The Impact of Methane Emitted from Coal Deposits on the State of the Atmosphere

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Abstract

This article presents an analysis of methane emissions into the atmosphere, the amount of captured and utilized methane, as well as methane released from the methane drainage system. The results are then compared with data from the State Mining Authority (WUG) and the European Pollutant Release and Transfer Register (E-PRTR), which is maintained in Poland by the Chief Inspectorate for Environmental Protection. Additionally, based on greenhouse gas emissions data from UNFCCC and JSW S.A., the article determines the impact of methane emitted from its mines on the atmosphere at the European and global scale.

Keywords: *methane emissions, methane drainage efficiency, atmospheric protection*

1. Introduction

Methane (CH_4) and carbon dioxide (CO_2) have been recognized by the Intergovernmental Panel on Climate Change as the two most significant greenhouse gases [1]. These gases absorb infrared radiation, contributing to global warming. Over the years, their atmospheric concentrations have been heavily influenced by human activities. For example, methane concentration has increased by approximately 160% in the last 250 years [2]. Despite its significantly lower atmospheric abundance compared to carbon dioxide, methane has a 28-fold higher Global Warming Potential (GWP) over a 100-year timeframe [3]. Recent studies indicate that its GWP has actually increased to 32 [2], and considering the additional carbon footprint, it reaches 34 over a 100-year timeframe and 86 over a 20-year timeframe [4]. Furthermore, the radiative forcing attributed to methane emissions is approximately 0.97 Wm [2,3], and considering its relatively short lifespan (11.2 +/- 1.3 years), reducing methane emissions can have a short-term impact on associated radiative forcing [5]. This makes methane emissions observations an excellent source of information about climate change.

Methane is a gas primarily generated through anaerobic decomposition of organic matter in biological systems. However, according to IPCC data, currently half of its present-day atmospheric flux comes from anthropogenic sources, which are predominantly influenced by human activities [2]. Although global methane emissions account for about 4% of anthropogenic CO_2 emissions in mass flow units, it contributes to 20% of the accumulated enhanced greenhouse effect in the lower atmosphere since 1750 [3]. Another challenge lies in the fact that methane emission sources have not been fully characterized, and accurately estimating the quantities of emitted methane remains a significant challenge. According to UNFCCC, global methane emissions in 2022 were approximately 274.6 Mt, while IEA reported 356.2 Mt [6,7]. These emissions comprised around 40% from natural sources and the remaining 60% from anthropogenic sources. The largest methane-emitting sector is Agriculture, accounting for about a quarter of the total emissions, followed closely by the Energy sector, where significant methane is released from coal, oil, natural gas, and biofuels.

Methane is emitted from various sources, which are widely distributed and often geographically overlapping. Uncertainties in estimating methane quantities from Agriculture, Waste, and Fossil Fuels range from 20% to 30% [4,5]. Lack of accurate methane emission data mainly applies to regional scales (e.g., South America, China, India). Therefore, numerous efforts are being made to accurately determine greenhouse gas emissions, including methane, in order to mitigate their negative impact on climate change.

Poland has been a member of the United Nations Framework Convention on Climate Change (UNFCCC) since 1994 and the Kyoto Protocol (KP) since 2002, actively participating in actions to mitigate climate change [8]. Upon ratifying the Kyoto Protocol, Poland committed to reducing greenhouse gas emissions by 6% during the period of 2008-2012 compared to the base year emissions. In the second commitment period, from 2013 to 2020 (Doha Amendment), Poland committed to achieving average annual emissions at 80% of the sum of emissions from all countries (European Union and Iceland) during the base years [8].

Poland reports its national emissions in five source categories under the Common Reporting Format: Energy, Industrial Processes and Product Use, Agriculture, Land Use, Land-Use Change and Forestry (LULUCF), and Waste [6,8]. Greenhouse gas emissions are presented in CO_2 equivalents, using the GWP100 metric, which assigns a value of 25 for methane according to IPCC guidelines [2]. Using an increased GWP100 value would result in higher total annual greenhouse gas emissions due to the increased methane contribution (approximately 20%). However, this would not significantly affect long-term climate change trends [2]. The choice of metrics impacts the selection of policies and methods aimed at mitigating climate change, especially for high-emission sec-

Fig. 2.1 Comparison of the world's largest coal producers [7]
Rys. 2.1 Porównanie największych światowych producentów węgla [7]

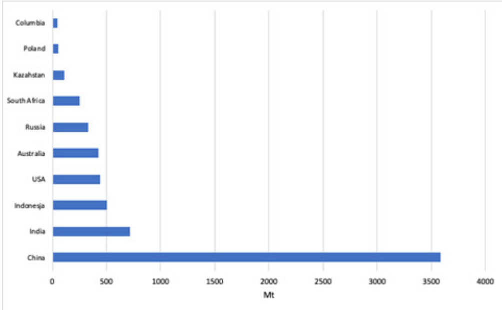
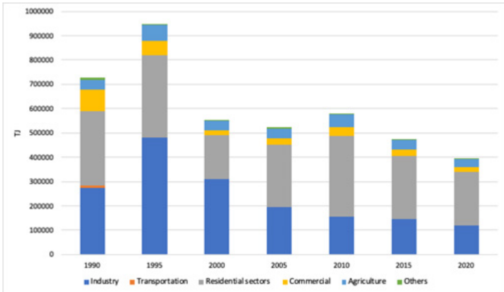


Fig. 2.2 Coal consumption in Poland by sectors [10]
Rys. 2.2 Zużycie węgla w Polsce według sektorów [10]



tors and countries other than CO_2. The detailed methodology for calculating emissions is described in the English version of the National Inventory Report for the period 1988–2020 [8].

From the perspective of the analyses conducted in this article, the most significant category is Energy, specifically the subcategory: Fugitive Emissions from Fuels, where emissions from underground mines have the largest share. The coal sector in Poland accounted for 38.7% of total methane emissions in 2020 [8].

The analyses presented in this article were conducted based on data available on the UNFCCC Greenhouse Gas Inventory Data website [6], which provides data on greenhouse gas emissions from all Annex I and non-Annex I countries.

