2015) to 402 million Mg of CO_2 eq (2018) was emitted to the Polish atmosphere. This fast and constant increase was caused by dynamic economic development (Central Statistical Office, 2005–2020).

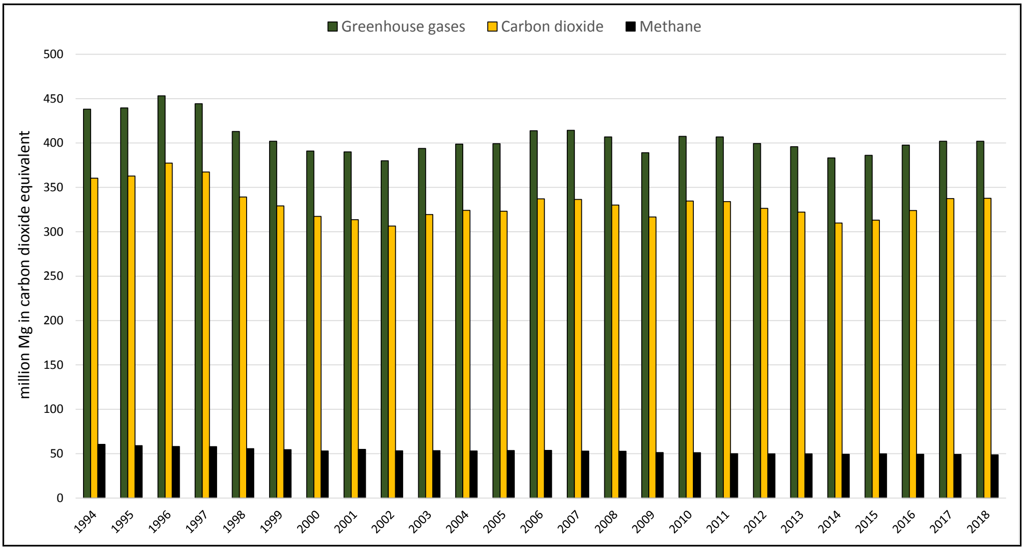

Fig. 3. All greenhouse gases, carbon dioxide and methane emissions in Poland in 1994–2018

2.2. CARBON DIOXIDE EMISSIONS

The dominant greenhouse gas in Poland is CO_2 (81.8% of the total greenhouse gases emissions). The majority of CO_2 in Poland comes from fuel combustion and power industry with over 50% of the total emission. The rest of carbon dioxide emission is shared by the cement production, transport, and industrial processes (Institute of Environmental Protection- National Research Institute, 2020, Central Statistical Office, 2005–2020) In the entire research period (1994-2018) over 7982 million Mg of CO_2 was emitted to the Polish atmosphere (Fig. 3). The biggest emission took place between 1994 and 1997 during a rapid economic growth, when 366 million Mg of carbon dioxide on average was emitted to the atmosphere. Subsequent years (1997–2002) saw a constant decrease in CO_2 emission– down to 305 million Mg in 2002. This decrease was caused by many actions promoting effective energy use, which resulted in the lowest CO_2 emission over the entire research period. Over subsequent years periods of increase and decrease (with small fluctuations) were observed, but emissions of the most dangerous greenhouse gas never exceeded the highest emissions in 1996 – when the biggest volume of CO_2 was released to the Polish atmospheric air – 375.30 million Mg. During the entire research period, the CO_2 emission trend was not uniform. It was changing year after year, but over the last five years (2014–2018) emission increased from 310 to 337.7 million Mg as a result of the economic recovery.

2.3 METHANE EMISSIONS

Methane is a 20 to 25 times stronger heat absorbent than carbon dioxide, but its existence in the atmosphere is shorter and its origin is varied (Ramaswamy et al. 2011; Archer, 2011; Kożuchowski and Przybylak, 1995; Ginty, 2016). The main sources of methane emissions in Poland have been divided into three main categories:

a) fuel emissions – 47% of the total emissions (as of 2018),
b) agriculture – 30%,
c) wastes – 23%.

