AKADEMIA GÓRNICZO-HUTNICZA
IM. STANISŁAWA STASZICA W KRAKOWIE

# Methane from JSW S.A. coal mines
# A real threat to the climate?

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# Spis treści

# 1 Introduction

The Intergovernmental Panel on Climate Change has recognized methane ($CH_4$) and carbon dioxide ($CO_2$) as the two most important greenhouse gases, i.e., substances that absorb infrared radiation and thus contribute to global warming[1]. Their concentrations in the atmosphere have been strongly affected over the years by human activity. According to IPCC, during the past 250 years, the $CH_4$ level in the atmosphere has increased by ca. 162%[2]. Despite its lower atmospheric concentration relative to $CO_2$, methane has a global warming potential (GWP) 28 times higher (on a 100-year horizon) than that of $CO_2$[3]. However, recent studies show that this value has increased to 32[4] and taking into account the additional carbon footprint, it amounts to 34 on a 100-year horizon and 86 on a 20-year horizon[5]. Additionally, the radiative impact attributed to methane emissions is approximately 0.97 Wm2[6] and considering its relatively short lifetime (11.2 +/- 1.3), a reduction of its emissions may have a short-term effect on its radiative forcing[7]. This, in turn, makes methane emissions observations an excellent source of information on climate change.

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[1] IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[2] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[3] Myhre, G., D. Shindell, F.-M. Bréon, et al., 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[4] Etminan, M., Myhre, G., Highwood, E.J., Shine, K.P., 2016: Radiative forcing of carbon dioxide, methane, and nitrous oxide: a significant revision of the methane radiative forcing. Geophys. Res. Lett. 43 (12), 623. https://doi.org/10.1002/2016GL071930. 614–12.

[5] Myhre, G., D. Shindell, F.-M. Bréon, et al., 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[6] Saunois, M., Bousquet, P., Poulter, B., et al., 2016.: The global methane budget, 2000–2012. Earth Syst. Sci. Data 8, 697–751. https://doi.org/10.5194/essd-8-697- 2016.
www.earth-syst-sci-data.net/8/697/2016/.
Myhre, G., D. Shindell, F.-M. Bréon, et al., 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[7] Prather, M.J., Holmes, C.D., Hsu, J., 2012. Reactive greenhouse gas scenarios: systematic exploration of uncertainties and the role of atmospheric chemistry. Geophys. Res. Lett. 39, L09803. https://doi.org/10.1029/2012gl051440. 2012.
Saunois, M., Bousquet, P., Poulter, B., et al., 2016.: The global methane budget, 2000–2012. Earth Syst. Sci. Data 8, 697–751. https://doi.org/10.5194/essd-8-697- 2016.
www.earth-syst-sci-data.net/8/697/2016/.
Saunois, M., Jackson, R.B., Bousquet, P., Poulter, B., Canadell, J.G., 2016b. The growing role of methane in anthropogenic climate change. Environ. Res. Lett. 11, 120207. https://doi.org/10.1088/1748-9326/11/12/120207.

Methane is a gas initially produced by anaerobic digestion of organic matter in biological systems, but according to IPCC data, now half of its current flow into the atmosphere comes from anthropogenic sources, i.e., those most influenced by human activity[8]. Although its global emissions account for about 4% of the anthropogenic $CO_2$ emissions in mass flow units, it nevertheless is responsible for 20% of the additional forced radiation accumulated in the lower atmosphere since 1750[9]. The additional problem is that the amount of methane released is not adequately quantified due to the measurements' inaccuracy, and its sources are not correctly defined. World methane emissions in 2019 were approximately 570 Mt[10]. They included emissions from natural sources in the amount of about 40%. The remaining 60% came from anthropogenic sources. The most significant is Agriculture, which accounts for about a quarter of the total emissions, followed closely by the Energy sector, including emissions from coal, oil, natural gas, and biofuels.

Methane is emitted from a wide variety of sources that are highly dispersed and often overlap geographically. Uncertainties in the evaluation of $CH_4$ emissions from sectors such as Agriculture, Waste, and Fossil fuels range from 20 to 30%[11]. The lack of precise results for determining the amount of emitted methane mainly applies to a regional scale (e.g., South America, China, or India). For this reason, numerous attempts are made to accurately determine the greenhouse gas emissions, including methane, and the knowledge acquired in this way is vital for adopting effective strategies aimed at reducing them.

Poland has been a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) since 1994, and the Kyoto Protocol (P.K.) since 2002 and contributes to the activities aimed at limiting climate change[12]. After the Kyoto Protocol's ratification, it committed to reducing greenhouse gas emissions in 2008-2012 by 6% compared to the base year. In turn, in the second commitment period, i.e., in the years 2013 to 2020 (Doha

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[8] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[9] Saunois, M., Bousquet, P., Poulter, B., et al., 2016.: The global methane budget, 2000–2012. Earth Syst. Sci. Data 8, 697–751. https://doi.org/10.5194/essd-8-697- 2016.
www.earth-syst-sci-data.net/8/697/2016/.

[10] Source: IEA World Energy Balances 2020 https://www.iea.org/reports/methane-tracker-2020

[11] Saunois, M., Bousquet, P., Poulter, B., et al., 2016.: The global methane budget, 2000–2012. Earth Syst. Sci. Data 8, 697–751. https://doi.org/10.5194/essd-8-697- 2016.
www.earth-syst-sci-data.net/8/697/2016/.
Kirschke, S. Saunois, M., Bousquet, P., et al., 2013: Three decades of global methane sources and sinks. National Geoscience, 6, 813–823, doi:10.1038/ngeo1955

[12] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw., polish text

amendment), it committed to achieving average annual emissions of 80% of the total emissions for all countries (European Union countries and Iceland) in the base years[13].

Following the obligations of the UNFCCC, Poland estimates and reports the national emissions under the adopted reduction targets in key five categories in the so-called Joint Reporting Boards: *Energy*, *Industrial Processes and Product Use*, *Agriculture*, *Land Use, Land Use Change and Forestry* (LULUCF), and *Waste*[14]. The emissions of individual greenhouse gases are presented in $CO_2$ equivalent, with the $GWP_{100}$ metric as a conversion factor, which for methane, according to the IPCC guidelines, is equal to 25[15]. It is assumed that the use of an increased $GWP_{100}$ value would result in a higher total annual greenhouse gas emissions as a result of the increased share of methane (approx. 20%) but would not significantly affect the long-term climate change trend[16]. The choice of other metrics, e.g., $GWP_{20}$, may significantly increase the share of various sources/sectors, including the mining sector, in total methane emissions. This, on the other hand, may entail the need to take quick action to mitigate climate change. In other words, the choice of metric influences the choice of policies and methods to be used to mitigate climate change, particularly in sectors and countries with high levels of non-$CO_2$ emissions. *The metric adopted in the "think tanku EMBER Coal to Clean Energy Policy" report is inconsistent with the IPCC guidelines and misleads the public opinion regarding the volume of methane emissions from the mining sector*. The exact methodology for calculating emissions is described in the English version of the "National Inventory Report 2020 (NIR)[17] Greenhouse Gas Inventory for 1988 to 2018". The unit responsible for preparing national inventory reports is the National Center for Emissions Management (KOBiZE) in the Institute of Environmental Protection - National Research Institute (IOŚ-PIB), supervised by the Climate's Minister.

From the analysis of methane emissions carried out in this report follows that, the most important category is *Energy*, including source: Fugitive emission from fuels, with the largest

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[13] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw, polish text

[14] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw, polish text

[15] IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[16] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[17] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw, English version

share of emissions from underground mines. The coal sector in Poland was responsible for 33.8% of total methane emissions in 2018[18].

The report in question was prepared at the request of Jastrzębska Spółka Węglowa S.A. Its purpose is to present the actual state of methane emissions from the mining sector, in particular JSW S.A. coal mines, and their impact on climate change in the context of total European and global emissions.

The first part of the report presents the balance of methane emissions from JSW S.A. coal mines from 2015 to 2020 based on the Company's data. As part of the balance sheet, the analysis of atmospheric methane emissions, the amount of methane captured by methane drainage, utilized, and released from the methane drainage system was performed. The results were then compared with the State Mining Authority inventory and the European Pollutant Release and Transfer Register (E-PRTR) coordinated in Poland by the Chief Inspectorate of Environmental Protection.

The next part of the study presents current and planned future projects to increase the use of captured methane and reduce its emissions to the atmosphere.

In the following chapters, an analysis of the mining sector's methane emissions in the world and Europe was carried out concerning the total emissions and the energy sector to show their impact on the atmosphere. Then, it was assessed for what proportion of methane emissions the JSW S.A. coal mines are responsible for.

The analyzes carried out in the report were based on the data available on the UNFCCC Greenhouse Gas Inventory Data website[19]. This inventory provides GHG emissions data for all Annex I and non-Annex I countries.

The last part of the report presents conclusions, a summary and indicates possible directions for reducing methane emissions from JSW S.A. mines.

[18] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw, polish text.
[19] UNFCCC Greenhouse Gas Inventory Data, https://di.unfccc.int/detailed_data_by_party

# 2 The state of methane emissions from the mining sector in Poland

The energy sector in the world is responsible for the emissions of 122.1 million tonnes of methane, of which the coal sector is responsible for 40 million tonnes[20]. China is the definite world's leader in coal production with a total amount of up to 3,500 million tonnes (Fig. 2.1). The rating presented in Figure 2.1 clearly shows that Poland, as a coal producer, ranks tenth[21]. In 2018 and 2019, domestic extraction of this raw material was 63.4 and 61.6 million tonnes, respectively[22].

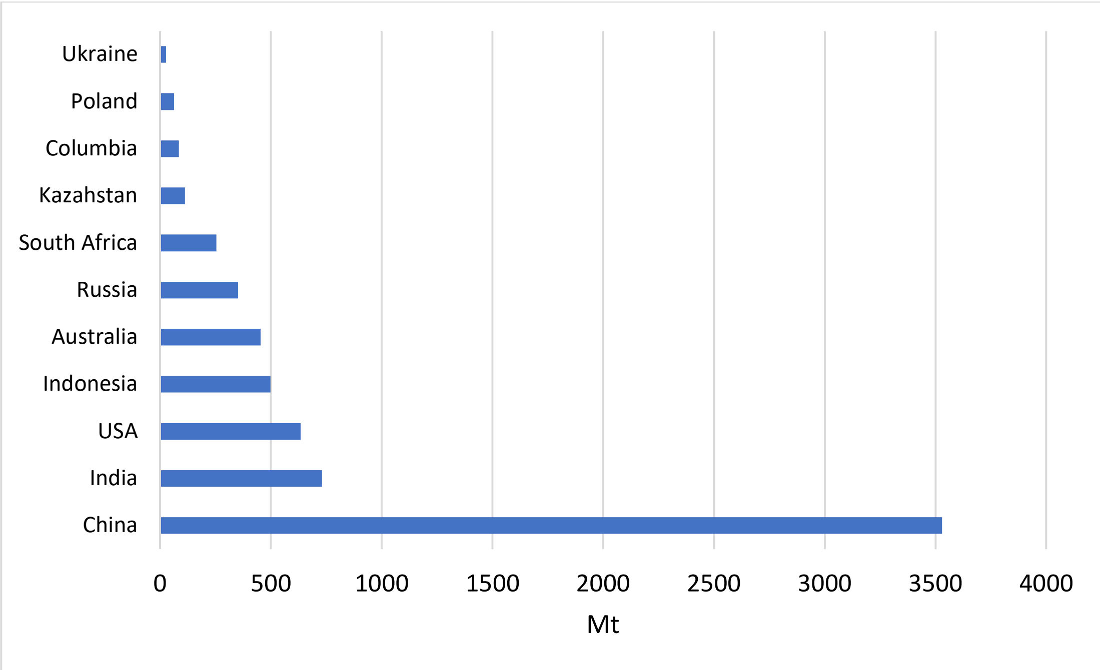


*Fig. 2.1 List of the world's largest coal producers[23]*

About 49.5% of the Polish energy sector is based on coal. Figure 2.2 shows the primary industries that use coal as a raw material[24]. Until 2000, the most significant amount was used for industrial and residential purposes as a fuel for heating buildings. After 1995, industrial use of coal decreased significantly, reaching 3,495 ktoe in 2018. From 2000 to 2018, coal

[20] IEA World Energy Balances 2020 https://www.iea.org/reports/methane-tracker-2021/methane-and-climate-change#abstract
[21] Statista: Leading hard coal producing countries worldwide in 2018: https://www.statista.com/statistics/264775/top-10-countries-based-on-hard-coal-production/
[22] WUG, 2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach.
[23] Statista: Leading hard coal producing countries worldwide in 2018: https://www.statista.com/statistics/264775/top-10-countries-based-on-hard-coal-production/
[24] Source: IEA World Energy Balances 2020 https://www.iea.org/subscribe-to-data-services/world-energy-balances-and-statistics

consumption was the biggest in the residential sector (from 7,888 ktoe in 2010 to 6,435 ktoe in 2018).

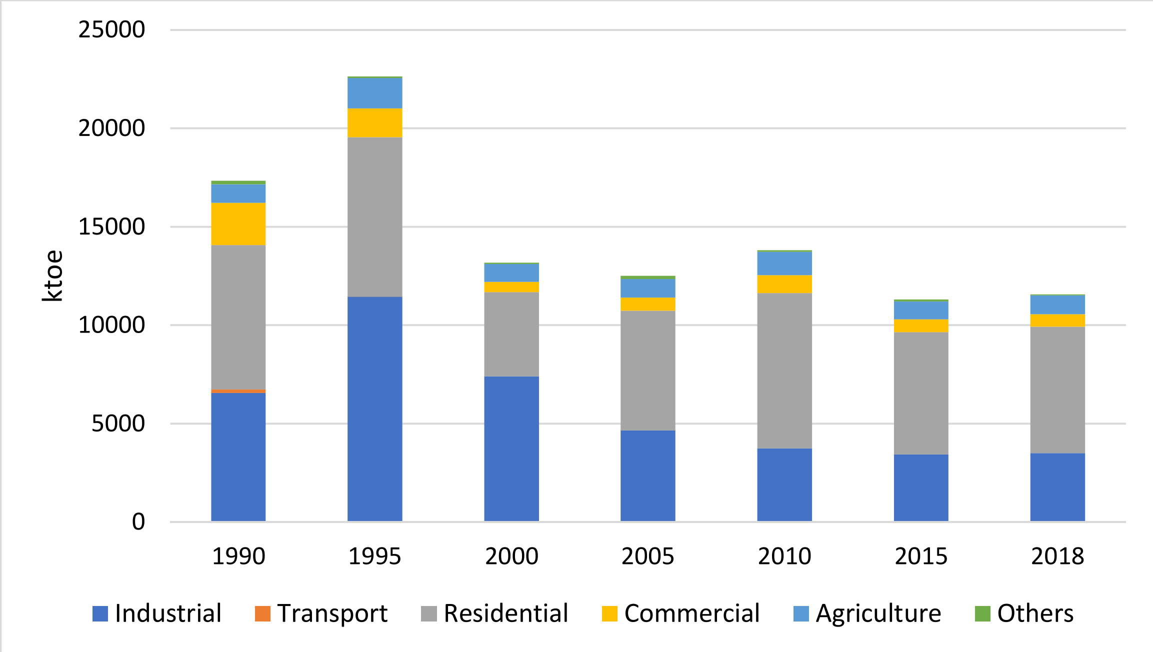


*Fig. 2.2 Coal consumption in Poland by sectors*[25]

Coal mining is accompanied by gas emissions, mainly methane, carbon dioxide, higher hydrocarbons, nitrogen, and steam. Mine gas contains from 86–99.6% methane,[26] but its composition largely depends on the type of deposit and the method of its extraction, and it changes with the course of time and extraction's conditions.