2. Methane emissions from the mining sector in Poland

The global energy sector, including the coal sector, is responsible for emitting 133.4 million tons of methane [7]. China is the leading global coal producer, with a total production of 3,500 million tons (Figure 2.1). From the presented ranking in Figure 2.1, it is evident that Poland ranks ninth as a coal producer [7]. In 2020 and 2021, coal production in the country amounted to 54.5 million and 55.0 million tons, respectively [9].

Around 49.5% of Poland's energy sector relies on coal. Figure 2.2 presents the main sectors of the economy using coal as a raw material. Until 2000, the largest amount of coal was consumed by the industry and residential sectors as a fuel for heating buildings. After 1995, industrial coal consumption significantly decreased, reaching 120,247 TJ in 2020. From 2000 to 2020, the residential sector had the highest coal consumption, ranging from 330,255 TJ in 2010 to 217,719 TJ in 2020 [7].

Coal mining is accompanied by the emission of gases, primarily methane, carbon dioxide, higher hydrocarbons, nitrogen, and steam. Mine gas contains 86-99.6% methane [2], but its composition largely depends on the type of deposit and mining method and changes over time and with changing mining conditions.

According to the balance of mineral resources and underground waters in Poland in 2020, the presence of methane in coal deposits was documented mainly in the Upper Silesian Coal Basin [10]. The methane conditions of the Lower Silesian Coal Basin and the Lublin Coal Basin are poorly recognized, and the detected methane concentrations are significantly lower, making it difficult to assess their economic significance. The documented extractable resources in the Upper Silesian Coal Basin in 2021 amounted to 106,660.94 million m^3 and decreased by 568.32 million m^3 compared to 2020 [10].

In 2021, 815.3 million m^3 of methane was released from the rock mass affected by mining activities, which means that, on average, 1,551.17 m^3 was released per minute [9]. From 2015 to 2021, the relative methane emission in relation to the extracted coal (methane yield) ranged from 12.9 to 15 m^3.

In 2020, methane emissions in Poland amounted to 1,774.23 kt, which was 39.7% lower than the baseline year (1988) [8]. This value corresponds to 44.35 Mt of CO_2 equivalent assuming a GWP100 of 25. Using a GWP100 of 28 would result in a value that is 12% higher (49.68 Mt CO_2eq). Methane accounted for 11.8% of the total national greenhouse gas emissions in 2020. Three main sources of methane emissions belong to the categories: Fugitive Emissions from Fuels (38.5%), Agriculture (31.9%), and Waste (22%). The first category includes emissions from the combustion of solid fuels (including underground and surface mines) and the oil and natural gas and other emissions from energy production (combined approximately 6.0% of emissions). Figure 2.3 shows the percentage distribution of methane emissions from each category.

Fig. 2.3 Structure of methane emissions categories in Poland in 2020 [8]
Rys. 2.3 Struktura kategorii emisji metanu w Polsce w 2020 r. [8]

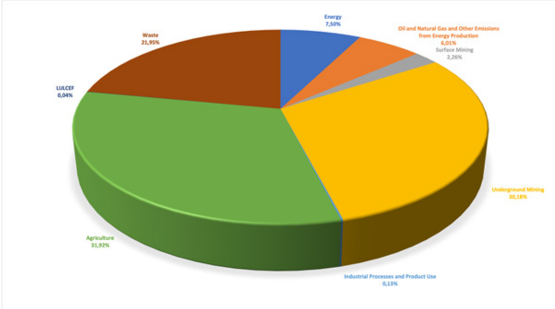


Fig. 2.4 Methane emissions status from Polish mines from 2015 to 2020 based on WUG data [9]
Rys. 2.4 Stan emisji metanu z polskich kopalń w latach 2015–2020 na podstawie danych WUG [9]

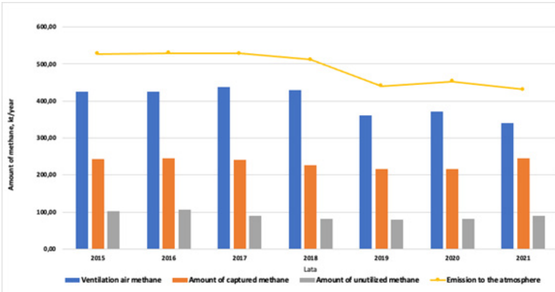


Fig. 2.5 Methane emissions status from Polish mines from 2015 to 2020 based on WUG and E-PRTR data [9, 12]
Rys. 2.5 Stan emisji metanu z polskich kopalń w latach 2015–2020 na podstawie danych WUG i E-PRTR [9, 12]

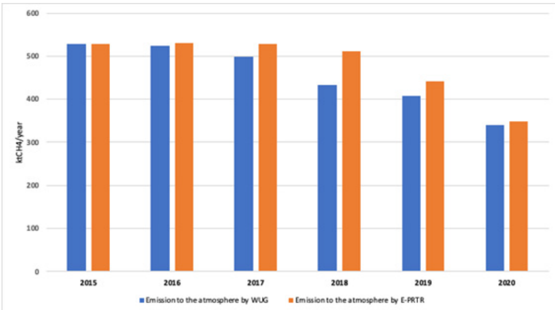
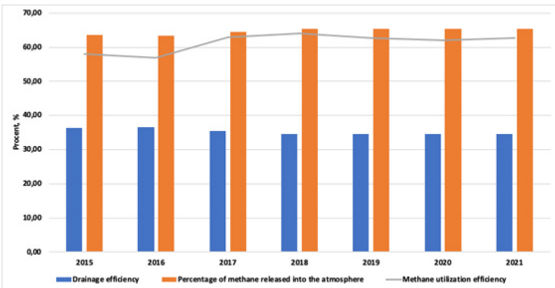


Fig. 2.6 Methane drainage status, methane utilization efficiency, and percentage of methane emissions into the atmosphere in Polish mines from 2015 to 2021 [9]
Rys. 2.6 Stan odmetanowania, efektywność wykorzystania metanu oraz procent emisji metanu do atmosfery w polskich kopalniach w latach 2015–2021 [9]



In the coming years, an increase in methane emissions from coal mines can be expected due to the increasing methane content with the depth of coal seams (in the last decade, methane emissions have increased by 60% per ton of coal extracted) [11]. Therefore, there should be a strong emphasis on its recovery and practical utilization.