The majority of the issue (a) comes from underground mining (33.8% of total emission). The rest derives from oil and gas exploitation, processing, and distribution (5.5% of total emission). In agriculture (b) the main emission of CH_4 hails from intestinal fermentation (26.8% of entire emissions), but in the last category (c) the emission from landfills contributes to the methane concentration increase in the atmosphere by 17.6%. It is clearly visible that the most heat-absorbent greenhouse gas emissions come from underground mining and cattle farming (Institute of Environmental Protection- National Research Institute, 2020). Globally, the largest methane issuers are agriculture (including cattle farming and rice cultivation), thermokarst lakes and peat lands (Yusuf et al. 2012; Kundziewicz, 2013; Matveev et al. 2018). Methane is also responsible for 17 % of the greenhouse effect (*Adler 1994*), but global hard coal mining accounts for about 6% of global methane emissions (*Best Practice Guidance* 2010).

Human activities over the past two hundred years have increased the CH_4 concentration in the atmosphere from a base global average of 722 ppb in 1750 to a global average of 1,823 ppb in 2015 (Ginty, 2016). Globally, agriculture is the key emitting sector of methane emission, responsible for 40% and over 60% of releasing CH_4 to the atmosphere comes from human activities. Methane as the second most harmful greenhouse gas does not affect direct on human health, agriculture or ecosystems. There are many indirect and long-term effects of methane emissions like premature respiratory deaths, heart and lungs diseases (estimated for 1 million worldwide per annum) caused by tropospheric ozone formation (Crutzen, 1973; Bates, 1998; Westi and Fiore, 2005; *UNEP Synthesis Report* 2011). There are also 15% annual yield loses in soy, wheat, maize and rice cultivation (*UNEP Synthesis Report* 2011).

The paper is focused on the geological origin of methane, its utilisation, and disposal out of the mine.

In USCB almost all CH_4 comes from hard coal mining. The mining methane gas can be distinguished due to the method of its acquisition. Coal Mine Methane (CMM) is a gas mixture captured during underground mining works with 25–60% of CH_4. Coal Bed Methane (CBM) is a gas almost entirely composed of CH_4 (90–98%) captured from virgin (unmined) coal seams (Kozłowski and Grębski, 1982; Karacan et al. 2011; Kędzior, 2012). When methane is released from coal to the mining atmosphere due to underground quakes and coal extraction, there are two ways to dispose of it. Firstly, the most common solution is to extract used mining air (heated and rich in methane and other gases) outside the mine by underground ventilation systems directly to the atmosphere. Degassing is the second method to keep the mining atmosphere free of methane. Underground degassing leads to draining many coal-bed gases outside of the mine or to a place equipped with a ventilation network, where these gases are not dangerous. Collected gases can be used economically or sold to external customers (Kozłowski and Grębski 1982; Szlązak, 2015; Dreger, 2020). Not all captured gas is used or sold outside. A significant part of collected and undeveloped CH_4 needs to be released directly to the atmosphere magnifying the greenhouse effect. Methane which goes to the atmospheric air is a mixture of undeveloped coal mine methane gas and methane coming from underground ventilation systems, described as *Ventilation Air Methane* emission. The emissions of CH_4 in Poland and from hard coal mines located in the Upper Silesia Coal Basin have a completely different course.

The largest methane emissions in Poland took place at the beginning of the study (1994), when 2.42 million Mg of this gas was emitted to the atmosphere (Fig. 4). Over subsequent years until the end of the research period (1995-2018) emissions of this strongest greenhouse gas were decreasing gently but constantly, from 2.36 million Mg released in 1995 to 1.95 million Mg of CH_4 in 2018. Only in 2001 the decreasing trend was disturbed by a 2.20 million Mg peak. Restructuring processes, greater awareness of the society, and better management in agriculture, heavy industry, and waste management caused a 19.4% drop in methane emission in Poland in the entire research period.