According to the 2019 balance of mineral resources and underground water in Poland, the presence of methane in hard coal seams has been appropriately documented only in the deposits of the Upper Silesian Coal Basin[27]. Recognition of the Lower Silesian Coal Basin's methane conditions and the Lublin Coal Basin is inferior. The detected methane concentrations are much lower; hence, it is difficult to assess their present economic importance. The documented recoverable reserves in the area of the Upper Silesian Coal Basin in 2019 amounted to 109,548.53 million m$^3$ and increased by 7,527.19 million m$^3$ compared to 2018[28].

[25] IEA World Energy Balances 2020 https://www.iea.org/subscribe-to-data-services/world-energy-balances-and-statistics

[26] Szlązak, N., Borowski, M., Obracaj, D., et al., 2014. Selected Issues Related to Methane Hazard in Hard Coal Mines. Wydawnictwa AGH, Kraków.

[27] Bilans zasobów złóż kopalin w Polsce wg stanu na 31 XII 2019. Państwowy Instytut Geologiczny- PIB, Warszawa 2020, https://www.pgi.gov.pl/oferta-inst/wydawnictwa/serie-wydawnicze/bilans-zasobow-kopalin.html

[28] Bilans zasobów złóż kopalin w Polsce wg stanu na 31 XII 2019. Państwowy Instytut Geologiczny- PIB, Warszawa 2020, https://www.pgi.gov.pl/oferta-inst/wydawnictwa/serie-wydawnicze/bilans-zasobow-kopalin.html

In 2019, 803.8 million $m^3$ of methane was released from the rock mass affected by mining, which on average equals 1,530.9 $m^3$ per minute[29]. In 2015–2019, this amount per tonne of coal extracted (relative methane capacity) fluctuated between 12.9 and 14.5 $m^{3}$.

In 2018, methane emissions in Poland amounted to 1,950.13 kt and, compared to the base year (1988), were lower by 35.6%[30]. This value corresponds to 48.75 Mt $CO_2$eq assuming $GWP_{100}$ of 25. Using a $GWP_{100}$ value of 28 results in the amount of methane in $CO_2$eq 12% higher (54.60 kt $CO_2$eq). The share of methane in the total national greenhouse gas emissions in 2018 was 11.8%. Three of its primary sources belong to the category: *Fugitive emissions from fuels* (39.3%), *Agriculture* (29.9%), and *Waste* (23%). The first category includes emissions from underground mines (approximately 33.8% of total emissions) and emissions from the extraction, processing, and distribution of oil and gas (about 5.5% of whole emissions). Figure 2.3 shows the percentage of methane emissions from each category.

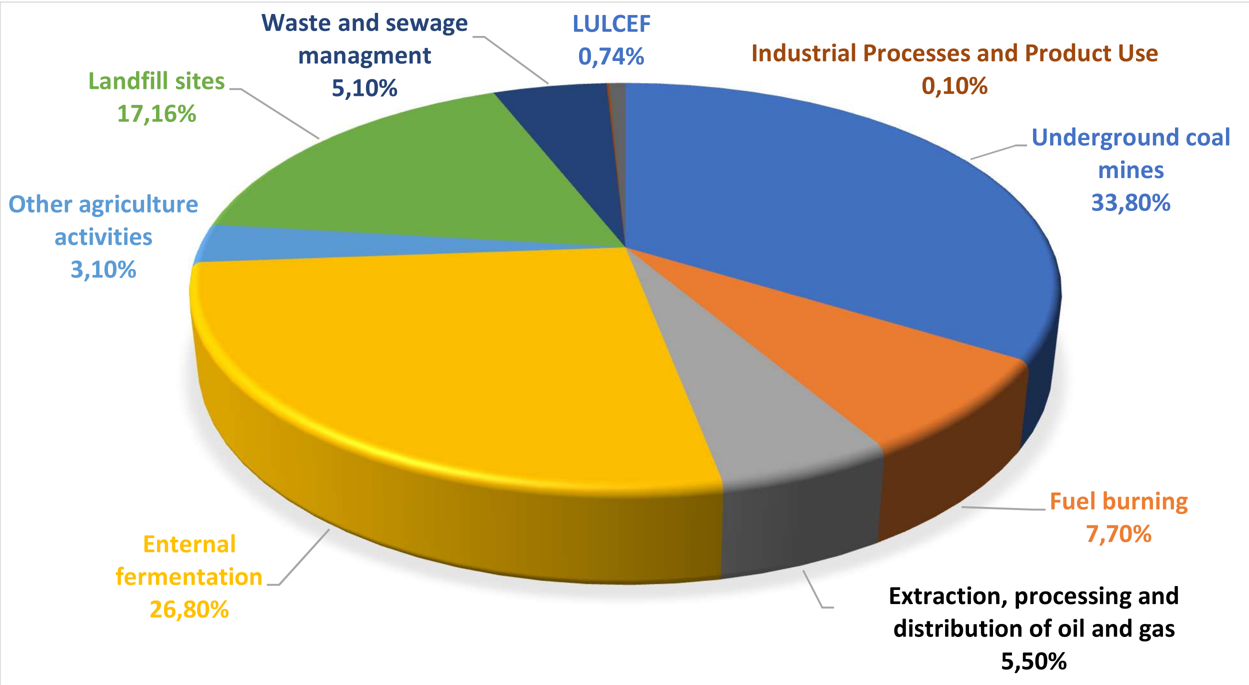


*Fig. 2.3 Structure of methane emission categories in Poland by 2018*

In the coming years, the amount of methane emitted in hard coal mines will probably increase due to the higher methane content of coal seams, which depends on the depth of their deposition (in the last decade, there has been an increase in methane emissions by 60% for each

[29] WUG, 2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach
[30] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw, polish text.

megagram of coal mined)[31]. For this reason, a lot of emphasis should be placed on its acquisition, and thus - commercial usage.

The state of methane emissions from the mining sector in Poland in the last five years is shown in Figure 2.4[32]. Data analysis shows that in the period from 2015 to 2017, the total atmospheric methane emissions remained at the level of about 530 kt (13.25 kt$CO_2$eq), and over the next two years, they dropped to 440 kt - 11.00 kt$CO_2$eq (blue line in Figure 2.4). The results of the *State Mining Authority* inventory are consistent with the data from the *European Pollutant Release and Transfer Register* (E-PRTR) presented in Figure 2.5[33]. Slight discrepancies can be observed in 2019 because the E-PRTR register did not include methane emissions from coal mine "Pniówek". In the data used to prepare Figure 2.5, the coal mine's methane emissions were assumed at the same level as in 2018, while the data from WUG inventory indicate that they were lower. It is worth noting that the two inventories differ slightly in the methodology of compiling the results. In the WUG inventory, the total atmospheric methane emissions are calculated based on individual coal mines' ventilation air methane and the total amount of not utilized methane. The E-PRTR database is based on the complete methane emissions data (ventilation air methane plus the amount of not utilized methane) coming directly from individual coal mines.

Considering that mines carry out methane drainage mainly for safety reasons, its total efficiency for 2015-2019 was 34.6% to 36.3% (Fig. 2.6). On the other hand, when analyzing the utilization efficiency (Fig. 2.6 - grey line), it can be concluded that, within the entire underground mining industry, it was ranging from 57% for 2017 to almost 64% in 2018. In 2019, its value decreased slightly.

The percentage of atmospheric methane emissions presented in Figure 2.6 was determined concerning total methane bearing capacity. That means it includes only ventilation air methane, not taking into account not utilized methane. Because of that, atmospheric methane emissions in the analyzed period ranged from 63.7% to over 65.0% in 2019. *Including not used methane would cause an increase of this value to 76%.*

[31] Szlązak, N., Borowski, M., Obracaj, D., et al., 2015. Odmetanowanie górotworu w kopalniach węgla kamiennego. Wydawnictwa AGH, Kraków.
[32] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach
[33] European Pollutant Release and Transfer Register (E-PRTR): https://prtr.eea.europa.eu/#/home

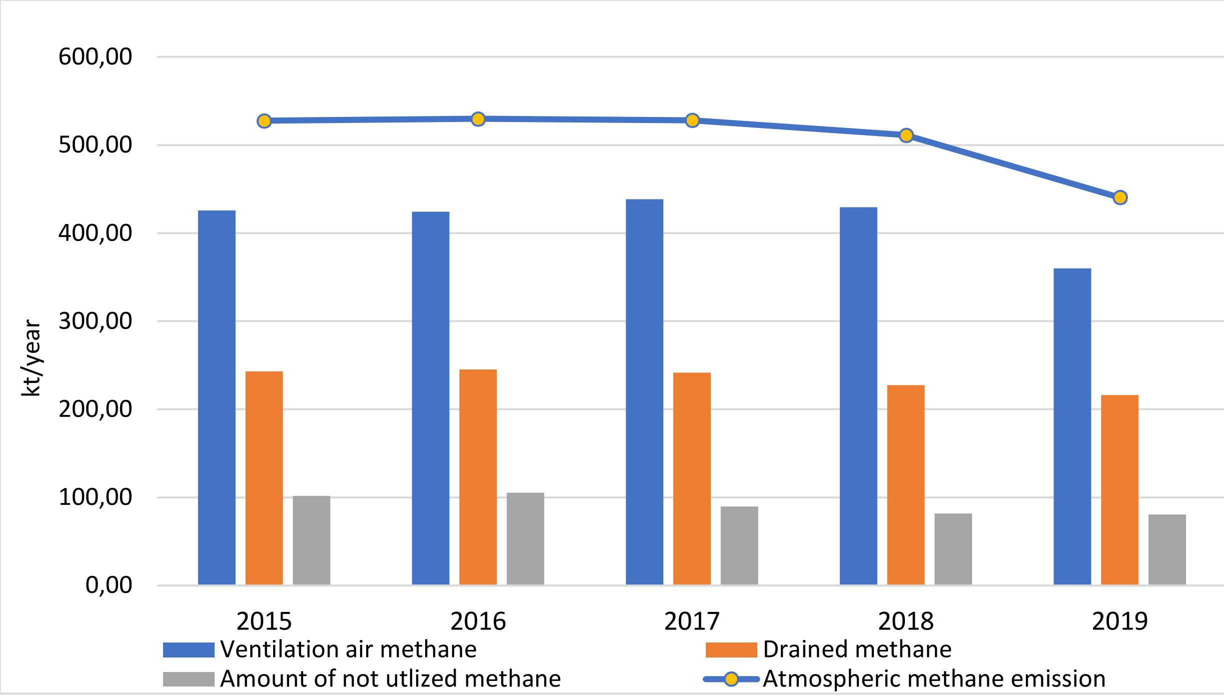


*Fig. 2.4 The state of atmospheric methane emissions from Polish coal mines in the period from 2015 to 2019 based on State Mining Authority inventory (WUG)* [34]

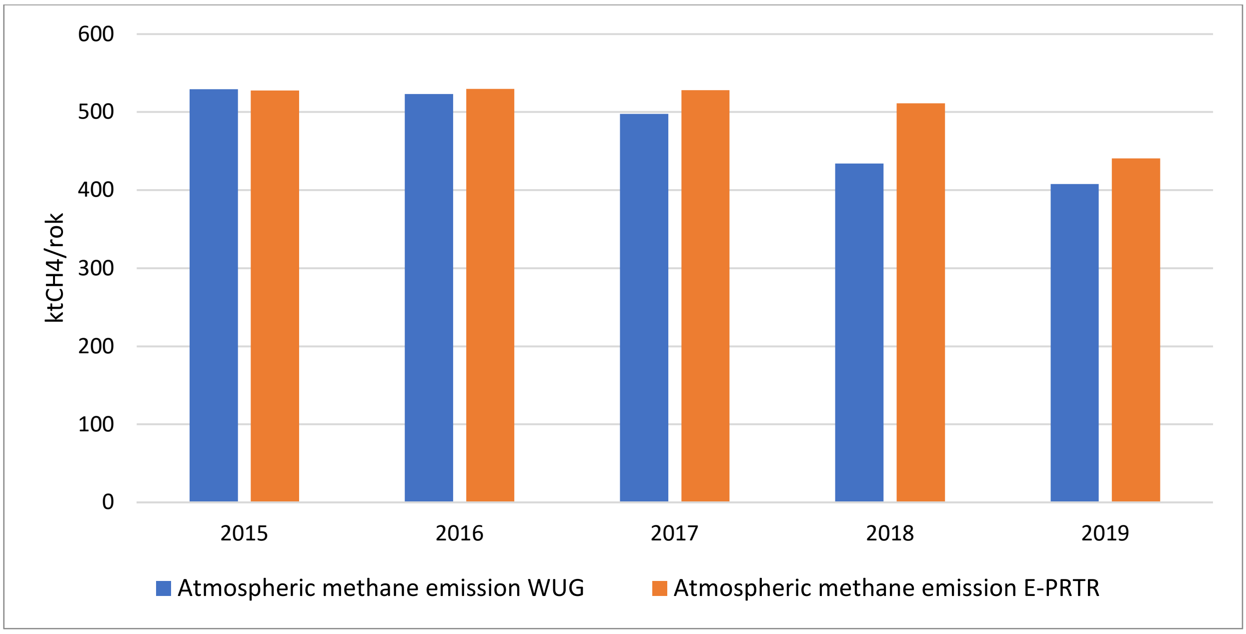


*Fig. 2.5 The state of atmospheric methane emissions from Polish coal mines in the period from 2015 to 2019 based on State Mining Authority inventory (WUG) and European Pollutant Release and Transfer Register (E-PRTR) data*[35]

[34] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach

[35] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach
European Pollutant Release and Transfer Register (E-PRTR): https://prtr.eea.europa.eu/#/home

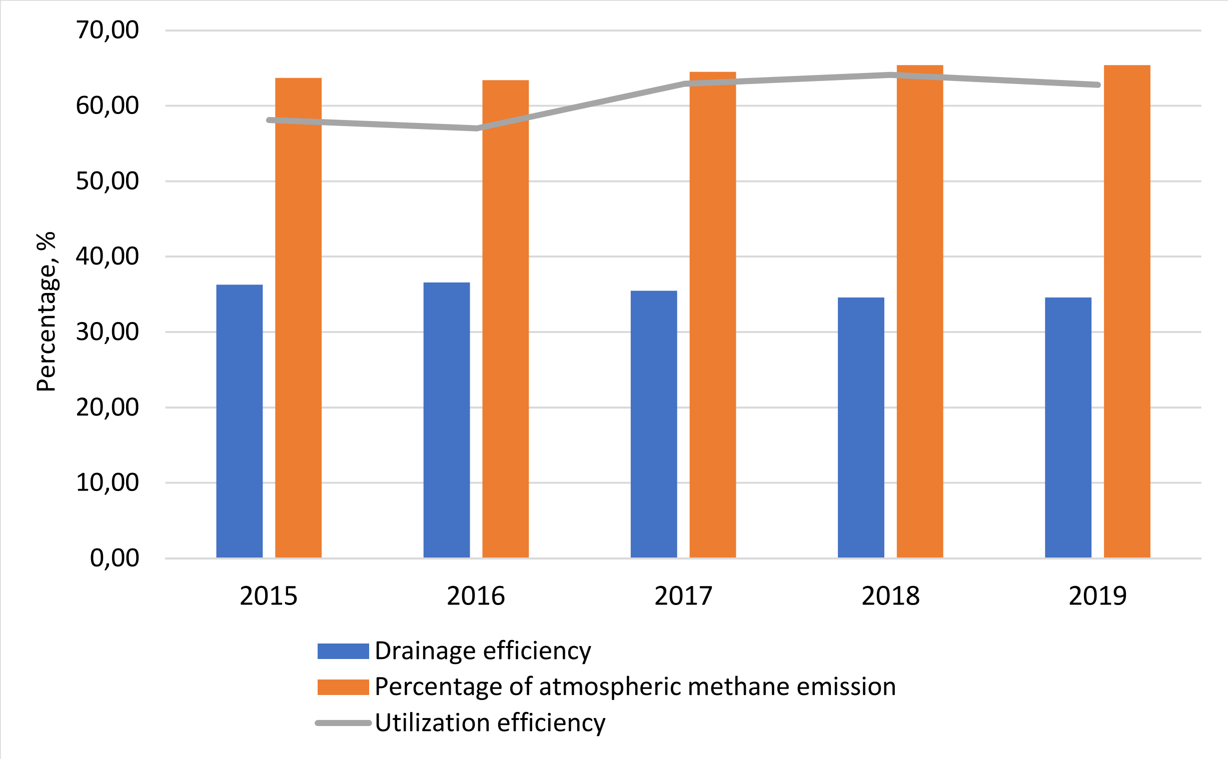


*Fig. 2.6 State of methane drainage, the efficiency of methane utilization and percentage of atmospheric methane emissions in Polish coal mines in 2015-2019*[36]

Currently, methane in active mines is captured using a drainage system only due to the obligations resulting from health and safety regulations. For this reason, technologies currently in use allow capturing approx. 30% of methane released during mining works, whereas the rest 70% is removed through ventilation. Due to methane properties as a greenhouse gas, it is crucial to reduce its atmospheric emissions.