The emission status of methane from the mining sector in Poland over the past five years is shown in Figure 2.4 [9]. Data analysis indicates that from 2015 to 2017, the total amount of methane released into the atmosphere remained around 530 kt (13.25 $ktCO_2eq$), and in the following five years, it decreased to 431 kt – 10.77 $ktCO_2eq$ (yellow line in Figure 2.4). The results from the State Mining Authority (WUG) align with the data from the European Pollutant Release and Transfer Register (E-PRTR) shown in Figure 2.5 [12]. Minor discrepancies in the reported data mainly result from the different methodologies used in the emission registries. The WUG registry calculates the total methane emissions to the atmosphe-

Fig. 3.1 Indirect methane emissions from the global mining sector [7]
Rys. 3.1 Pośrednie emisje metanu z globalnego sektora wydobywczego [7]

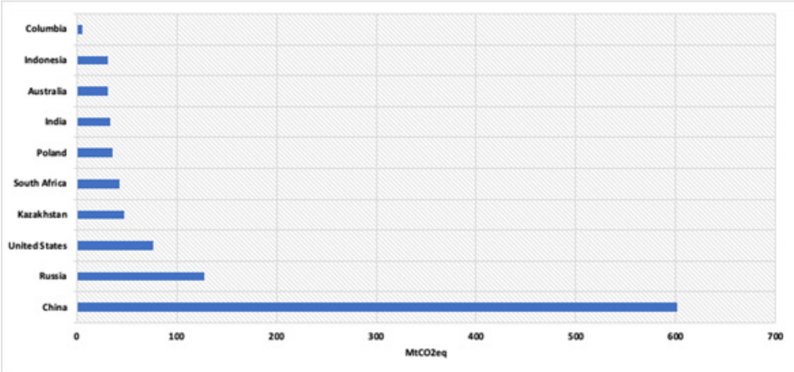
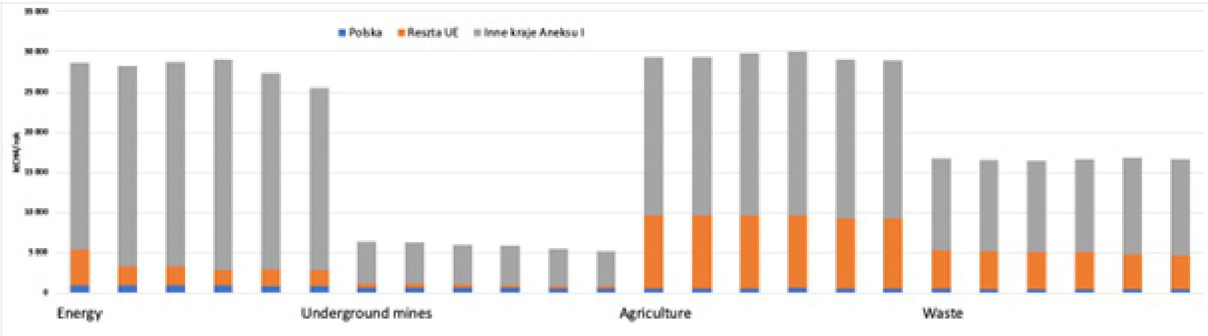


Fig. 3.2 Methane emissions from various sectors in Poland, other European Union countries, and other Annex I countries from 2015 to 2020 [6]
Rys. 3.2 Emisje metanu z różnych sektorów w Polsce, innych krajach Unii Europejskiej i innych krajach Załącznika I w latach 2015–2020 [6]



re based on the ventilation air methane from individual units and the total amount of unutilized methane. The E-PRTR database relies on data on the total methane emissions (ventilation air methane plus unutilized methane) directly from individual mines.

Considering that methane drainage in mines is mainly done for safety reasons, the overall efficiency for the years 2015–2021 ranged from 34.6% to 36.3% (Fig. 2.6). Analyzing the utilization level of the captured methane (gray line in Figure 2.6), it can be concluded that, compared to the entire underground mining industry, the efficiency remained at around 57% in 2017 and reached nearly 64% in 2018. However, its value slightly decreased from 2019 to 2021.

The data presented in Figure 2.6 regarding the percentage of methane released into the atmosphere is determined based on absolute methane emission, meaning they only include ventilation air methane values without considering unutilized methane. In this context, the percentage of methane released into the atmosphere during the studied period ranged from 63.7% in 2015 to over 65.40% in 2021. If the amount of unutilized methane were taken into account, this value would increase to 76%.

Currently, methane in active mines is only recovered through the methane drainage process carried out due to occupational safety regulations. Therefore, the technologies currently used result in approximately 30% of methane being captured through drainage and as much as 70% being removed through ventilation. Given the properties of methane as a greenhouse gas, it is crucial to reduce its emissions for atmospheric protection.

3. The impact of coal seam methane emissions on the atmosphere worldwide and in Europe

As a member of the United Nations Framework Convention on Climate Change (UNFCCC), Poland is obliged to report its national greenhouse gas emissions within the adopted reduction targets in five source categories using the format of the Common Reporting Tables [8]. The conducted analyses were based on data available on the UNFCCC Greenhouse Gas Inventory Data website [6], concerning greenhouse gas emissions from all countries belonging to the European Union, as well as those outside the EU but included in the Annex I. Like EU members, they are required to provide data on greenhouse gas emissions from all sectors of the economy. China, India, South Africa, Colombia, and Indonesia are not part of Annex I. While these countries are encouraged to submit reports, they are not obligated to do so. Therefore, data on methane emissions from the mining sectors of these countries are very limited, with the latest available data for China from 2014 and for India from 2016. Figure 3.1 presents the status of methane emissions from countries that are the largest coal producers based on data from the International Energy Agency [7]. According to this ranking, Poland ranks sixth in terms of methane emissions from the mining sector.