Methane emissions to the atmosphere from the USCB coal mines are completely different than the emission in the entire territory of Poland. From 1994 to 2004 CH_4 released by hard coal mines was variable and fluctuated between 410 and 480 thousands Mg of gas yearly (Fig. 5). Next, there was a four-year (2005–2008) increase period, during which the ventilation air methane emission (VAM) rose from 500 to 520 thousand Mg. Over the next six years (2009–2014) methane emissions were decreasing (between 460 and 500 thousands Mg of CH_4). But in the most recent period (2015–2018) a big increase in emissions was observed –more than 520 thousand Mg of CH_4 was released every year. Due to the increasing depth of coal extraction every year and the concentration of coal production connected with entering more methane rich seams, methane emissions are going to increase or remain at a high level of CH_4 emitted in the forthcoming years (Dreger, 2019; Dreger and Kędzior, 2019).

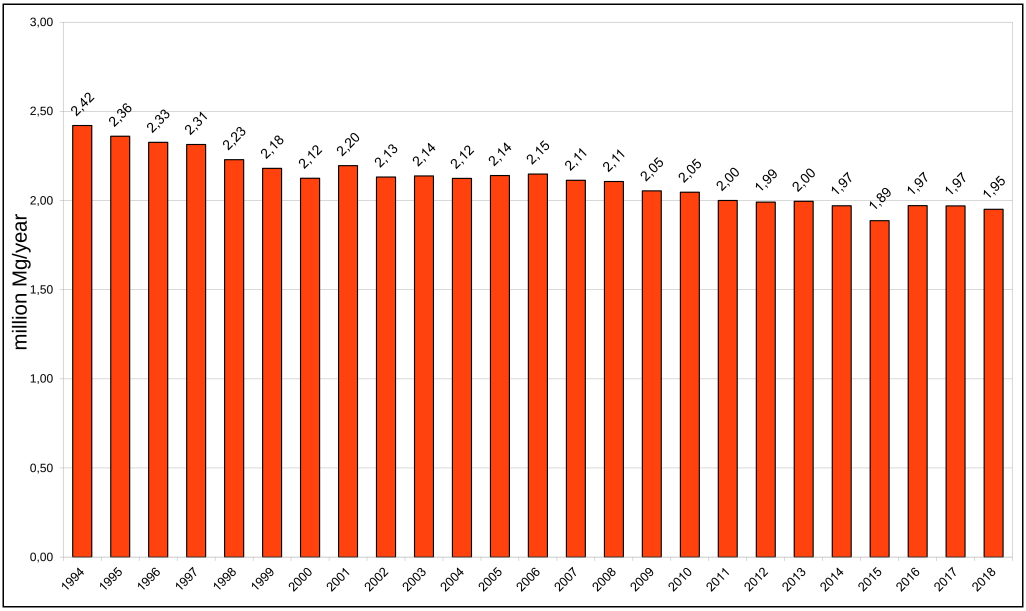

Fig. 4. Methane emissions in Poland in 1994–2018

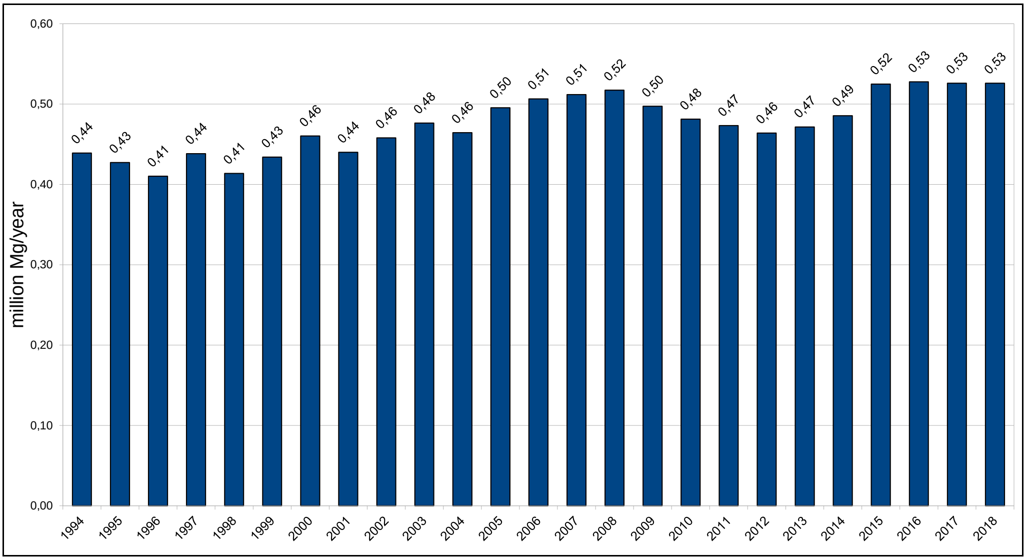

Fig. 5. Methane emission in USCB in 1994-2018

2.4. CONTRIBUTION OF METHANE EMISSION IN USCB TO THE TOTAL EMISSION IN POLAND

As mentioned above, methane is 20 to 25 times stronger heat absorbent than the commonly known carbon dioxide (e.g., Central Statistical Office, 2005–2020; Ginty, 2016). More than thirty percent of methane emissions in Poland come from underground mining. Total methane emissions in USCB are a significant part of all methane emissions in Poland (Institute of Environmental Protection – National Research Institute, 2020). The coal mine CH_4 emissions reported in this study consist of captured and undeveloped methane from mine drainage systems which is released directly to the atmosphere and from the ventilation air methane (VAM emissions). The total methane emissions in Poland consist of emissions from agriculture, waste management, hard coal mining, and other fuel emissions.