[36] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach

# 3 Balance of methane emissions in the Jastrzębska Spółka Węglowa S.A. coal mines

Jastrzębska Spółka Węglowa S.A. is the largest coking coal producer in the European Union and one of the leading producers of coke, which is an essential ingredient for steel production. The E.U. has classified coking coal as strategic raw material from the point of view of the community's economic interests. It is one of the 27 raw materials included in the list of Critical Raw Materials for the E.U., and therefore of the highest importance for the economy and challenging to replace[37].

The JSW S.A. Capital Group is composed of five coal mines, two of which consist of two Fronts, and they are:

- Coal mine "Borynia-Zofiówka",
- Coal mine "Budryk",
- Coal mine "Knurów-Szczygłowice",
- Coal mine "Pniówek",
- Coal mine "Jastrzębie-Bzie".

On October 1, 2016, the coal mine "Jas-Mos" and on April 1, 2017, the coal mine "Krupiński" were excluded from the Company and transferred to Spółka Restrukturyzacji Kopalń S.A. Currently, these coal mines conduct methane drainage and its utilization, reaching the levels of 86.91% for "Krupiński" (in 2019) and 99.43% for "Jas-Mos"(in 2019). The balance sheet presented in the report below includes both mentioned mines only when they belonged to JSW S.A.

In 2019, coal mines owned by JSW S.A. produced a total of 14.8 million tonnes of coal and 3.2 million tonnes of coke. On January 1, 2020, Front Jastrzębie was merged with Bzie to form the "Jastrzębie-Bzie" coal mine.

The primary source of greenhouse gas emissions resulting from the Group's operations is methane released with the air that flows through the mining workings (approx. 71% of the total emissions per $CO_2$eq) and carbon dioxide from fuel combustion processes in the coking segment. The reduction of greenhouse gas emissions in the Company is achieved through the maximum use of captured methane. Since 2017, the Company has been conducting integrated calculations and reporting the organization's carbon footprint to monitor greenhouse gas emissions consciously and strive to optimize energy consumption, eliminate energy-intensive

[37] Strona JSW https://www.jsw.pl/odpowiedzialny-biznes/slad-weglowy-gk-jsw

solutions, and maximize methane's economic use. That will allow the reduction of greenhouse gas emissions in the long term significantly. The applied solutions and technologies ensure transformation towards a *circular economy*, which is an essential element in creating a low-emission, innovative and competitive economy. On the other hand, they will contribute to changes in the economic model development so vigorously promoted by the European Commission.

This chapter analyzes the balance of total methane emissions, methane captured by the drainage system, and its utilization in the individual coal mines owned by JSW S.A. The analyses are based on emission data from 2015 to 2020, provided by JSW S.A.[38] as well as WUG and E-PRTR emission inventories.

## 3.1 Analysis of the total methane emission from JSW S.A. coal mines

JSW S.A. carries out extraction in five coal mines. The data analysis shows that from 2015 to 2020, a total of 1,775.14 kt (2,475.78 million $m^3$) of methane was released from the Company's coal mines and annual total methane capacity ranged from 260 kt to 346 kt. Figure 3.1 presents the summary balance of methane emissions, including drained and utilized methane in the entire Company. The average ventilation air methane amounted to 182 kt/year (483 $m^3$/min). On the other hand, the total atmospheric methane emissions ranged from 198.5 to 264 kt/year; however, from 2016 to 2020 were systematically decreasing. *As a whole, over the five years, JSW S.A. emitted 1,383.73 kt of methane into the atmosphere, which corresponds to 34.6 million tonnes of* $CO_2$*eq, assuming a* $GWP_{100}$ *of 25; applying the* $GWP_{100}$ *index of 28 results in the increase in the amount of* $CO_2$ *emitted by 4.14 million tonnes (approximately 12%). The amount of drained methane in the discussed period was 683 kt in total and 113.83 kt on average*. From 2016 to 2018, there was a decrease in drainage efficiency from 43.5% to 32% (Fig. 3.1). Its average value for the Company throughout the period was 38.28%. The efficiency of methane utilization in the entire analyzed period remained at 55% to over 60%.

[38] JSW S.A.'s internal data made available for this report

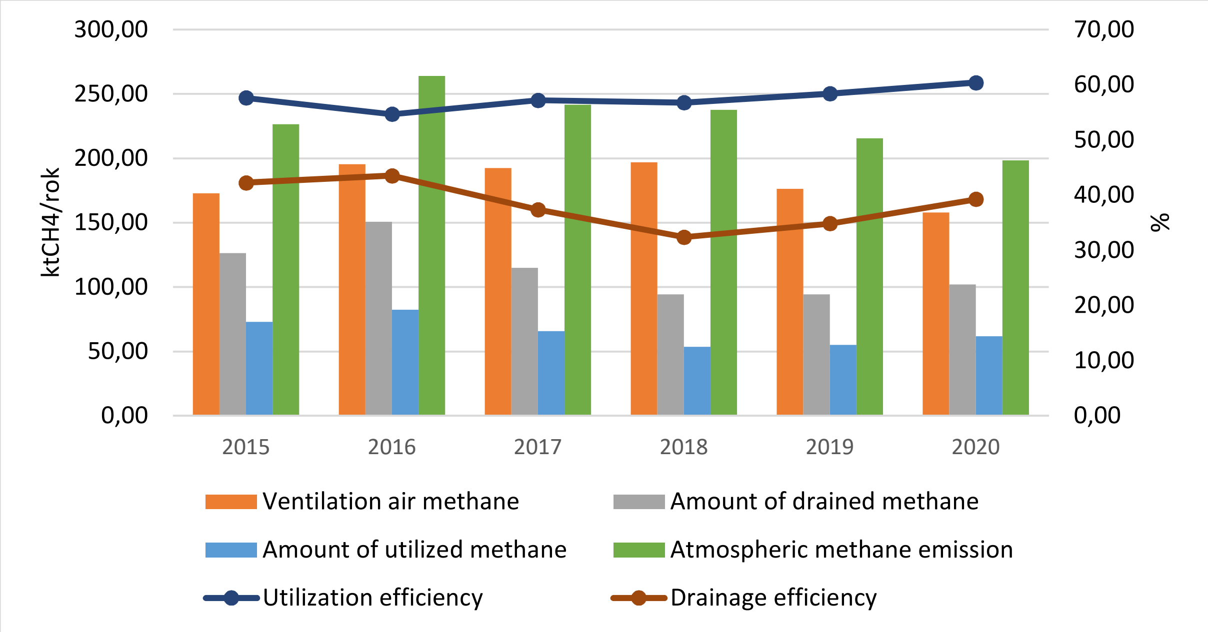


*Fig. 3.1 Balance of methane emission captured and utilized methane in the JSW S.A. coal mines.*

Analyzing the data from the State Mining Authority (WUG) and E-PRTR, the coal mines with the highest methane emissions were "Budryk" and "Pniówek" (Figures 3.2 and 3.3)[39]. In the first one, the highest ventilation air methane reached 66 kt (175.51 $m^3$/min) in the year 2018. The average ventilation air methane for this mine was 53.17 kt/year (140.08 $m^3$/min) throughout the entire period. In the "Pniówek" coal mine, its average ventilation air methane was 51.7 kt/year (137.38 $m^3$/min). The next in line were combined mines "Borynia-Zofiówka-Jastrzębie" and "Knurów-Szczygłowice", 43.3 kt/year (114.91 $m^3$/min) and 30.42 kt/year (80.74 $m^3$/min), respectively. The data obtained from the E-PRTR register differ slightly from that of WUG but is consistent with the Company's results. The difference mentioned above results from the fact that the WUG data, unlike the E-PRTR, do not contain information on the amount of not utilized methane per each coal mine. This discrepancy for WUG (regarding JSW S.A. data) ranges from 36 to 67 kt/year (16% to 25%), whereas, in E-PRTR, it is between 6 to 26 kt/year (3% to 10%); due to adoption of different methane density value to determine the mass of released methane.

[39] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach

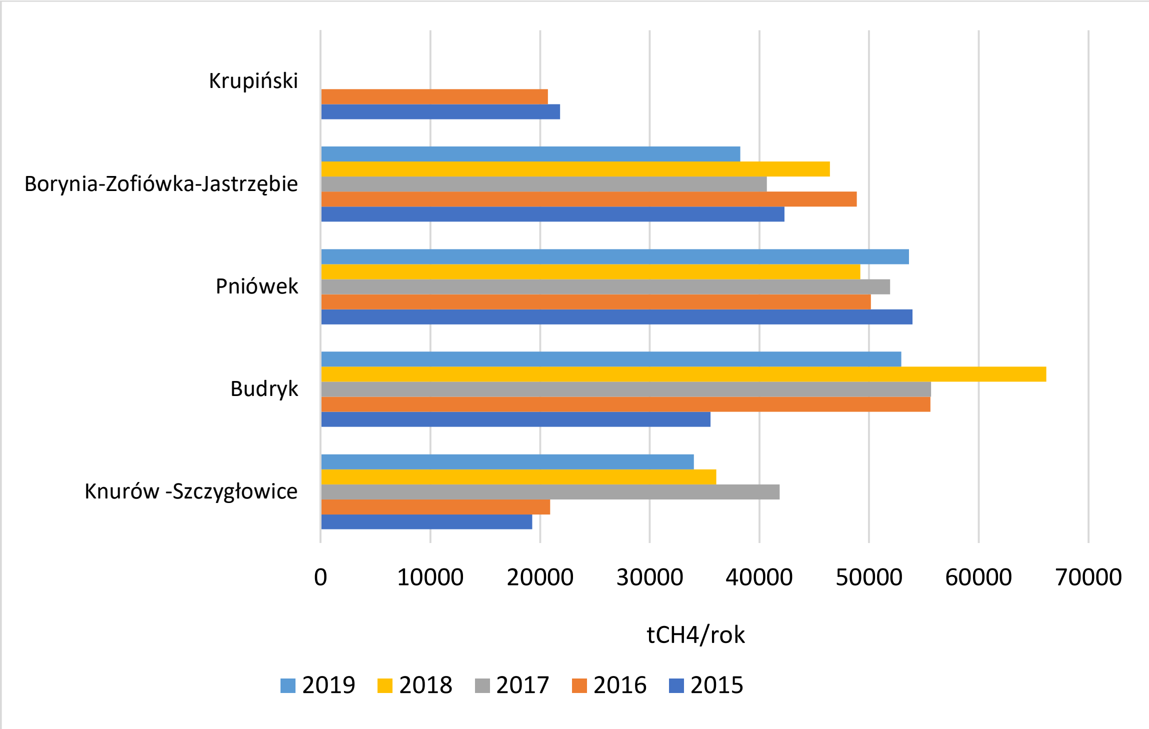


*Fig 3.2 Emissions of methane from JSW S.A. coal mines based on the WUG register*[40]

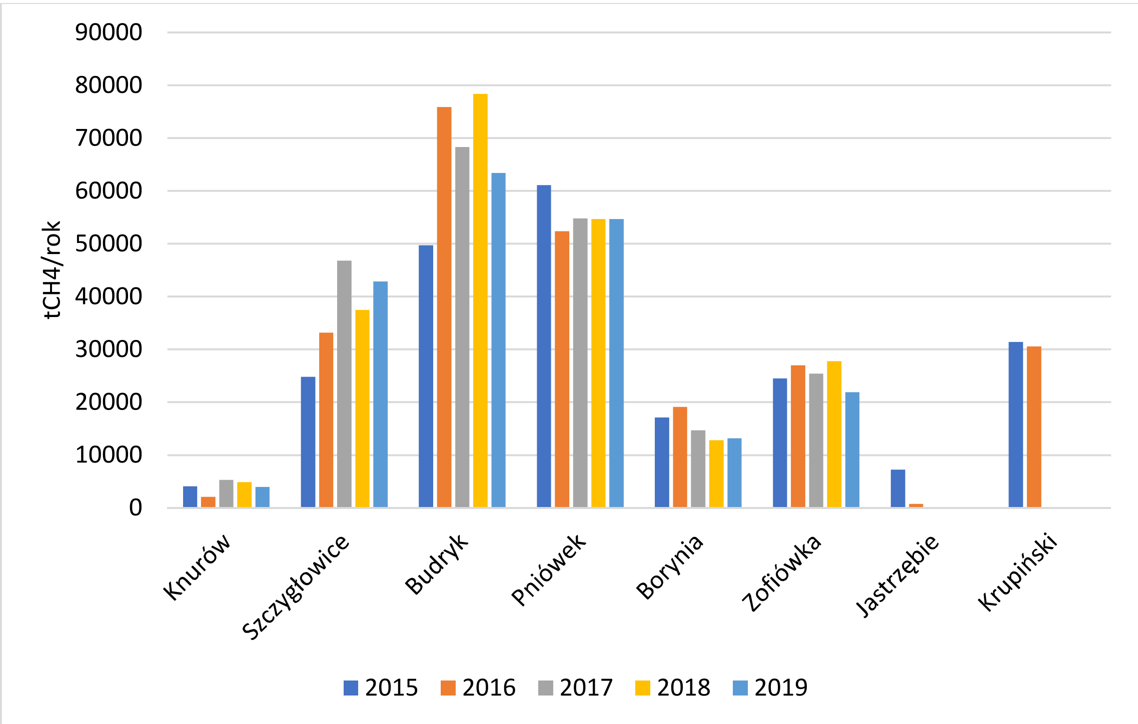


*Figure 3.3. State of methane emissions from individual JSW S.A. coal mines according to the E-PRTR register*[41]

[40] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach
[41] European Pollutant Release and Transfer Register (E-PRTR): https://prtr.eea.europa.eu/#/home

## 3.2 Analysis of methane captured through the drainage system and its utilization in JSW S.A. coal mines

### *3.2.1 Analysis of the amount of captured methane*

The methane hazard in hard coal mines determines the increase in coal extraction costs related to the financial outlays incurred for its prevention and control. Higher expenses are generated in connection with the necessity to carry out methane drainage[42]. Currently, most hard coal mines in Poland are equipped with methane drainage systems, carried out to ensure safety or for technological reasons (draining methane results in lower gas emissions to the mine workings)[43]. On the other hand, methane captured in methane drainage systems can be an energy carrier that, if properly managed, can cover the costs of drainage and even bring additional profits. Because JSW S.A. coal mines belong to highly methane prone, the Company must carry out active drainage. Figure 3.4 shows the amount of methane captured in individual JSW S.A. coal mines from 2015 to 2020.