The data presented in this chapter will cover the analysis of methane emissions from European Union countries and Annex I countries from 2015 to 2020. However, it should be noted that China, currently the world's largest coal producer, has an annual production of approximately 3,580 million tons, and India of approximately 716 million tons [13]. Therefore, a comparison will be made between the available UNFCCC results from 2020 and the latest available emission data for China and India [6].

Fig. 3.3 Methane emissions from the energy sector in Annex I countries [6]
Rys. 3.3 Emisje metanu z sektora energetycznego w krajach Aneksu I [6]

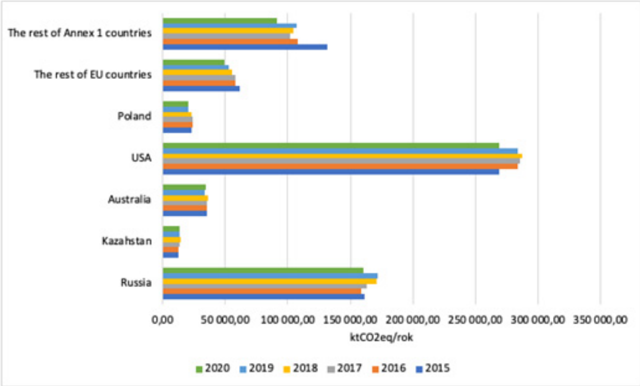
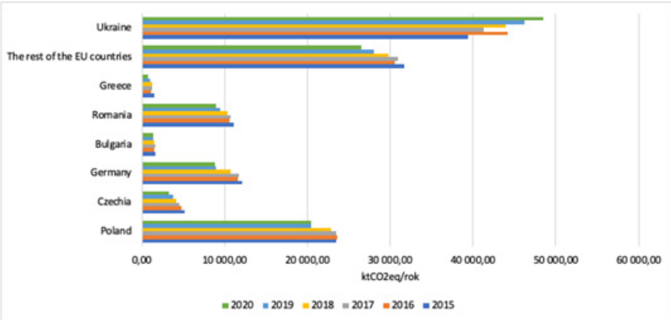


Fig. 3.4 Methane emissions from the energy sector in Europe [6]
Rys. 3.4 Emisja metanu z sektora energetycznego w Europie [6]



3.1. Methane emissions from various sectors of the economy in European and global countries

Methane is emitted from various sources, both of natural and anthropogenic origin, accounting for about 60% of its global emissions. Figure 3.2 shows the amounts of emitted methane from key sectors in Poland, other EU countries, and Annex I countries. Additionally, the chart illustrates the share of methane emissions from the mining sector in the energy sector.

The total methane emissions from the five main sectors of the economy in Annex I countries in 2020 amounted to 74.9 Mt (including the LULUCF category), which corresponds to 1872 $MtCO_2eq$ (GWP100=25). The main sectors of the economy that are sources of methane are Energy, Agriculture, and Waste. The data presented in the chart indicate that the Agriculture sector is the largest emitter of methane, with an average emission of 28.9 Mt during the study period, followed by the Energy sector with an average of 25.5 Mt of methane. The Waste sector ranks third with an average of 16.6 Mt of methane.

The data presented in Figure 3.2 also show that the global underground mining sector is a source of emissions, averaging 5.15 Mt of methane, of which Polish mines release 0.53 Mt. It should be noted that these data do not include emissions from China and India.

Taking into account the data available on the UNFCCC Greenhouse Gas Inventory Data website [6] regarding methane emissions from individual categories for China (last available data for 2014) and India (last available data for 2016), the total methane emissions for these two countries amount to approximately 75.0 Mt CH4 (1500 $MtCO_2eq$), which practically represents 100% of the methane emissions from Annex I countries.

Looking more closely at the energy sectors of individual countries, as shown in Figure 3.3, it is clear that the United States and Russia have the largest share of methane emissions, with average shares of 279.78 $MtCO_2eq$ and 164.46 $MtCO_2eq$, respectively. Poland's energy sector is responsible for an average emission of 22.37 $MtCO_2eq$.

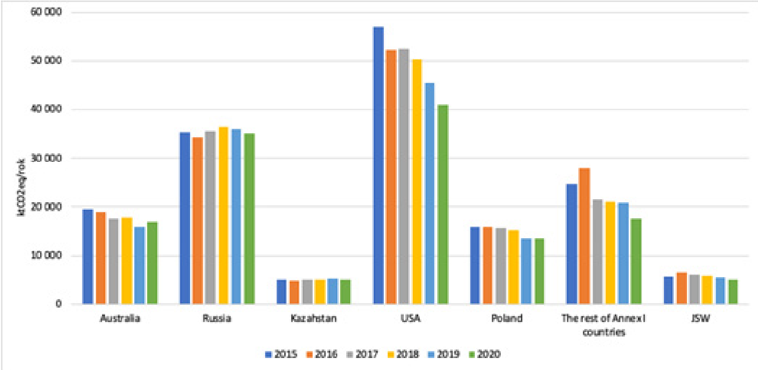
The energy sector of the entire European Union accounts for about 11.55% of methane emissions compared to all Annex I countries, with Poland accounting for 3.3%.

Analyzing the state of methane emissions from the energy sector in European countries, as presented in Figure 3.4, it is evident that Ukraine releases the highest amounts, averaging 43.94 $MtCO_2eq$, which accounts for 35.5% of the total emissions in Europe. Poland's energy sector is responsible for 18.23% of methane emissions (averaging 22.36 $MtCO_2eq$), while Germany and Romania account for 8.8% and 8.4% of the total emissions in Europe, respectively. The remaining countries in Europe account for the remaining 29.07%.

3.2. Methane emissions from the underground mining sector in European and global countries

In the global energy sector, the share of methane emissions from underground mines averages 5.15 Mt of methane (Fig. 3.2), which corresponds to approximately 128.75 $MtCO_2eq$. Taking a closer look at the underground mining sectors of individual Annex I countries (Fig. 3.5), it is observed that the United States dominates with an average emission of 49.78 $MtCO_2eq$, accounting for 35.0% of the total methane emissions from this sector. The next countries in line are Russia

Fig. 3.5 Methane emissions from the underground mining sector, including JSW S.A., compared to Annex I countries [6]
Rys. 3.5 Emisje metanu z sektora górnictwa podziemnego, w tym JSW S.A. na tle krajów Aneksu I [6]



(35.49 $MtCO_2eq$ – 23.5%), followed by other Annex I countries, including Ukraine (15.4%), Australia (12.3%), Poland (14.84 $MtCO_2eq$ – 10.3%), and Kazakhstan (3.5%). The mines of the largest coal company in Poland, JSW S.A., are responsible for approximately 3.97% of the total methane emissions.