At the beginning of the study (1994-1998) the contribution of methane emissions in USCB to the total methane emission in Poland oscillated at about 18% and it was rising over subsequent years, reaching a 24.56% share in the entire emission of CH_4 in 2008 (Table 2). Similarly to the methane emission trend in 2009–2014, the share of emitted gas decreased to 23–24% in this period. In subsequent years (2015–2018) USCB coal mines released over 26% of all the methane emitted to the Polish atmospheric air. It is clear to see that the trend relating to the share of methane emissions by USCB mines increased by 49% between 1994 and 2018.

In the near future, USCB mines need to extract coal from deeper and deeper seams, where methane-related danger will be increasing. To keep exploitation safe, CH_4 utilisation (methane emission) should be at a very high rate, possibly higher than in the last three years (2015–2018). In this way, the contribution of USCB methane emission to total CH_4 emission in Poland can be at the same high rate or can exceed 30%.

We can observe the same trend in emissions when we take a closer look at methane emissions in USCB as compared to the total greenhouse gases (CO_2, CH_4, etc) emissions in Poland. Trends in emissions were changing in a very similar manner as compared to total methane emissions in USCB and the contribution in the CH_4 emission of USCB to the total emissions in Poland. In Table 2 we can see that underground coal mining in Silesia and Małopolska region is responsible for 2.26 to 3.40 % of greenhouse gases emissions in Poland (CH_4 was only counted as the strongest heat absorbent and the main greenhouse gas occurring in hard coal mining). Developing new, pure technologies, such as solar energy and windmills farms, can reduce greenhouse gas emissions in Poland in the coming years. Thus, the contribution of methane emissions from the USCB coal mines is going to increase, because power production in Poland is still based on coal and it will not change for a long time.