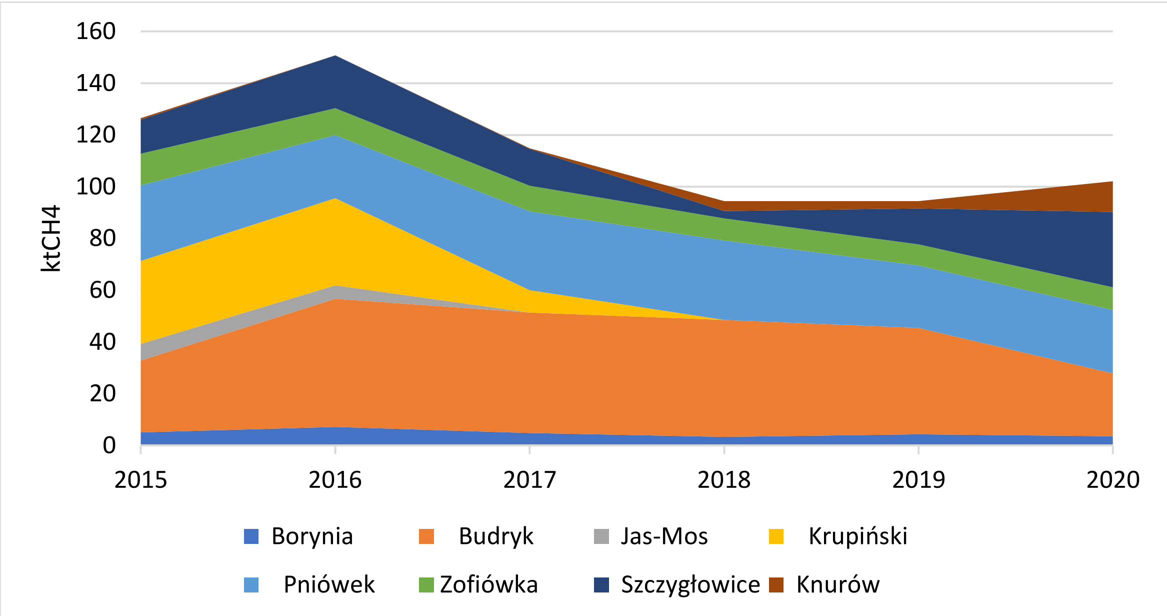


*Figure 3.4. Methane captured in the JSW S.A. coal mines in the period from 2015 to 2020*

*The data presented in the chart show that the Company captured from 94 to 150 kt of methane in total, which in the entire adopted period gives the amount of 683 kt.* The highest

[42] Szlązak, N., Borowski, M., Obracaj, D., et al., 2015. Odmetanowanie górotworu w kopalniach węgla kamiennego. Wydawnictwa AGH, Kraków.
[43] Szlązak, N., Borowski, M., Obracaj, D., et al., 2015. Odmetanowanie górotworu w kopalniach węgla kamiennego. Wydawnictwa AGH, Kraków.

amount was drained in "Budryk," i.e., 234.12 kt in total. In 2016, this number increased by 22 kt compared to 2015 and until 2018 remained at a similar level (41.1 kt to 49.4 kt). In 2020, however, it decreased to the value of 24.2 kt. Large amounts of methane were also captured in "Pniowek"- a total of 163.3 kt. The annual capture ranged from 24.4 kt to 30.4 kt. Active drainage was also carried out in the "Borynia-Zofiówka-Jastrzębie" coal mine, where 98 kt of methane was captured for six years.

It should be noted that the least methane (from 3.3 kt to 7.25 kt) was captured in the "Borynia" Front. By far, Front "Knurów" drained the smallest amount of methane of all coal mines. In 2016 no methane drainage was conducted in this Front, and in other years the level ranged from 0.3 kt to 3.7 kt. Front "Szczygłowice" managed to drain 93 kt of methane, but in 2018, there was a significant decrease compared to previous years - from 14 kt to 2.9 kt. In total, the entire combined coal mine captured almost 113 kt of methane.

From 2015 to 2017, the "Krupiński" coal mine was also operating in JSW S.A. and conducted drainage at an average level of 24.8 kt/year. In total, this coal mine managed to capture 74.5 kt of methane over the three years.

Table 3.1 presents the methane drainage efficiencies for individual coal mines based on the WUG register. "Budryk" coal mine had the highest average methane drainage efficiency - 44%, and then "Knurów-Szczygłowice" - 33%. *The entire Company's average drainage efficiency for five years was 34.7%, based on the register data*. However, when calculating this value, the "Krupiński" coal mine, which is 2015-2016, was characterized by a very high methane drainage efficiency of 60%, was not taken into account.

*Table 3.1. Summary of methane drainage efficiency in JSW S.A. coal mines in the period from 2015 to 2019 based on the WUG register*[44]

| *Drainage efficiency* | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| *"Knurów-Szczygłowice"* | 41,70 | 49,38 | 25,65 | 15,61 | 34,15 |
| *"Budryk"* | 43,84 | 47,06 | 45,48 | 40,57 | 43,73 |
| *"Pniówek"* | 35,11 | 32,70 | 36,94 | 38,43 | 24,60 |
| *"Borynia-Zofiówka-Jastrzębie"* | 35,98 | 31,82 | 26,76 | 20,36 | 24,60 |
| *"Krupiński"* | 59,48 | 62,81 | - | - | - |

[44] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach

### *3.2.2 Analysis of methane utilization*

The directions of gas utilization captured through the drainage system can be different. The four primary groups include[45]:

- energy use
    - heat production (heating and technological needs),
    - for electricity production,
    - combined systems (generation of electricity, heat, cold),
- gas transmission to the external customers,
- production of network gas,
- gas liquefaction.

In the conditions of Polish coal mines, methane is drained in active mining workings. Variability of conditions often changes the quantity and composition of drained gas. Mine gas, which does not have stable quantitative and qualitative parameters, cannot be used in municipal networks. It would require expensive cleaning and enrichment.

Power systems that allow for the economical use of methane must be located in the mine or its close vicinity. Generation of energy, in this case, may be associated with the production of proper heat or electricity and waste heat in the so-called combined cogeneration systems. The trigeneration systems also allow for the generation of cold.

An alternative method of utilizing drained methane in hard coal mines is its purification and liquefaction into LNG. The thus obtained liquid product contains 97% of $CH_4$ and 3% of $N_2$ and constitutes, after its regasification, is a fuel with properties practically identical to network natural gas. The main differences are that the LNG from the methane drainage gas does not contain higher-order hydrocarbons and no water, which is removed before the start of the cryogenic processes.

[45] Szlązak N., Tor A., Jakubów A, 2002.: Analiza ujęcia i wykorzystania metanu w kopalniach Jastrzębskiej Spółki Węglowej S.A. Materiały 2. Szkoły Aerologii Górniczej, Zakopane 7–11 października 2002, Sekcja Aerologii Górniczej Komitetu Górnictwa PAN, Kraków, s. 339–355
Szlązak N., Borowski M., Obracaj D., Szlązak A, 2004: Bilans energetyczny pracy układu sko- jarzonego centralnej klimatyzacji w KWK „Pniówek". Górnictwo i Geoinżynieria, r. 28, z. 1, s. 85–102
Szlązak N., Korzec M., 2009: Ujęcie i możliwości wykorzystania metanu w polskich kopalniach węgla kamiennego. Zagrożenia i korzyści występowania metanu w pokładach węgla – teo- ria i praktyka: XXVI seminarium, Rybnik, 28 października 2009 r.: XXXV Dni Techniki ROP '2009, Instytut Eksploatacji Złóż, Wydział Górnictwa i Geologii Politechniki Śląskiej, Gliwice, s. 101–111
Szlązak N., Korzec M., 2010: Zagrożenie metanowe oraz jego profilaktyka w aspekcie wykorzy- stania metanu w polskich kopalniach węgla kamiennego. Górnictwo i Geoinżynieria, r. 34, z. 3/1, s. 163–174

In the JSW S.A. coal mines, methane utilization is based on generating electricity and heat and internal combustion engines. Table 3.2 summarizes the utilization's technologies used in the Company's coal mines.

*Table 3.2. List of technologies for the methane utilization in JSW S.A. coal mines in the period from 2015 to 2020*

| | Economical use of methane, x $10^3$ $m^3$ | | | | | |
|---|---|---|---|---|---|---|
| **JSW S.A. coal mines** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| **Suma** | **16940,00** | **30846,90** | **24110,00** | **18732,80** | **20459,10** | **0,00** |
| Gas boilers Front Ruch „Borynia” 2x 1,2 MWt | 933,80 | 927,70 | 952,10 | 707,90 | 670,90 | **PGNiG Termika S.A.** |
| Boiler station „Budryk” | 51,40 | 380,70 | 460,40 | 408,40 | 310,20 | 330,50 |
| Flotation concentrate dryer „Krupiński” | 3525,60 | 3689,00 | 393,50 | - | - | - |
| Gas engines Caterpillar „Krupiński” | 4776,50 | 6987,00 | 1411,30 | - | - | - |
| Gas engines JMS 612 GS 1,8 Mwel Front „Borynia” | 3379,30 | 3149,70 | 2229,10 | 3469,60 | 3371,00 | **PGNiG Termika S.A.** |
| Gas engines Deutz 2 x 2,0 MW Szczygłowice | 4273,40 | 7693,90 | 5826,00 | 455,10 | 1573,80 | 5987,70 |
| Gas engines Front "Knurów" CAT CG 260-16 3x4MWel | - | - | - | - | - | 8024,8* |
| Gas engines JMS624GS-SL „Budryk” | - | 8018,90 | 12837,60 | 13691,80 | 14533,20 | 11833,3** |
| **SEJ S.A.** | | | **PGNiG Termika S.A.** | | | |
| **Sum** | **69374,70** | **72892,80** | **55688,70** | **44648,40** | **41504,40** | **47598,60** |
| Heat and power plant „Moszczenica” (including gas engine) | 16565,50 | 14475,00 | - | | | - |
| Heat and power plant „Zofiówka” | 6245,70 | 12465,20 | - | | | - |
| Gas engines TBG 632V16 i TCG 2032 V16 | 43348,20 | 43038,30 | - | | | - |
| Gas boilers and WR | 1579,20 | 1441,60 | - | | | - |
| **ZPC „Żory” Sp. z o.o.** | | | | | | |
| **Sum** | **11119,90** | **10655,10** | **11831,30** | **11367,30** | **14914,50** | **12254,70** |
| Gas engines TBG 620 V 20K | 9154,00 | 7974,00 | - | - | - | - |
| Boiler WR-10 | 1965,90 | 2681,10 | - | - | - | - |
| **LNG Silesia** | **4252,60** | **485,50** | **-** | - | - | - |
| **Sum for JSW S.A.** | **101687,20** | **114880,30** | **91630,00** | **74748,50** | **76878,00** | **59853,30** |
| **Gas engines** | **78206,90** | **89696,00** | **22304,00** | **17616,50** | **19478,00** | **25845,80** |
| **Economic use of methaneu, kt/year** | | | | | | |
| **Sum for JSW S.A.** | **72,91** | **82,37** | **65,70** | **53,59** | **55,12** | **42,91** |
| **Gas engines** | **56,07** | **64,31** | **15,99** | **12,63** | **13,97** | **18,53** |

* CAT CG 260-16 3x4 $MW_{el}$ gas engines with a total capacity of 12 $MW_{el}$
** Gas engines: JMS624GS-SL "Budryk" $MW_{el}$ 2x4 $MW_{el}$ + (from July 2020) gas engine ECOMAX 2 $MW_{el}$

Figure 3.5 shows the amount of utilized methane by all coal mines owned by the Company from 2015 to 2020. *Over time, coal mines used 391.40 kt of methane, which corresponds to 9785.23 kt of $CO_2$ equivalent (assuming $GWP_{100}$ = 25).* Over the entire period, this value ranged from 53.6 kt (2018) to 82.4 kt (2016). Out of the whole amount of utilized methane, 181.51 kt was used in internal combustion engines (Table 3.2). *The drained methane's total utilization* *efficiency for the analyzed period ranged from 55% to 60%, and the average value for the last six years was equal to 57%.*

Of all JSW S.A. coal mines, "Pniówek" utilized the highest amount of methane - 142.3 kt (from 22 kt/year to 27 kt/year). Next was "Budryk" - a total of 97 kt of methane (from 8.0 kt/year to 21.33 kt/year). By far, the lowest amount of methane was used in the "Knurów" Front because it did not carry the utilization for five years (from 2015 to 2019). It was not until 2020 that CAT CG 260-16 gas engines were put into operation at the coal mine drainage station, with a total capacity of 12 $MW_{el}$ (3x4 $MW_{el}$), thus burning 5.75 kt of methane.

During their operation in JSW S.A., the "Krupiński" and "Jas-Mos" coal mines were also utilizing methane. In the case of the first one, the amount of used methane reached almost 51 kt.

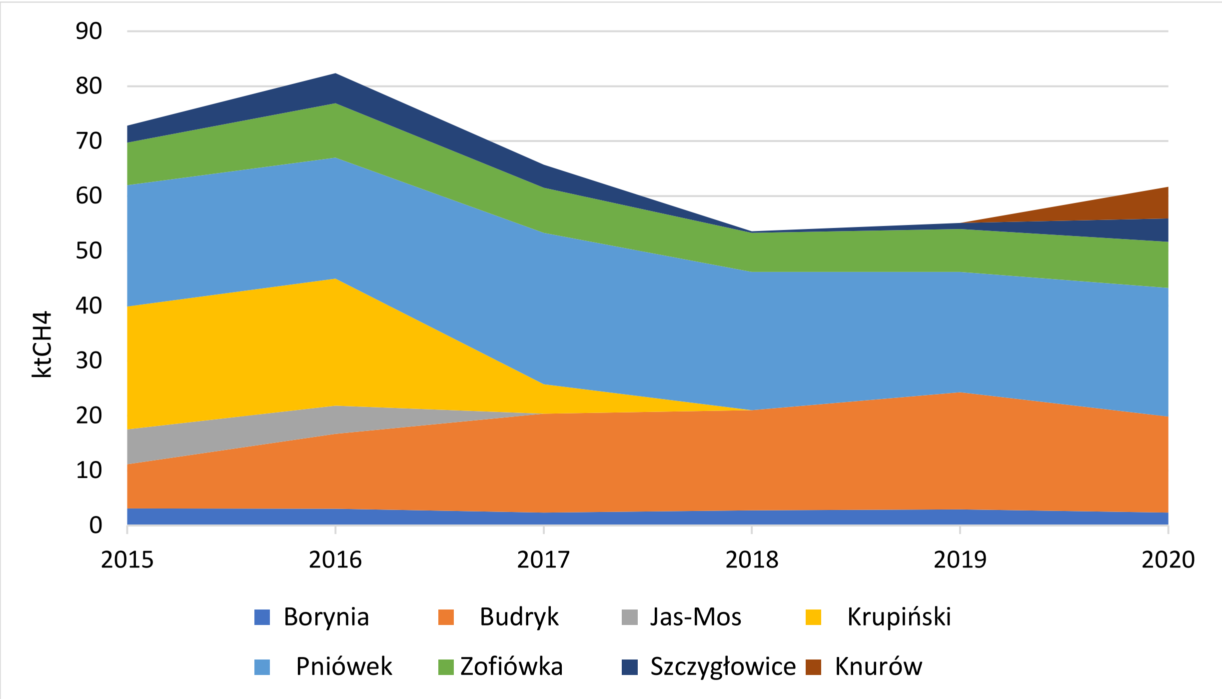


*Figure 3.5. Utilization of the captured methane in the coal mines of the JSW group*

Analysis of the efficiency of methane utilization concerning individual JSW S.A. coal mines (Fig. 3.6) shows that its highest value was achieved by the coal mine "Pniówek" - 76% to 96%, and then Front "Zofiówka" - 64% to 95%. In both of these coal mines, methane usage throughout the period was considered very high.