Considering the fact that China and India do not provide data on methane emissions from the mining sector, only approximate data can be provided for these two countries. The data from 2014 [13] indicate a total emission from the mining sector at around 441.31 $MtCO_2eq$. Available literature data [14] suggest emissions ranging from 350 to 700 $MtCO_2eq$. In the case of India [15], the emission value for 2015 is approximately 24.6 $MtCO_2eq$. Figure 3.6 presents methane emissions from the underground mining sector worldwide for the year 2020, including literature data for China (550 $MtCO_2eq$) and India (24.6 $MtCO_2eq$), as well as emissions attributed to JSW S.A. The data presented in the chart clearly show that emissions from Polish underground mining rank seventh, accounting for 1.9% of the total methane emissions worldwide in this category, while JSW S.A. is responsible for 0.7%.

Now, in Figure 3.7, the state of methane emissions from the entire mining sector (including underground and surface mines) in 2020 is presented. The emission values assigned to China and India are based on the UNFCCC registry [6]. Similar to above, Poland's mining sector ranks seventh in terms of methane emissions, accounting for 2.3% of the total emissions. The discrepancies in percentage results are due to adopting lower emission values for China and India.

In the European context, the largest emitters of methane from underground mines (Fig. 3.8) are Poland and Ukraine. They account for an average emission of 39.35% and 34.86%, respectively. The remaining 25.79% comprises other European countries, including Romania (5.42 $MtCO_2eq$), Germany (1.57 $MtCO_2eq$), and the Czech Republic (1.40 $MtCO_2eq$). JSW S.A. mines are responsible for approximately 15.28% of the total methane emissions.

4. Methane emissions from JSW S.A. mines in the context of Europe, the world, and the energy sector

In the period from 2015 to 2020, the Polish underground mining sector accounted for an average methane emission of 14.84 $MTCO_2eq$ worldwide. During this period, Polish mines released a total of 3,560.71 kt of methane into the air, equivalent to 89.02 $MtCO_2eq$. In this context, JSW S.A. mines were responsible for emitting 1,383.73 kt of methane, equivalent to 34.59 $MtCO_2eq$. Figures 4.1 and 4.2 show the share of methane emissions from JSW S.A. mines in relation to different sectors in European countries (Fig. 4.1) and Annex I countries (Fig. 4.2).

The data presented in Figure 4.1 shows that JSW S.A. mines were responsible for 1.27% of methane emissions on a European scale. Other underground mines in Poland accounted for 2.00% of emissions. The highest methane emissions were from the Agriculture sector at 52.30%, followed by Waste at 27.33% and Energy at 17.45%.

In the case of Annex I countries (Fig. 4.2), JSW S.A. mines accounted for 0.30% of methane emissions, while other Polish mines accounted for 0.47%. The dominant sectors were Agriculture at 38.13% and Energy at a combined 38.66%.

The emission of methane at the national level takes a different shape. From 2015 to 2020, JSW S.A. mines accounted for 9.88% of the total methane emissions, while other mines accounted for 15.48% (Fig. 4.3). Considering the entire analyzed period, the highest emissions in Poland were attributed to the Energy sector, approximately 38.08%, followed by Agriculture at 34.46% and Waste at 27.26%.

In Poland, the Energy sector is 49.5% reliant on hard coal, which is accompanied by methane emissions during its extraction. Table 4.1 presents the percentage contribution of methane emissions from Polish coal mines and JSW S.A.

The data clearly show that methane emissions from JSW S.A. mines accounted for 24% to nearly 27% of the energy sector's emissions in Poland. At the European Union level, this value decreases and ranges from 6.65% to 7.85%, while in Annex I countries, it only represents 0.79% to 0.94%.

5. Methane emissions from closed mines

Polish coal mining has undergone significant changes in the past five years. Thirteen mines were closed, and some were merged. In 2019, a total of five mines were in the process of closure [9], including two owned by JSW S.A.: KWK "Jas-Mos" (October 1, 2016) and KWK "Krupiński" (April 1, 2017). Both mines have active methane capture at levels of 99.43% and 86.91%, respectively.

In the Greenhouse Gas Inventory Data report sent to the UNFCCC registry [6], the emission factor for methane from abandoned mines is assumed to be 0.652 million m^3/mine. According to this factor, the average methane emissions from this activity amounted to 264.53 $ktCH_4$, which is equivalent to 6.61 $MtCO_2eq$ from 2015 to 2020. Figure 5.1 shows the methane emissions from

Fig. 3.6 Methane emissions from the underground mining sector worldwide for the year 2018 [6]
Rys. 3.6 Emisje metanu z górnictwa podziemnego na świecie w 2018 roku [6]

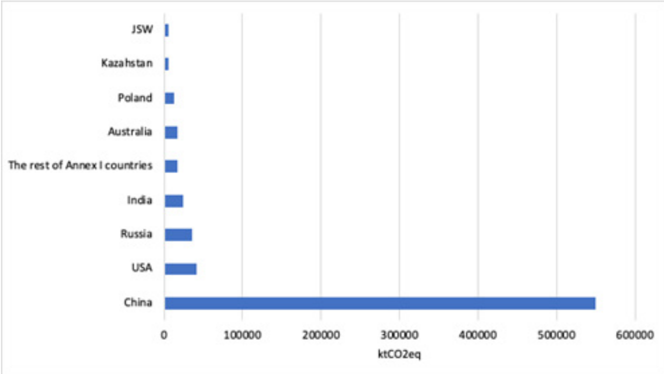
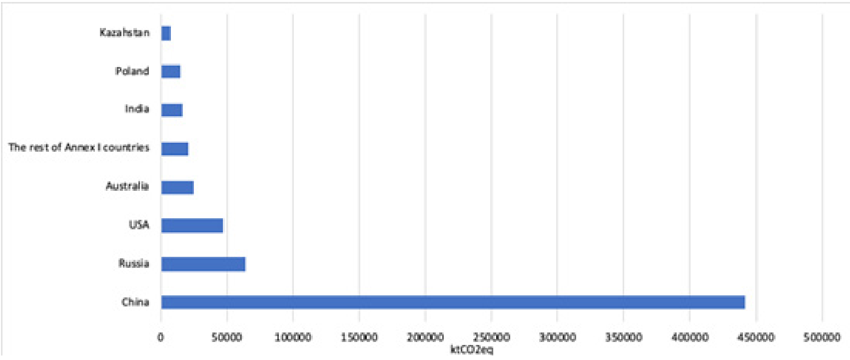