Table 2. Contribution of the methane emissions

Year	Contribution of methane emission in the USCB to the total emission in Poland in %	Contribution of methane emission in the USCB to the total greenhouse gases emission in Poland in %
1994	18.14	2.51
1995	18.11	2.43
1996	17.64	2.26
1997	18.94	2.47
1998	18.56	2.50
1999	19.91	2.70
2000	21.67	2.94
2001	20.04	2.82
2002	21.49	3.01
2003	22.29	3.02
2004	21.87	2.91
2005	23.15	3.10
2006	23.57	3.06
2007	24.22	3.09
2008	24.56	3.18
2009	24.21	3.20
2010	23.52	2.95
2011	23.66	2.91
2012	23.31	2.90
2013	23.63	2.98
2014	24.64	3.17
2015	26.34	3.40
2016	26.77	3.32
2017	26.71	3.27
2018	26.97	3.27

2.5. GREENHOUSE GASES EMISSIONS IN EUROPEAN COUNTRIES

Changes in greenhouse gases emissions are noticeable in almost each country which signed the Kyoto Protocol. The highest increase in greenhouse gases emissions between the base year (1990) and 2017 was noticed in Cyprus (53.8% increase), Iceland (45%), Spain and Portugal (19%). On the other hand, the biggest decrease in the emissions was observed in the Baltic region countries, such as Lithuania (57%), Latvia (54%), Estonia (50%), as well as in Romania (53%). Almost nothing has changed in Malta, Slovenia and Luxembourg– these three countries have been emitting similar volumes of greenhouse gases in comparison to the base year. Poland is classified in the middle of the statement with a 13% reduction in emissions. Changes in greenhouse gases emissions were caused by a diverse economic structure, using or not using renewable energy sources, and emission trading between countries (Eurostat database on 2017 in Central Statistical Office, 2005–2020).

2.6. OPTIONS TO REDUCE METHANE EMISSIONS

The European Union's International Energy Agency attempts to include CH_4 in the European Emissions Trading System (ETS) treating methane as 25–30 times stronger heat absorbent than carbon dioxide. This type of solution is going to impose extra fees on every Mg of released methane direct into the atmosphere and force the improvements in, e.g., coal mining sector (EU Emissions Trading System). Capturing methane during underground mining works (CMM) and direct from the virgin coal beds (CBM) can limit the CH_4 emission to the open-air. Captured gas mixture, rich in methane can be sold to external customers or used in the internal mining processes to produce energy (Karacan et al. 2011; Jureczka et al. 2015; Dreger and Kędzior 2019; Kędzior and Dreger, 2019; Dreger, 2020). In the European Union's Final Report from 1998 titled *Options to Reduce Methane Emissions* points some solutions to utilize mining methane like: steam turbines, gas turbines, spark-ignition reciprocating engine, dual-fuel compression-ignition engine or flaring (EU Final Report 1998). The main source of CH_4 within the European Union and worldwide is the agricultural sector, where emission comes from enteric fermentation in ruminant livestock, manure and rice cultivation (Bates, 1998; Curnow 2020; *Global Methane Initiative* 2020). One of the possibilities to reduce methane is the reduction in the livestock numbers or adding feed additives and supplements which inhibit methanogens in the rumen, and subsequently reduce enteric methane emissions. The other opportunity to limit the gas emission is to recover and use methane from animal waste (Bates, 1998; Curnow, 2020).

3. CONCLUSIONS

Methane is one of the strongest greenhouse gases, produced by underground coal mines in the Upper Silesia Coal Basin. To protect workers and keep the mining atmosphere free of methane, thousands of Mg of this gas need to be extracted out of the mine directly to the air.

Over the last four years (2015-2018) methane emissions from coal mines exceeded 520 thousand Mg annually due to the increasing depth of coal extraction and more methane rich coal seams which are being operated. In the forthcoming years methane emissions are going to increase or remain at a high level. Deeper coal seams are highly rich in methane, which accounts for the fact that the contribution of the USCB mines methane emissions is bigger and exceeds 3% in the total greenhouse emission in Poland

and 26% in the total CH_4 emission.

On the other hand, methane emissions from all sources in Poland have dropped by 20% in the entire research period. European and world leaders have been working on the greenhouse effect slowdown. Kyoto, Paris, and Katowice agreements determine how to improve air quality, but without a global consent, mainly from the Asian part of the globe, the reduction in greenhouse gases emissions may fail.

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