During their operation in JSW S.A., coal mines "Jas-Mos" and "Krupiński" also achieved very high utilization efficiency, reaching 98% and 67%, respectively.

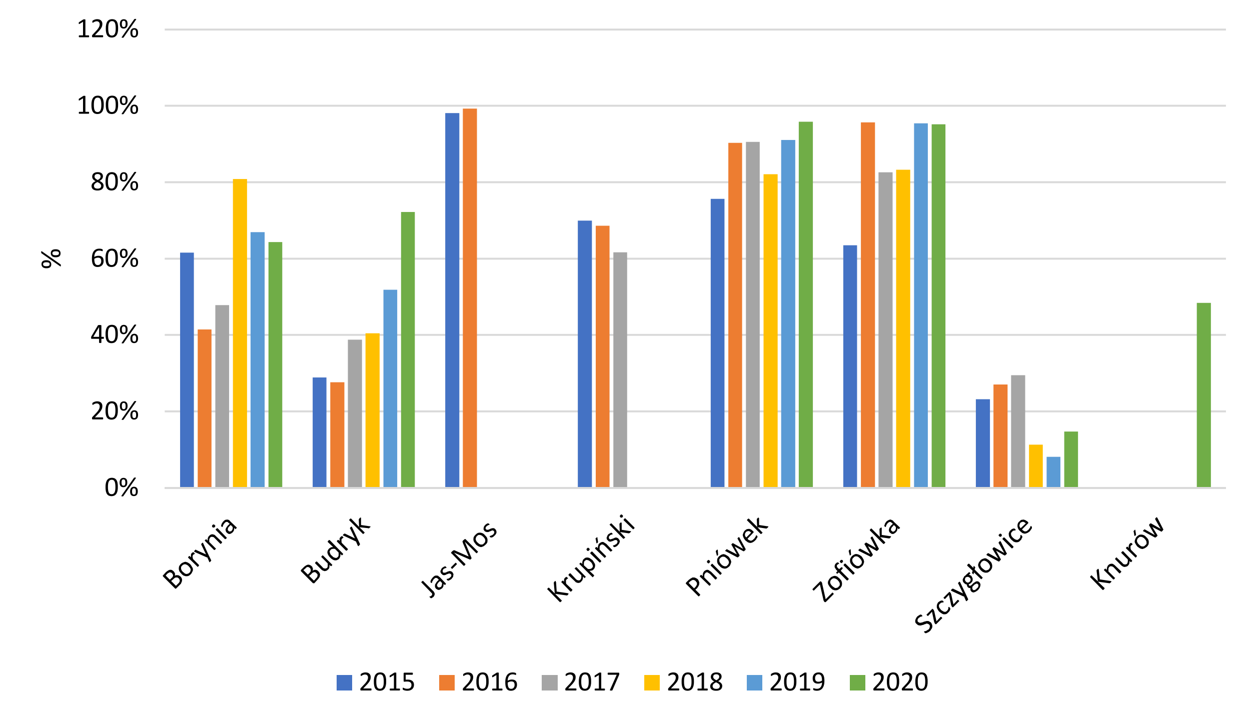


*Fig. 3.6 Efficiency of methane utilization in the coal mines of the JSW S.A. group in the period from 2015 to 2020*

In the "Budryk" coal mine, despite the high methane capture, the efficiency of its utilization was from 28% to 52% (2019). It is worth noting that in 2020 this value increased to 72%, which is the result of the methane drainage station modernization and the start-up of the ECOMAX gas engine with a total capacity of 2 $MW_{el}$ from July 2020, which in combination with the already installed JMS624GS-SL 2x4$MW_{el}$ engines gives an absolute power of 10 $MW_{el}$ (table 3.2).

In the years 2016-2019, the captured methane was not used in the "Knurów" Front, while in 2020, the efficiency was almost 48% (Fig. 3.6). Launching from July 2020, the gas engines CAT CG 260-16 3x4 $MW_{el}$ with a total power of 12 $MW_{el}$ caused this increase.

The methane utilization in the JSW S.A. is based on:

- the production of thermal energy,
- electricity production,
- use in cogeneration systems,
- for gas transmission to the external customers.

Table 3.3 and Fig. 3.7 present the total methane utilization by the entire Company in the analyzed period. The most significant amount of captured methane was transferred to external customers, including PGNiG Termika S.A. and ZPC "Żory" sp z o.o. Altogether it was 292.96 kt of methane discharged (48.83 kt/year on the average). From 8.91 kt to 18.53 kt was used in the cogeneration system. Production of thermal energy devoured the minor amounts of methane because only 4.43 kt. In total, JSW S.A. produced 836.462 GWh of electricity and 1,596.225 TJ of heat in its installations.

*Table 3.3. Methane utilization in JSW group in the period from 2015 to 2020*

| **Methane utilization** | | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
|---|---|---|---|---|---|---|---|
| Production of thermal energy | | 1,44 | 1,45 | 1,45 | 1,45 | 1,45 | 1,45 |
| Production of electricity | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Use in cogeneration systems | | 0,01 | 0,02 | 0,01 | 0,01 | 0,01 | 0,01 |
| Used for other purposes | | 0,04 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 |
| Transferred to external customers | | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Sum of the utilized methane | kt/rok | **1,44** | **1,45** | **1,45** | **1,45** | **1,45** | **1,45** |
| | | | | | | | |
| The amount of energy produced in own installations | | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| Electricity | MWh | 273 181 | 226 234 | 88 649 | 70 610 | 77 980 | 99 809 |
| Thermal energy | GJ | 853 103 | 495 041 | 83 891 | 78 253 | 74 154 | 11 783 |

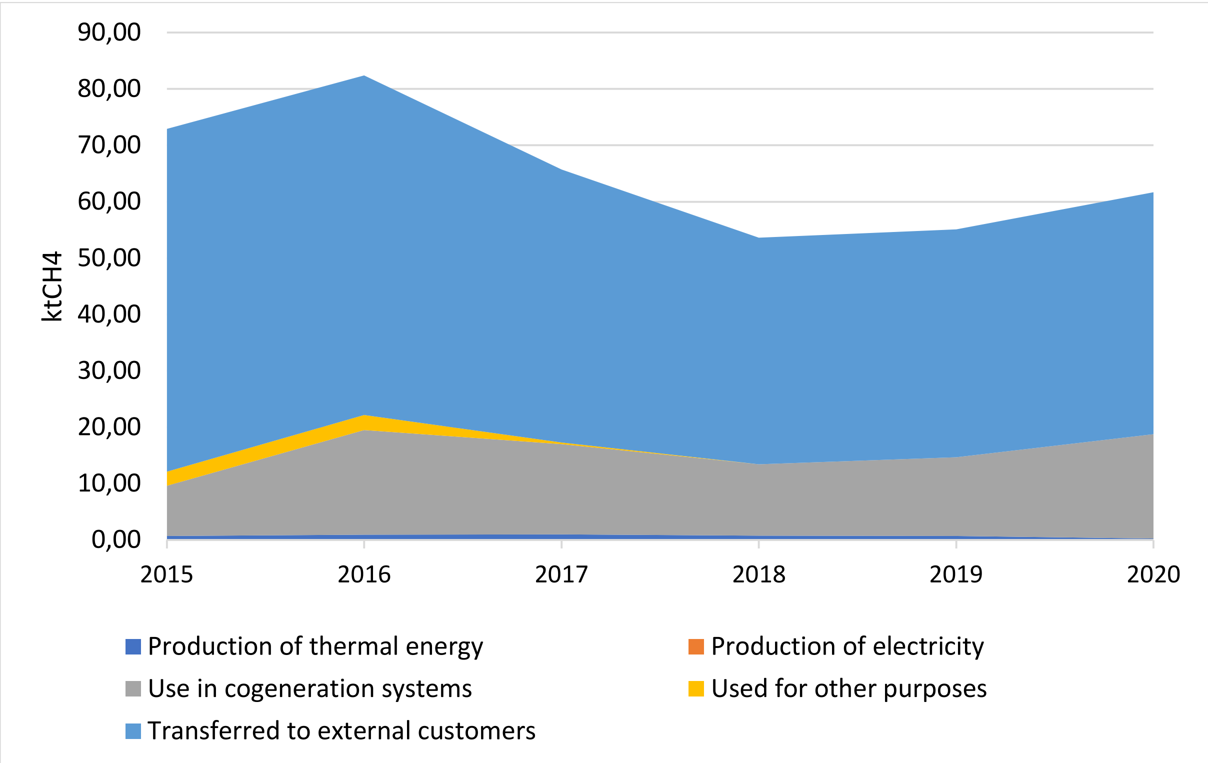


*Fig. 3.7 Utilization of methane at JSW S.A. from 2015 to 2020.*

### *3.2.3 Atmospheric emissions of not utilized methane at JSW S.A.*

*Despite modern technological solutions, the average methane drainage efficiency in the analyzed period does not exceed 40% and exactly amounts to 38.28%.* The methane capture technologies currently available allow obtaining efficiencies of 75%, depending on the forecasted total methane bearing capacity, which means that 25% of methane is still released via ventilation. *In JSW S.A. coal mines, this ratio is 57% (drainage efficiency) to 43% of methane released to the atmosphere*. Figure 3.8 shows the atmospheric methane emissions from individual JSW S.A. coal mines.

The chart analysis clearly shows that "Budryk" and Front "Szczygłowice" released the highest amount of methane - a total of 117.58 kt and 65 kt, respectively. In both of these mines, JSW S.A. conducts activities to increase methane use (chapter 3.2.2). In the first coal mine, the installation of an additional gas engine significantly contributed to the reduction of methane emissions in 2020 by 13 kt compared to 2019 (utilization efficiency higher by 20% compared to 2019) and by 20 kt compared to 2018 (an increase of the efficiency by 32%). The installation of engines at the Front "Knurów" methane drainage station in July 2020 reduced atmospheric methane emissions by 48%, i.e., by almost 144 kt$CO_2$eq ($GWP_{100}$ = 25).

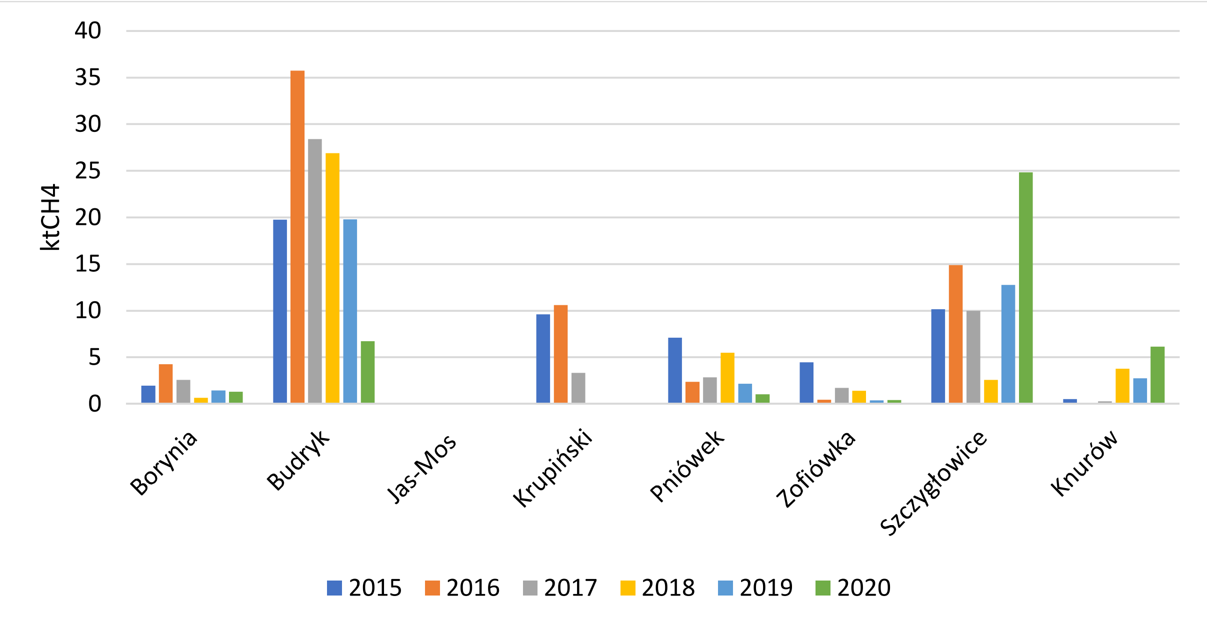


Fig. 3.7 Emissions of not utilized methane in coal mines of the JSW S.A. Group in the period from 2015 to 2020

Table 3.4 presents the balance of atmospheric methane emissions from JSW S.A. coal mines in $CO_2$ equivalent using different GWP metric values. *The application of an increased value of* $GWP_{100}$ *results in an increase in the total emissions from JSW S.A. by around 12% but should not impact the long-term climate change trend. On the other hand, the GWP metric choice for a 20-year horizon increases the value of emissions by 244%. This factor significantly increases the share of the mining sector represented by JSW S.A. in the context of total methane emissions* *worldwide and Europe, which may influence government policy choice regarding the methods used to mitigate climate change caused by its operations.*

*Table 3.4. Balance of atmospheric methane emission per kilo tonne of $CO_2$ equivalent for JSW S.A. in the period from 2015 to 2020*

| **Global Worming Potential** | **Ventilation air methane** | | **Amount of drained methane** | | **Amount of utilized methane** | | **Atmospheric methane emission** | |
|---|---|---|---|---|---|---|---|---|
| | $ktCH_4$ | $ktCO_2eq$ | $ktCH_4$ | $ktCO_2eq$ | $ktCH_4$ | $ktCO_2eq$ | $ktCH_4$ | **$MtCO_2eq$** |
| $GWP_{100}$=25 | 1092,13 | 27303,31 | 683,01 | 17075,21 | 391,40 | 9785,23 | 1383,73 | **34,59** |
| $GWP_{100}$=28 | - | 30579,70 | - | 19124,23 | - | 10959,46 | - | **38,74** |
| $GWP_{20}$=86 | - | 93923,38 | - | 58738,72 | - | 33661,20 | - | **119,00** |

# 4 Currently implemented and planned for the near future projects to increase methane utilization in JSW S.A. coal mines

JSW S.A., as a conscious and responsible entrepreneur, is aware of the harmful impact of the coal mining process on the environment. Care for the natural environment is understood by JSW S.A. as Corporate Social Responsibility towards the local community, and not only as a fulfillment of obligations resulting from applying the law. The Group's operating strategy is based on the highest environmental standards, product, and quality safety and consistently carries out ecological tasks. In its activities, it uses solutions and technologies that ensure transformation towards a circular economy[46], which is an essential element in creating a low-emission, resource-efficient, innovative and competitive economy. According to the European Commission's recommendations, these activities can significantly change the Company's economic development.