Fig. 3.7 Methane emissions from the mining sector (underground and open-pit mines) worldwide in 2020
Rys. 3.7 Emisje metanu z sektora wydobywczego (kopalnie podziemne i odkrywkowe) na świecie w 2020 r.



the underground mining category divided into mining activity, post-mining, and closed mines in comparison to Europe.

In Poland, the majority of methane emissions in the underground mining category came from mining activity (78% of total emissions), followed by post-mining activity (19%), and abandoned mines accounted for 3% of the emissions. In comparison to Europe, Poland was characterized by high emissions from mining activity (approximately 42% in this category in Europe) and post-mining activity (about 58%). Emissions from abandoned mines accounted for an average of 7% of the total methane emissions from abandoned mines in the sector. The highest emissions in this category were primarily attributed to Romanian mining, accounting for an average of 78%.

Considering the cumulative methane emissions from the underground mining category in Europe, emissions from abandoned mines in Poland accounted for approximately 1.16% of the total emissions, mining activity accounted for an average of 30% of the emissions, and post-mining activity accounted for 7%.

The methane emissions from the former JSW S.A. mines in 2019 amounted to 1.88 million m^3, which corresponds to 1.35 $ktCH_4$ (0.03375 $MtCO_2eq$).

In comparison to Annex I countries, methane emissions in Poland in the mining activity category accounted for 10%, in the post-mining activity category 17%, and emissions from closed mines accounted for an average of 3% of the total methane emissions from closed mines in the sector (Fig. 5.2).

Polish coal mining is characterized by very low rock permeability. Methane emissions occur due to its expansion under the influence of mining activity. Increased methane release from the rock often occurs, and its capture becomes necessary. After mining operations are completed, the pressures in the rock equalize, resulting in increased stress and decreased permeability, ultimately leading to a decrease in methane emissions over time. Taking this into account, the release of methane from abandoned mines over a longer time period should not have a significant impact on the total methane emissions from the underground mining category.

6. Summary

Methane has been recognized by the Intergovernmental Panel on Climate Change (IPCC) as the second most significant greenhouse gas, contributing to global warming by absorbing infrared radiation. Methane emissions are associated with coal mining, and Poland is the ninth largest producer of coal. In the country, 88% of methane is released from underground mining activities, while only 12% comes from surface mines.

In Poland, the majority of methane emissions in the underground mining category come from mining activity (78% of total emissions), followed by post-mining activity (19%), and abandoned mines account for 3% of emissions.

In 2021, approximately 815.3 million m^3 of methane was released from the rock affected by mining activities, which means that on average, 1551.17 m^3 of methane was released per minute [9]. From 2015 to 2021, the relative methane emission rate, measured in cubic meters per ton of extracted coal, ranged from 12.9 to 15 m^3.

The cumulative methane capture efficiency in Polish mines for the years 2015–2019 ranged from 34.6% to 36.3%, and the utilization rate remained at the level of 57% to almost 64%

Fig. 3.8 Methane emissions from underground mines in European countries
Rys. 3.8 Emisje metanu z podziemnych kopalń w krajach europejskich

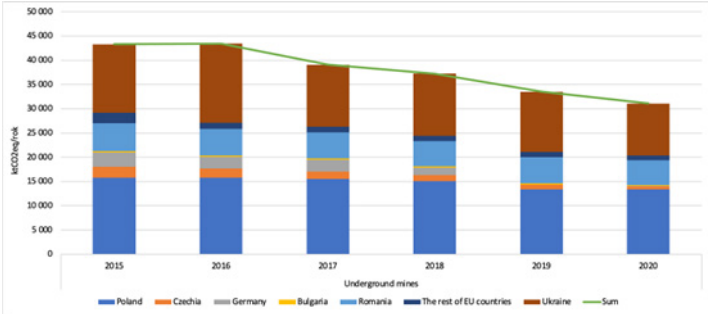


Fig. 4.1 Methane emissions from JSW S.A. mines in relation to different sectors in European countries from 2015 to 2020 [6]

Rys. 4.1 Emisje metanu z kopalń JSW S.A. na tle poszczególnych sektorów w krajach europejskich w latach 2015–2020 [6]

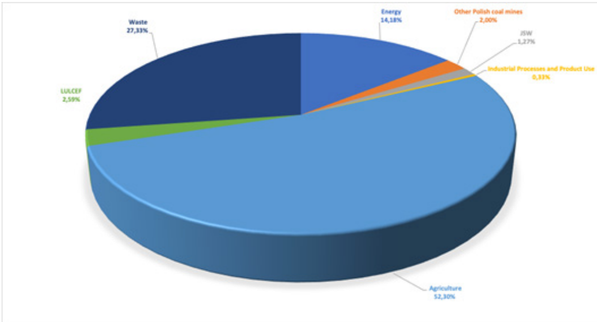
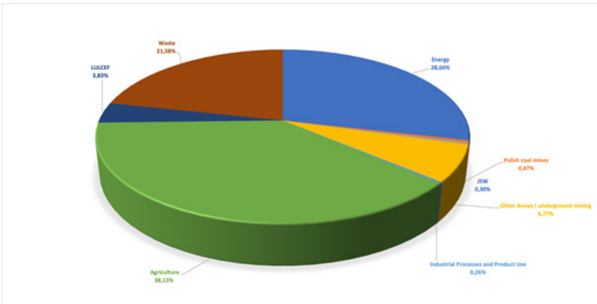


Fig. 4.2 The methane emissions from JSW S.A. mines in relation to different sectors in Annex I countries from 2015 to 2020 [6]

Rys. 4.2 Emisje metanu z kopalń JSW S.A. w odniesieniu do poszczególnych sektorów w krajach Załącznika I w latach 2015–2020 [6]



in 2018. However, from 2019 to 2021, these values slightly decreased. On the other hand, the percentage of methane released into the atmosphere during the examined period ranged from 63.7% to over 65.4% in 2021. It is important to note that these data are determined based on absolute methane content and only include ventilation air methane, excluding unutilized methane. If unutilized methane was taken into account, the percentage of methane released into the atmosphere would be around 76%.