JSW S.A. conducts activities in methane usage for electricity production and records organization and the product carbon footprint. Because the activities carried out by JSW S.A. are inevitably accompanied by the emission of methane (as an accompanying mineral), the Company tries to capture and utilize it as much as possible. Still, for safety reasons, it is impossible to avoid emission along with the ventilation air altogether. Actions aimed at minimizing methane's harmful effect on the atmospheric air are carried out through the maximum use of the captured methane. Currently, methane is used in cogeneration engines to produce electricity and heat (Chapter 3.2.2).

In 2012, the Company launched a measurement and billing system for the quantity and quality of gas from methane drainage, which covered coal mines "Borynia - Zofiówka", "Pniówek" and owned back then, by JSW S.A., "Jas-Mos" and "Krupiński" and belonging to SEJ Sp. Z o.o. Heat and Power Plant "Moszczenica"[47]. In 2015, a new methane drainage station in the coal mine "Budryk" at shaft VI in Chudów was launched, equipped with this system while still under construction. All elements of the system, i.e., gas capture at methane drainage stations and its transmission to individual consumers, are measured. The devices used are characterized by very high accuracy enabling commercial and related to the EU ETS settlements. These are gas chromatographs, turbine flow meters and cooperating with them

[46] Dane wewnętrzne JSW S.A. udostępnione na potrzeby wykonania niniejszego opracowania
Strona JSW https://www.jsw.pl/odpowiedzialny-biznes/slad-weglowy-gk-jsw
[47] www. cmm-energy. E.U

temperature, humidity, and pressure sensors. All obtained data are archived in a superior computer system, which enables visualization and on-line access to all data for persons responsible for the process of economic use of methane. In the coal mines "Budryk" and "Knurów-Szczygłowice", the measuring devices used to determine the concentration of methane in the captured gas, as well as to determine its flow, are not very accurate. Due to the ongoing program of "*economic use of methane*" (GWM) in these mines (construction of new cogeneration systems), it is necessary to obtain accurate data for billing purposes.

*As a result of methane utilization for energy production in high-efficiency cogeneration systems, in 2019, its atmospheric emissions were reduced by approx. 76.9 million $m^3$ (approx. 3% more compared to 2018).* Investments involving installing other gas-fired engines in the coal mines "Budryk" and "Knurów-Szczygłowice" with a total capacity of 48 $MW_e$ are undergoing. *Thanks to them, it will be possible to reduce organization's carbon footprint by approx. 1.6 million Mg $CO_2$eq by 2025.*

By 2022, the Company plans to implement activities to obtain the installed capacity in both mines at the level of 43.9 $MW_{el}$[48]. The annual production potential of "Green Electricity" in both mines will amount to 330 thousand MWh, covering 33% of JSW S.A.'s electricity demand. *It is assumed that pro-ecological activities will reduce methane emissions to the atmosphere by 80 million $m^3$ of $CH_4$, which gives about 1.6 million Mg$CO_2$eq. By 2025 investments implemented by the Company will allow using the entire drained methane economically.* The first effects of the made investments were noticeable in 2020 by reducing methane emissions. In Front "Knurów", the methane utilization efficiency increased by 48%, and in "Budryk" by 20% compared to 2019 and 32% compared to 2018 (chapter 3.3). In total, 32 million $m^3$ of $CH_4$ was managed in these two coal mines.

Investments outlays related to the economic use of methane in Front "Knurów" accounted for 48% of the Company's total expenditure for environmental protection and constructing a cogeneration system at the coal mine "Budryk" was 14% of all.

JSW Group conducts activities to reduce greenhouse gas emissions and meet the new guidelines for disclosing climate change information; since 2017, it has been performing integrated calculations and reporting its carbon footprint.

The purpose of determining JSW S.A.'s carbon footprint is to monitor greenhouse gas emissions within the organization's defined boundaries and strive to optimize energy consumption, eliminate energy-intensive solutions, and maximize methane's economic use.

[48] www. cmm-energy. E.U

Figure 4.1 shows a diagram of the Company's carbon footprint calculated from 2017 to 2019. These calculations are carried out following the international methodology of The Greenhouse Gas Protocol: A Corporate Accounting and Reporting, according to which determination of the metrics used to convert methane emissions to $CO_2$ equivalent should follow the guidelines included in the fifth IPCC report[49]. For methane, the GWP metric over a 100-year time horizon should be 28.

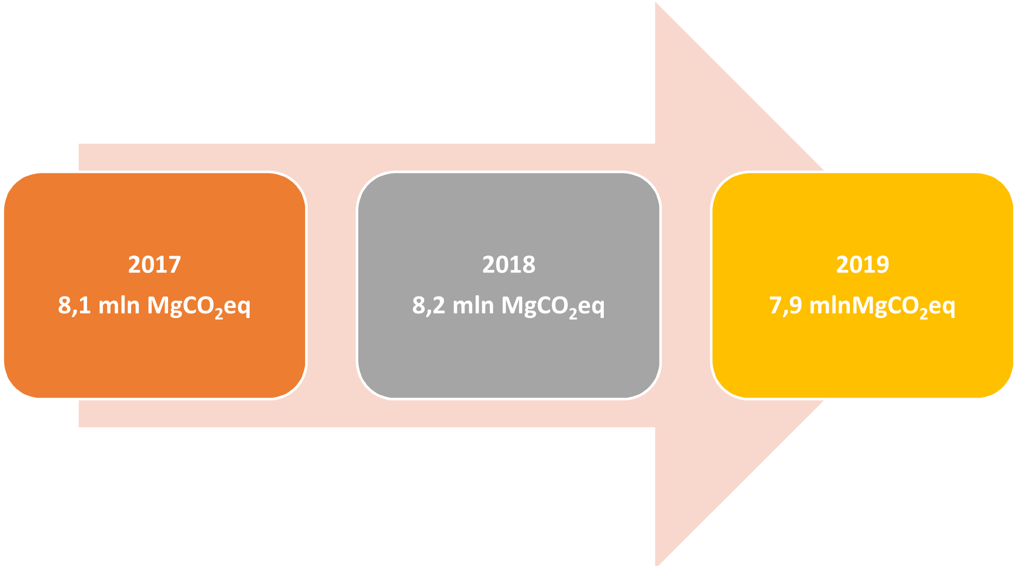


*Figure 4.1. The carbon footprint for JSW S.A. in the years 2017-2020*[50]

The primary source of greenhouse gas emissions resulting from JSW S.A.'s activities is ventilation air methane coming from mine workings (approx. 71% of the total emissions as $CO_2$eq) and carbon dioxide from fuel combustion processes in the coking segment. Due to that, for two years, the Company has been actively participating in auctions of Carbon Dioxide Units organized by the State Forests as part of the project Forest Coal Farms. JSW S.A. bought a total of 12,000 JDWs. The funds allocated for their purchase were used to implement the Kobiór Forest District project - "Modernization of the educational path: In the land of the Pszczyna bison".

In the "JSW S.A. and subsidiaries of the JSW Capital Group strategy for years 2020-2030", adopted in February 2020, the main directions of actions in the field of climate change mitigation have been defined, and they include:

[49] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[50] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

- searching for low-emission technological and process solutions,
- optimization of energy consumption in operating activities,
- increasing the energy efficiency of production processes - machines and devices,
- continuation of activities aimed at reducing greenhouse gas emissions,
- reducing the organization and its individual products' carbon footprint - coal and coke.

# 5 The influence of methane emitted from coal deposits in the world and Europe on the atmospheric state

As a member of the United Nations (UNFCCC), Poland is obliged to register domestic greenhouse gas emissions under the adopted reduction targets in five categories in the so-called Joint Reporting Boards[51]. The analyzes carried out in this chapter are based on the detailed data available on the UNFCCC Greenhouse Gas Inventory Data website[52] concerning greenhouse gas emissions from all countries belonging to the European Union and other countries included in the so-called Annex I. Like the E.U. members, they are obliged to provide data on greenhouse gas emissions from all sectors of the economy. *China, India, South Africa, Colombia, and Indonesia* belong to non-Annex I countries. They are encouraged to submit reports but are not obliged to do so. For this reason, data on these countries' mining sectors' methane emissions are very sparse. The last values for China come from 2014 and for India from 2016. Figure 5.1 presents the state of methane emissions from the biggest coal producers in the world according to the International Energy Agency data[53]. *Based on it, Poland ranks sixth in terms of methane emissions from the mining sector.*

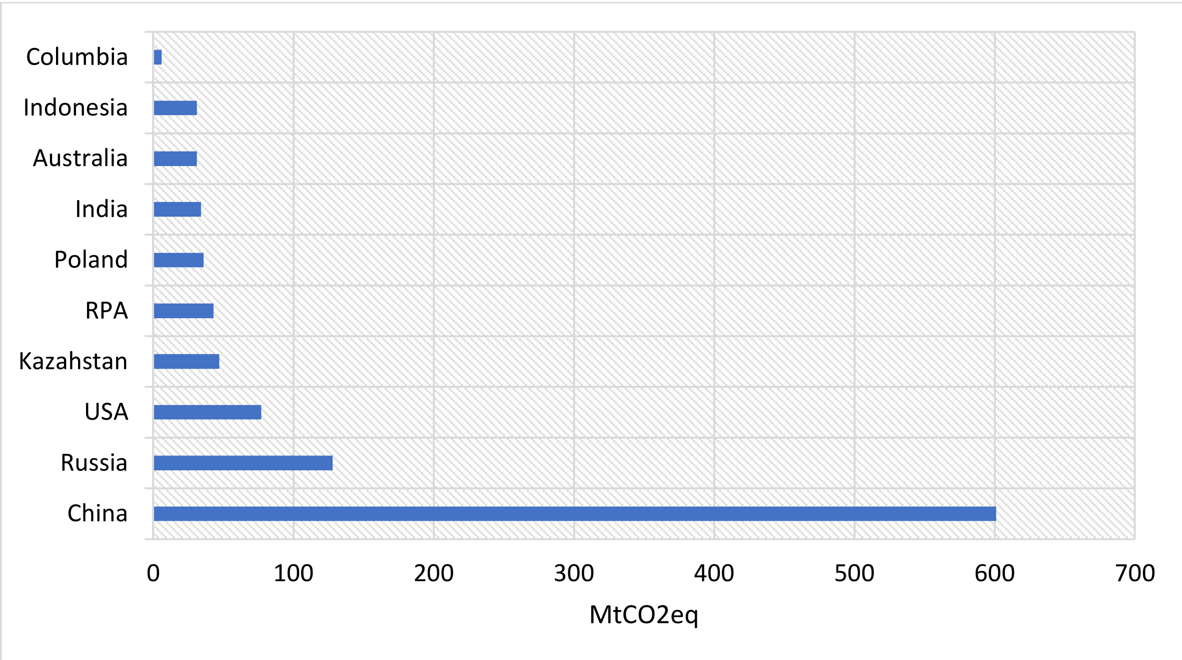


*Fig. 5.1 Indirect methane emissions from the mining sector in the world*[54]

[51] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw, English version

[52] UNFCCC Greenhouse Gas Inventory Data, https://di.unfccc.int/detailed_data_by_party

[53] Source: IEA World Energy Outlook 2019 https://www.iea.org/reports/methane-tracker-2020

[54] Source: IEA World Energy Outlook 2019 https://www.iea.org/reports/methane-tracker-2020

The data presented in this chapter will include the analysis of methane emissions from the European Union and Annex I countries from 2015 to 2018. However, it should be remembered that China is the largest coal producer globally at the moment with a production of approx. 3,500 million t/year and India with about 730 million t/year[55]. *Therefore, a comparison of the available UNFCCC data from the year 2018 will be made, including China and India's latest available emissions.*

## 5.1 Methane emissions from various sectors of the economy in the countries of Europe and the world

Methane is released from various natural and mainly anthropogenic sources. The second one is responsible for approximately 60% of its global emissions. Figure 5.2 shows the amount of methane emitted from the main sectors in Poland, other E.U., and Annex I countries. Additionally, the graph shows the share of underground mines in methane emissions from the energy sector.

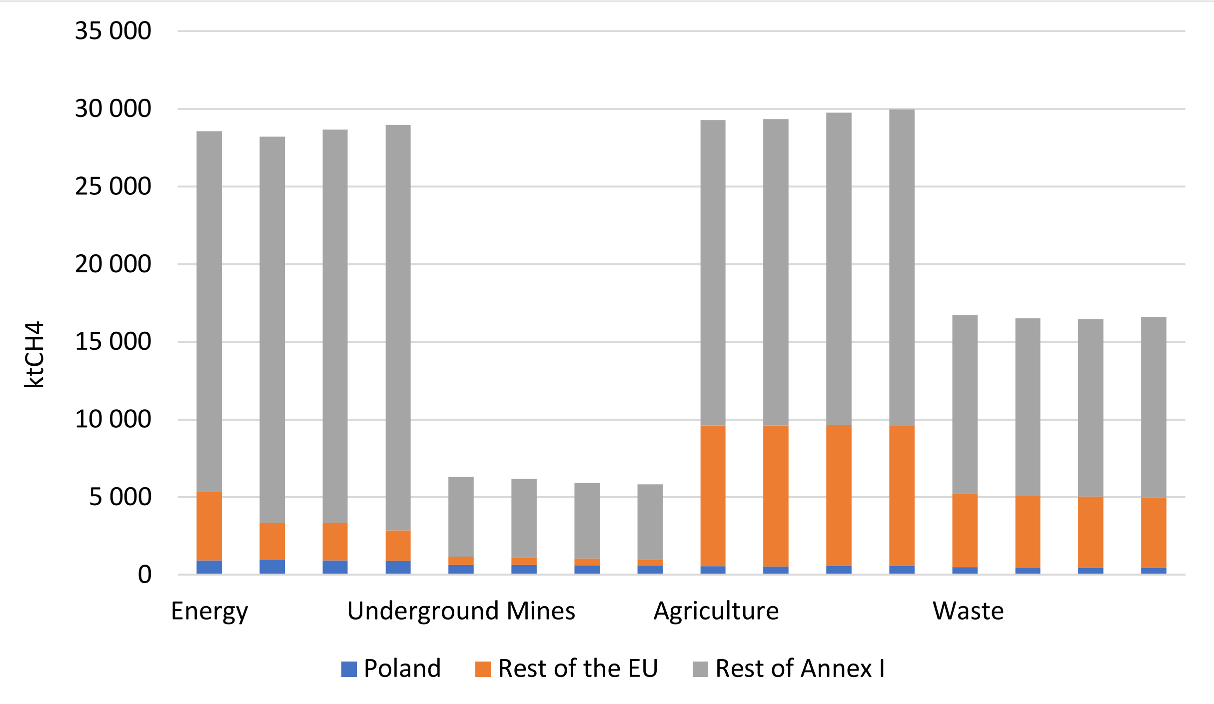


*Fig. 5.2. Methane emissions from various sectors in Poland, other European Union and Annex I countries*

The total emission of methane from the five main sectors of the economy in Annex I countries in 2018 was 78.6 Mt (including the LULUCF category), which corresponds to 1965 $MtCO_2eq$ ($GWP_{100} = 25$). The main sectors of the economy responsible for methane emissions

[55] Statista: Leading hard coal producing countries worldwide in 2018: https://www.statista.com/statistics/264775/top-10-countries-based-on-hard-coal-production/

are *Energy*, *Agriculture*, and *Waste*. The data presented in the chart shows that the agricultural sector is the largest emitter of methane, with the average emission, for the period under study, at the level of 29.5 Mt. The energy sector is responsible for an average emission of 28.6 Mt. The third place belongs to waste with an average emission of 16.5 Mt. *The data presented in Figure 5.2 also show that the global underground mining sector emits an average of 6.0 Mt of methane. Polish coal mines are responsible for 0.62 Mt. Note that these figures do not include China and India's emissions.*

Taking into account the data available on the UNFCCC Greenhouse Gas Inventory Data[56] website for China (last available data for 2014) and India (last available data for 2016), the total methane emissions for these two countries are around 75.0 Mt $CH_4$ (1500 MtCO2eq), which is practically 100% of all Annex I countries methane emissions.

Looking more closely at methane emissions from the energy sector of individual countries, shown in Figure 5.3, it is clear that the United States of America and Russia have the largest share in methane emissions, with the average share for the analyzed period 258.61 $MtCO_2eq$ and 230.29 $MtCO_2eq$ respectively. *The Polish energy sector is responsible for the average emission of 23.35* $MtCO_2eq$.

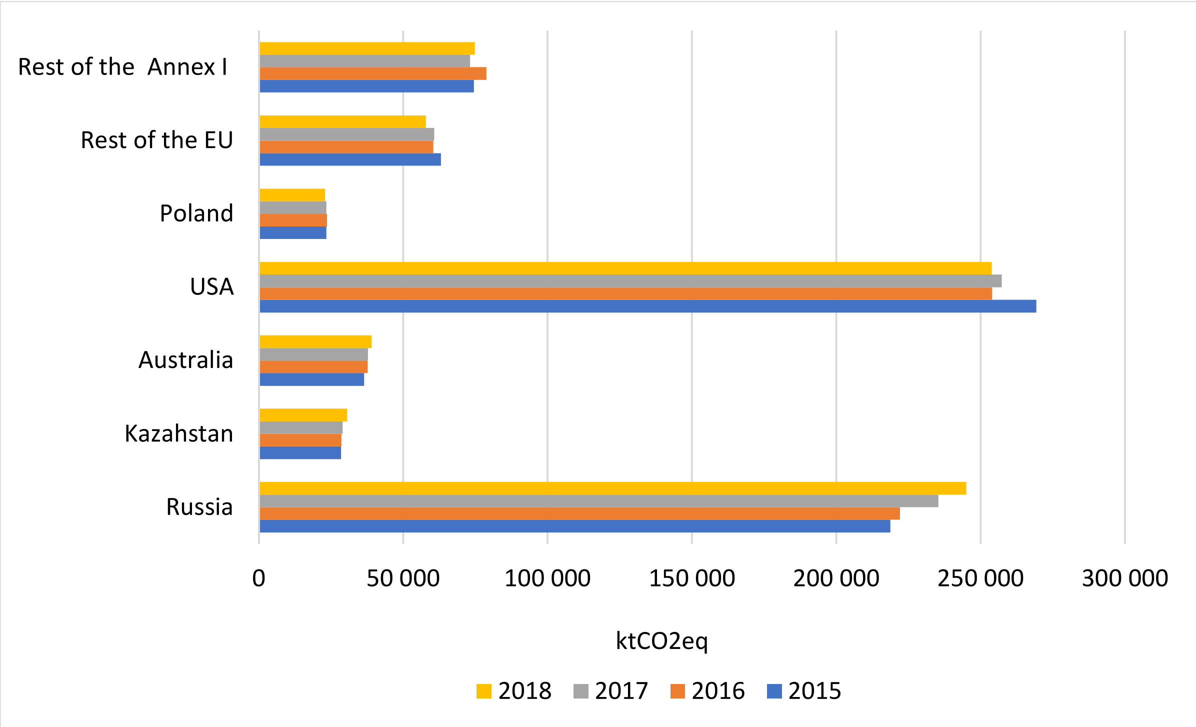


*Figure 5.3. Methane emissions from the energy sector in Annex I countries*

[56] UNFCCC Greenhouse Gas Inventory Data, https://di.unfccc.int/detailed_data_by_party

*Compared to all Annex I countries, the entire European Union's energy sector is responsible for approximately 11.7% of methane emissions. Polish energy sector is responsible for 3.3% of this emissions.*

Data in Figure 5.4 clearly show that the most significant amounts of methane are released by Ukraine - 42.23 $MtCO_2eq$ on average, for the period under study, which constitutes 33.5% of the total emissions in Europe. *The Polish energy sector is responsible for 18.5% of methane emissions (23.3 $MtCO_2eq$ on average) in Europe, Germany and Romania for 9.2% and 8.5%, respectively. The rest of Europe accounts for the remaining 30.3%.*

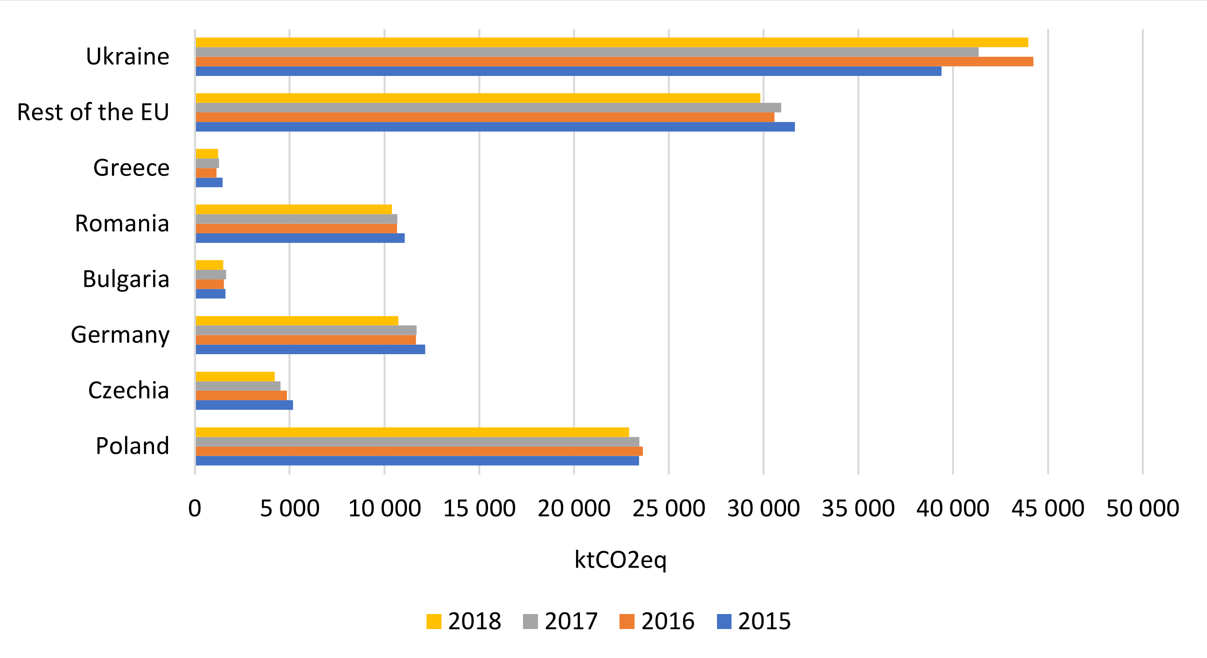


*Fig. 5.4 Methane emissions from the energy sector in European countries*

## 5.2 Methane emissions from the underground mining sector in Europe and the world

In the global energy sector, the share of methane emissions from underground mines amounts to an average of 6 Mt of methane (Fig. 5.2), which corresponds to approx. 151.36 $MtCO_2eq$. Looking at the underground mining sectors of Annex I countries (Figure 5.5), it can be seen that the United States of America dominates with an average emission of 53.02 $MtCO_2eq$. It accounts for 35.03% of the total methane emissions from this sector. *The next countries are Russia (35.47 $MtCO_2eq$ - 23.5%), other Annex I countries, including Ukraine (15.7%), Australia (12.18%), Poland (15.55 $MtCO_2eq$ - 10.28%) and Kazakhstan (3.31%).* In Kazakhstan, the majority of methane emissions, namely 77.74%, come from opencast mining. *JSW S.A. coal mines are responsible for around 4% of total methane emissions.*

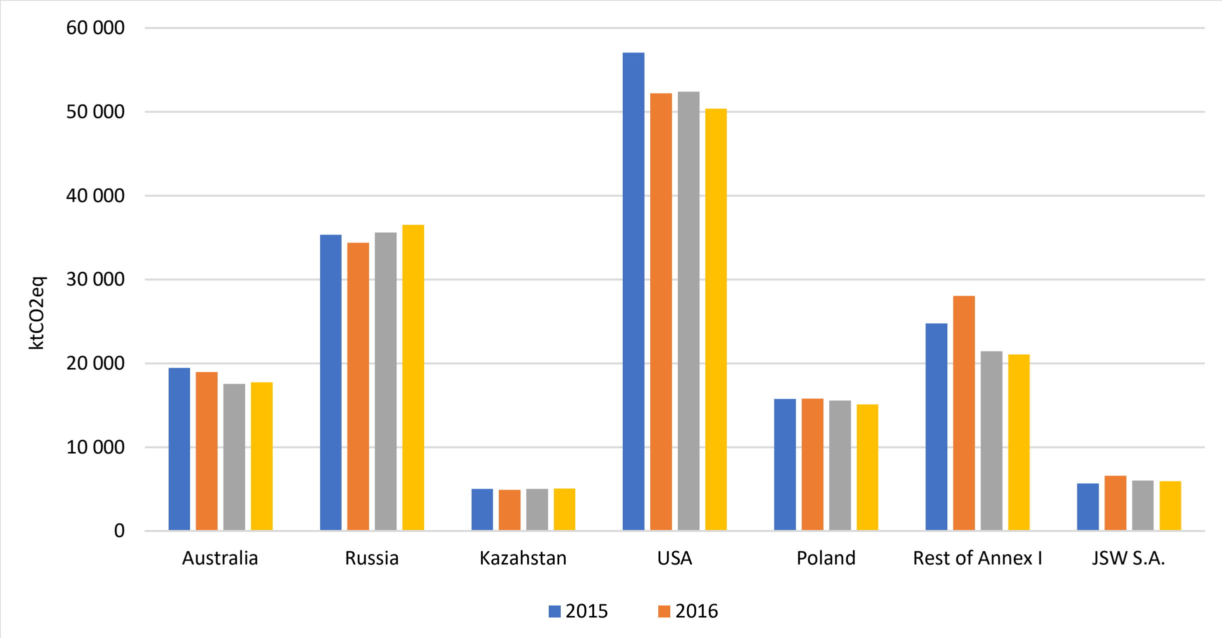


*Figure 5.5. Methane emission from the underground mining sector, including JSW S.A., against the Annex I countries*

Because China and India do not provide data on methane emissions from the mining sector, these two countries are only indicative. The data from 2014[57] for China show the total emissions from the mining sector at the level of 441.31 MtCO$_2$eq. On the other hand, available literature data[58] suggest that these emissions are at the level of 350 to 700 MtCO$_2$eq. In the case of India, the literature data[59] provide for 2015 the value of emissions from underground mines at the level of 24.6 MtCO$_2$eq. Figure 5.6 shows methane emissions from underground mining globally for 2018, taking into account literature data for China (550 MtCO$_2$eq) and India (24.6 MtCO2eq) and emissions for JSW S.A.

*The data presented in the chart clearly show that the emissions from Polish underground mining rank seventh, accounting for 2% of the total global methane emissions in this category. In comparison, the emissions from JSW S.A. are 0.8%.*

Figure 5.7 shows the state of methane emissions from the entire mining sector (underground mines plus opencast mines) in 2018. The emission values for China and India were taken from the UNFCCC register[60]. *Similarly, to the above, the Polish mining sector ranks*

[57] UNFCCC Greenhouse Gas Inventory Data, https://di.unfccc.int/detailed_data_by_party
[58] Sheng J., Song, Sh., Zhang Y., Prinn, R.G., Janssens-Maenhou G., 2019:Bottom-Up Estimates of Coal Mine Methane Emissions in China: A Gridded Inventory, Emission Factors, and Trends
Environ. Sci. Technol. Lett. 2019, 6, 8, 473–478 Publication Date:May 31, 2019 https://doi.org/10.1021/acs.estlett.9b00294
[59] India Coal Mine Methane Market Study EPA Publication No: 456R19001 May 2019 https://www.epa.gov/sites/production/files/2019-05/documents/india_cmm_market_study_may2019.pdf
[60] UNFCCC Greenhouse Gas Inventory Data, https://di.unfccc.int/detailed_data_by_party

*seventh in terms of methane emissions, i.e., it accounts for 2.5%.* The discrepancy in the percentages in both calculations is due to adopting the lower emission values for China and India.

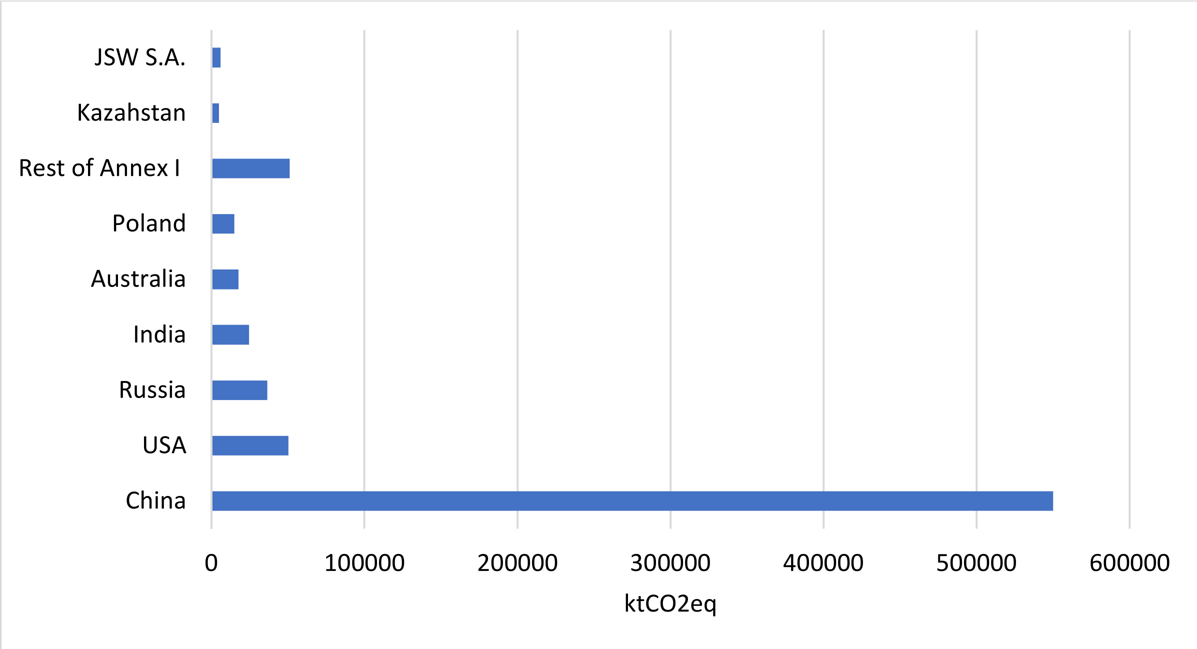


*Fig. 5.6 Methane emissions from the underground mining sector in the world in the year 2018*