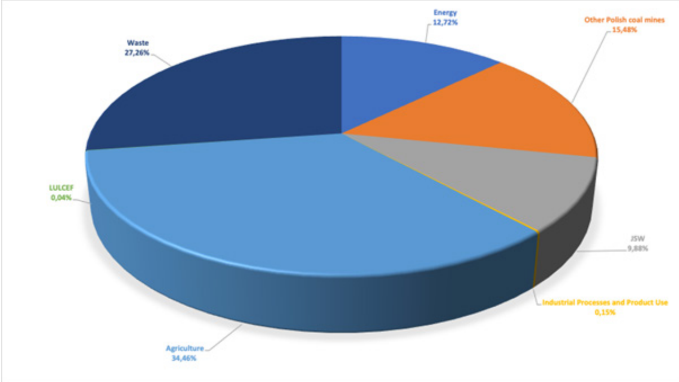
In accordance with the obligations of the UNFCCC convention, Poland reports national emissions within the adopted reduction targets in five source categories using the Common Reporting Format [8]. Greenhouse gas emissions are presented in CO_2 equivalent, using the GWP100 metric, which, according to the IPCC guidelines, is 25 for methane [2]. Using an increased GWP100 value would result in higher total annual greenhouse gas emissions due to the increased contribution of methane (approximately 20%), but it would not significantly affect the long-term trend of changes [15]. However, the choice of other metrics, such as GWP20, could significantly increase the share of the mining sector in total methane emissions, which could influence the government's policy choices regarding climate change mitigation methods. This particularly applies to sectors and companies with high emissions levels other than CO_2, such as JSW S.A.

Compared to all Annex I countries, the Polish energy sector is responsible for approximately 3.3% of emitted methane, and on a European scale, it accounts for 18.23% of methane emissions (an average of 22.36 $MtCO_2eq$).

According to the ranking prepared by the International Energy Agency [7], Poland ranks sixth in terms of methane emissions from the mining sector. On a global scale (Annex I countries), the underground mining sector is a source of an average of 5.15 Mt of methane emissions, of which Polish mines release 0.53 Mt. It is important to note that these data do not include emissions from China and India.

Taking a closer look at the underground mining sectors of individual Annex I countries, it can be seen that

Fig. 4.3 Percentage of methane emissions from JSW S.A. mines in relation to other sectors in Poland from 2015 to 2020 [6]
Rys. 4.3 Udział procentowy emisji metanu z kopalń JSW S.A. w stosunku do innych sektorów w Polsce w latach 2015–2020 [6]



Tab. 4.1. Comparison of the percentage of methane emissions from Polish mines and JSW S.A. mines in relation to the energy sector in Poland, the European Union, and all Annex I countries [6]
Tab. 4.1. Porównanie udziału procentowego emisji metanu z polskich kopalń i kopalń JSW S.A. w odniesieniu do sektora energetycznego w Polsce, Unii Europejskiej i wszystkich krajach Aneksu I [6]

Percentage of methane emissions in the energy sector						
Lata	**2015**	**2016**	**2017**	2018	2019	2020
	Percentage of methane emissions in the energy sector in the European Union					
Percentage of methane emissions from Polish underground mines	18,52	18,78	18,48	19,24	18,34	19,16
Percentage of methane emissions from JSW S.A.	**6,65%**	**7,85%**	**7,17%**	**7,57%**	**7,37%**	**7,10%**
Percentage of methane emissions in the Polish energy sector						
Percentage of methane emissions from Polish underground mines	67,37%	66,76%	66,37%	65,93%	65,68	65,68
Percentage of methane emissions from JSW S.A.	**24,17%**	**27,90%**	**25,76%**	**25,95%**	**26,40%**	**24,33%**
Percentage of methane emissions in the energy sector of Annex I countries						
Percentage of methane emissions from Polish underground mines	1,42%	1,30%	1,33%	1,26%	1,17%	1,32%
Percentage of methane emissions from JSW S.A.	**0,79%**	**0,94%**	**0,84%**	**0,82%**	**0,79%**	**0,78%**

the United States is the dominant emitter, accounting for 35.0% of total methane emissions (in the underground mining sector). The next countries are Russia (35.49%), other Annex I countries including Ukraine (15.4%), Australia (12.3%), Poland (10.3%), and Kazakhstan (3.5%). In the case of Kazakhstan, the majority of methane emissions come from surface mining, accounting for 77.74%. The mines of JSW S.A. are responsible for approximately 3.97% of the total methane emissions from the underground mining sector.

When incorporating literature data on methane emissions from the mining sector for China (550 $MtCO_2eq$) and India (24.6 $MtCO_2eq$), two of the largest methane emitters, and adding JSW S.A., the Polish underground mining sector ranks sixth, accounting for 1.9% of the total global methane emissions from this sector, while emissions from JSW S.A. amount to 0.7%.

In the European context, Poland and Ukraine are the largest emitters of methane from underground mines, accounting for approximately 39.35% and 34.38% of emissions,

Fig. 5.1. The methane emissions from the underground mining category divided into mining activity, post-mining activity, and abandoned mines in Europe from 2015 to 2020 [6]

Rys. 5.1. Emisje metanu z kategorii górnictwo podziemne w podziale na działalność górniczą, działalność pogórniczą i kopalnie opuszczone w Europie w latach 2015–2020 [6]

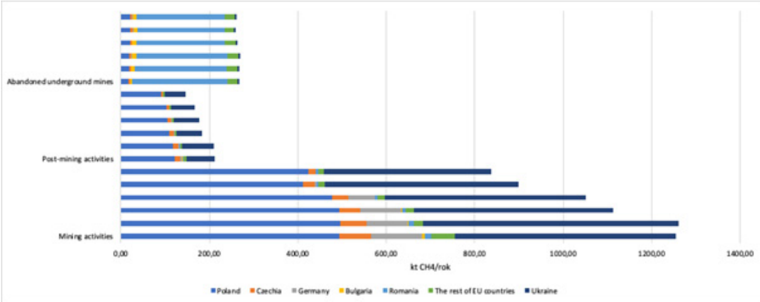
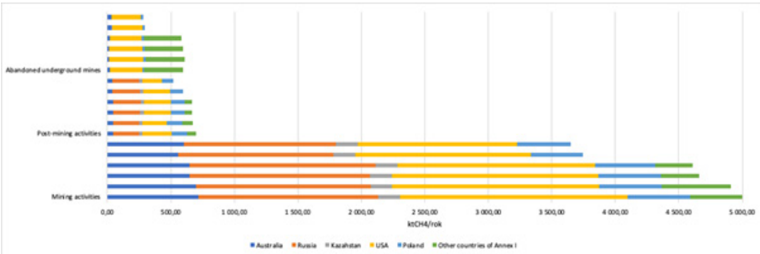


Fig. 5.2. The methane emissions from the underground mining category divided into mining activity, post-mining activity, and abandoned mines in Annex I countries from 2015 to 2020 [6]

Rys. 5.2 Emisje metanu z kategorii górnictwo podziemne z podziałem na działalność górniczą, działalność poeksploatacyjną i kopalnie opuszczone w krajach załącznika I w latach 2015–2020 [6]



respectively. The remaining 27.79% of emissions come from other European countries, including Romania (5.42 $MtCO_2eq$), Germany (1.57 $MtCO_2eq$), and the Czech Republic (1.40 $MtCO_2eq$). The mines of JSW S.A. are responsible for approximately 15.28% of the total methane emissions.

In terms of total methane emissions in Europe, including the energy sector, the mines of JSW S.A. contributed only 1.27% of emissions from 2015 to 2020. Other underground mines in Poland accounted for 2.0%. The largest sources of methane release were the Agriculture sector (52.30%), followed by Waste (27.33%) and Energy (17.45%).

When compared to the Annex I countries, these values significantly decrease, with JSW S.A. accounting for 0.3% of methane emissions and other Polish mines accounting for 0.47%. The dominant sectors were Agriculture (38.13%) and Energy (38.66%) combined.

At the national level, the emissions of methane were distributed differently. From 2015 to 2020, the mines of JSW S.A. accounted for 9.88% of total methane emissions, while other mines accounted for 15.48% (Figure 4.3). Over the entire analyzed period, the largest emissions in Poland were attributed to the Energy sector (approximately 38.08%), followed by Agriculture (34.46%) and Waste (27.26%).

From the presented data, it is clear that methane emissions from JSW S.A. mines ranged from 24% to almost 27%. At the scale of the European Union, this value decreases to between 6.65% and 7.85%, and within the Annex I countries, it represents only 0.79% to 0.94%.

Given that methane emissions (as an associated gas) are inseparable from the activities of JSW S.A., the company strives to capture and utilize it to the greatest extent possible. However, due to safety reasons, it is not possible to completely avoid emissions with the ventilation air.

Including methane in the emissions trading system, with higher fees compared to carbon dioxide, would result in enormous costs for coal companies, ultimately leading them to bankruptcy. Therefore, the complete elimination of methane emissions from mines seems necessary, as proposed by the European Union regulations. However, the implementation of methane ventilation air management (VAM) would require significant financial investments to fully utilize it, which is not feasible. VAM methane utilization technology is costly and not adapted to the amount of airflow in the shafts.

The solution appears to be the funding of methane mitigation technology development and modernization, as well as the introduction of an obligation to apply it regardless of safety conditions (capturing from post-mining works). Legislative solutions are also necessary, such as treating methane captured through mitigation systems as a renewable energy source or a primary source for producing environmentally friendly electricity. The lack of such regulations significantly reduces the attractiveness of methane utilization in energy production since it does not allow for preferential pricing of the sold electricity. One possible solution could be treating investments in coal gas management as preferential due to environmental protection. However, this would require changes to Polish legislation that unequivocally include financial support for electricity and/or heat generated from coal gas processing on the same terms as support for renewable energy, regardless of the installed capacity in the source – granting it the status of environmentally friendly energy.

Due to the harmfulness of methane released into the atmosphere, any measure reducing its presence should be unequivocally supported by legislation, promoted, and financially supported to the extent possible and in accordance with environmental regulations in the country. It is one of the ways to intensify the fight against harmful climate change caused by excessive emissions of this greenhouse gas into the atmosphere, while significantly increasing the safety of mining crews and reducing the costs of coal mining.

Considering the inclusion of electricity generated from coal gas as meeting the obligation to purchase energy from renewable sources would enable the intensification of investment processes in coal gas management by encouraging investors and significantly improving the safety of coal mining.

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Wpływ metanu emitowanego ze złóż węgla na stan atmosfery

W artykule przedstawiono analizę emisji metanu do atmosfery, ilości metanu wychwyconego i wykorzystanego, a także metanu uwolnionego z systemu odmetanowania. Wyniki są następnie porównywane z danymi pochodzącymi z Wyższego Urzędu Górniczego (WUG) oraz Europejskiego Rejestru Uwalniania i Transferu Zanieczyszczeń (E-PRTR), który w Polsce prowadzony jest przez Główny Inspektorat Ochrony Środowiska. Dodatkowo, na podstawie danych o emisji gazów cieplarnianych z UNFCCC i JSW S.A., w artykule określono wpływ metanu emitowanego z jej kopalń na atmosferę w skali europejskiej i światowej.

Słowa kluczowe: *emisje metanu, efektywność odmetanowania, ochrona atmosfery*