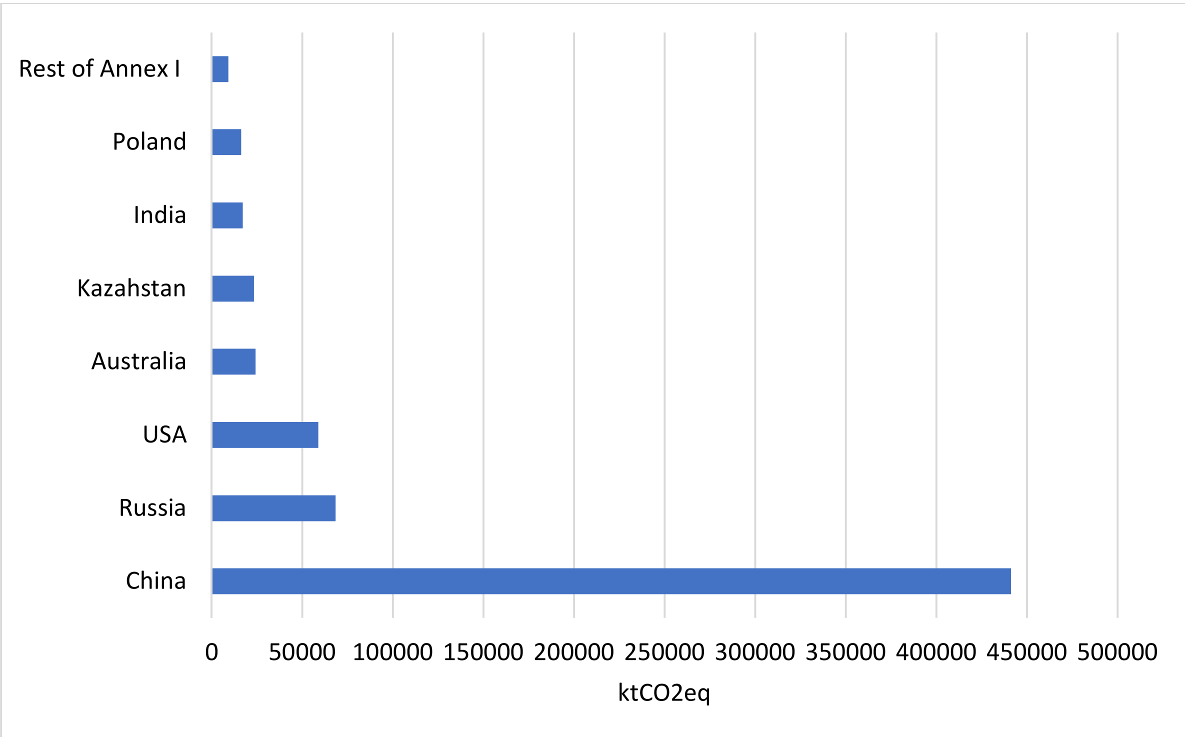


*Fig. 5.7 Methane emissions from the mining sector (underground mines and opencast mines) in the world in the year 2018*

*Poland and Ukraine are the largest emitters of methane from underground mines in Europe (Figure 5.8). They are responsible for the emissions at the average level of 38.3% and 34.38%, respectively.* The remaining 27.32% are European countries, including Romania (5.48 $MtCO_2eq$), Germany (2.32 $MtCO_2eq$), and the Czech Republic (1.72 $MtCO_2eq$). *JSW S.A.'s coal mines are responsible for approximately 15% of total methane emissions.*

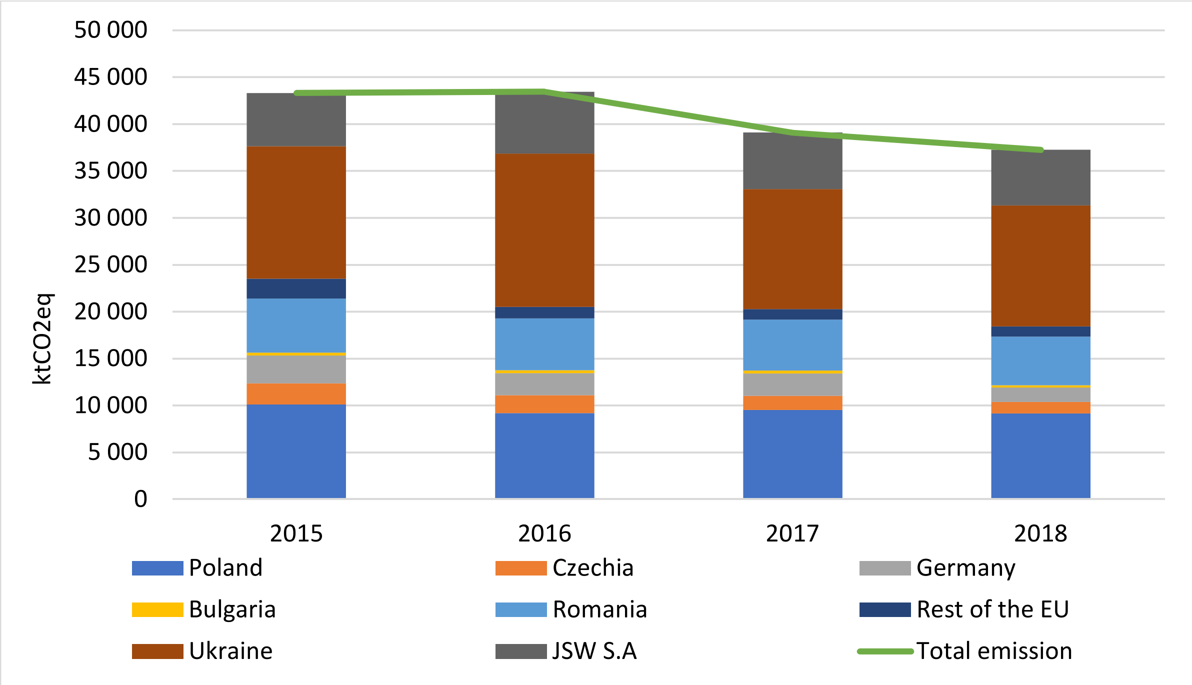


*Fig. 5.8 Methane emissions from underground mines in European countries*

# 6 Methane emissions from JSW S.A. coal mines aginst the Europe, world and Energy sector

The Polish underground mining sector in the world in the period from 2015-2018 was responsible for the average emission of 15.55 MT$CO_2$eq of methane. *Polish mines discharged 2,488.7 kt of methane into the air during this period, which amounts to 62.22 Mt$CO_2$eq. Against this background, the JSW S.A. coal mines were responsible for the emission of 969.68 kt of methane, which gives 24.24 Mt$CO_2$eq*. Figures 6.1 and 6.2 show the share of methane emissions from the Group's coal mines against various sectors in European countries (Fig. 6.1) and Annex I (Fig. 6.2).

*The data presented in Figure 6.1 show that the JSW S.A. coal mines, on a European scale, accounted for 1.29% of methane emissions*. The remaining underground mines in Poland accounted for 2.03%. The highest amount of methane was released from the *Agriculture* sector - 51.32%, then *Waste* - 27.14%, and *Energy* - 19.91%.

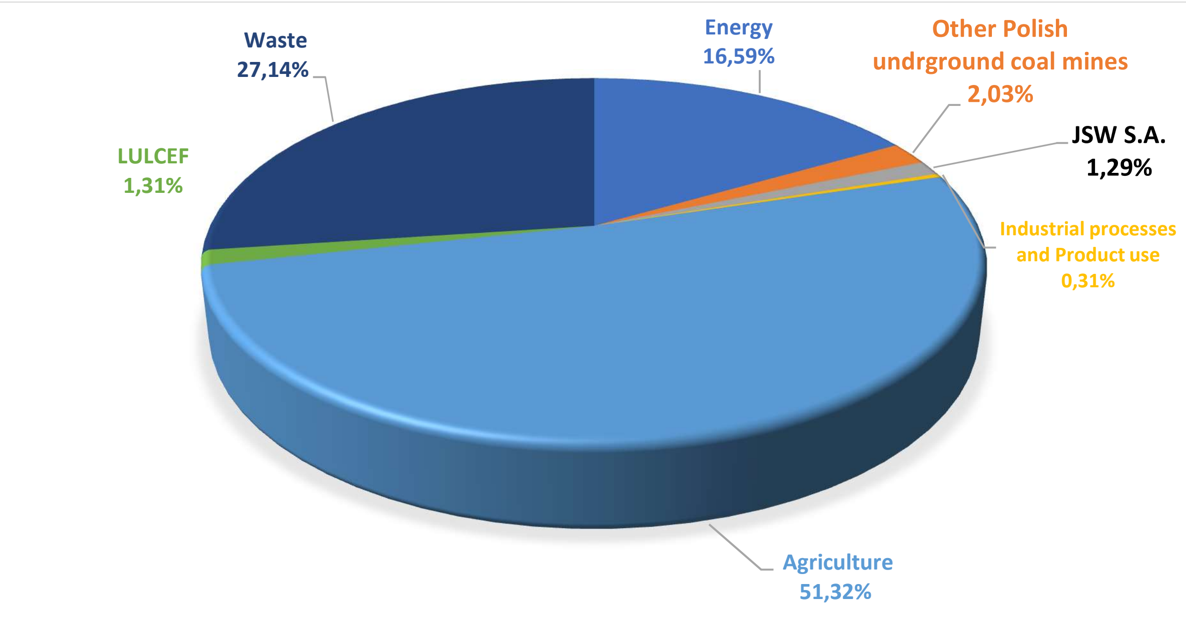


*Fig. 6.1. Methane emissions from JSW S.A. compared to various sectors of European countries in the period from 2015 to 2018*

*In Annex I countries (Fig. 6.2), the JSW S.A. coal mines were responsible for 0.31% of methane emissions, and the remaining Polish mines for 0.49%.* The dominant sector was *Agriculture* - 38.10% and *Energy* - a total of 36.83%.

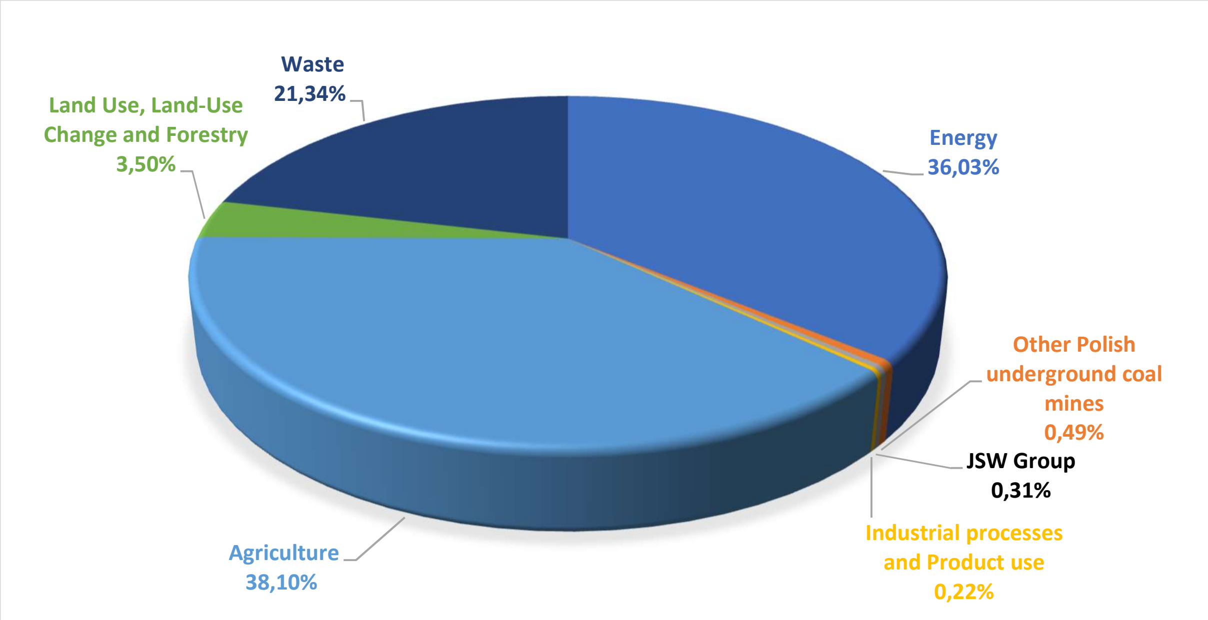


*Fig. 6.2 Methane emissions from JSW S.A. compared to various sectors of the Annex I countries in the period from 2015 to 2018*

*The methane emissions were slightly different at the national level. From 2015 to 2018, the JSW S.A. coal mines accounted for 12.3% of total methane emissions, and the remaining mines for 19.26% (Fig. 6.3).* Poland's highest methane emissions fell in the category *Energy*, approximately 47.38%, followed by *Agriculture* - 28.63% and *Waste* - 23.83%.

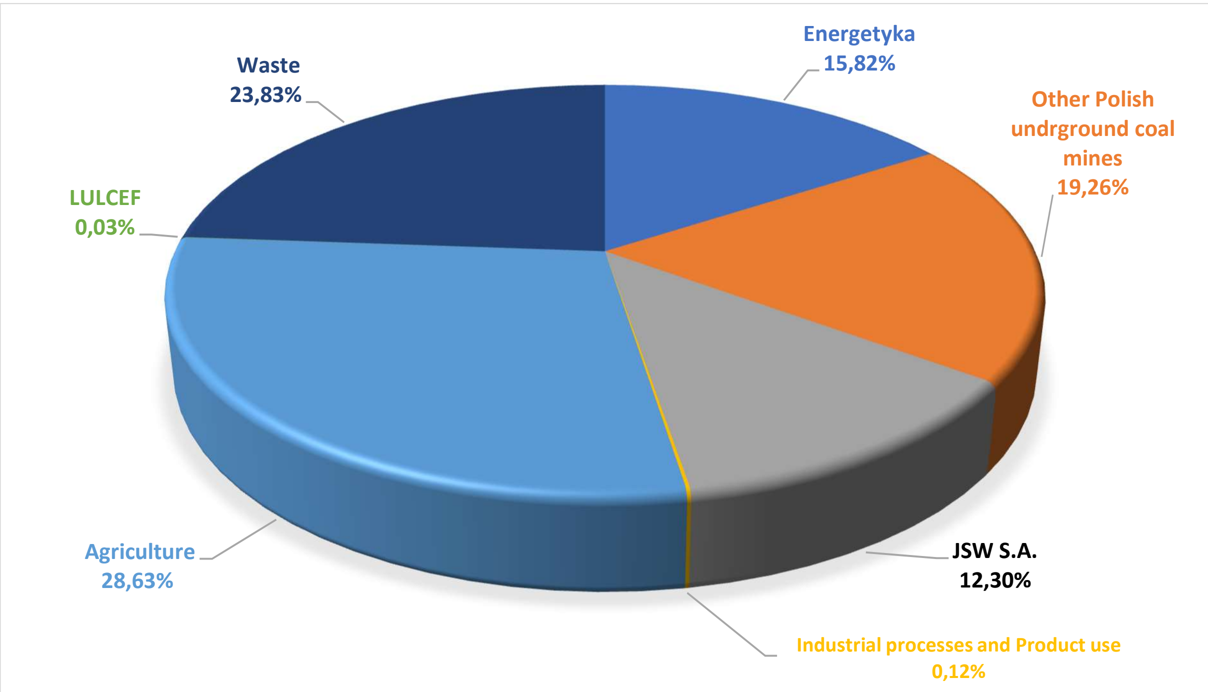


*Fig. 6.3 Percentage of methane emissions from JSW S.A. coal mines compared to other sectors in Poland in the period from 2015-2018*

49.5% of the Polish energy sector is based on hard coal extraction, accompanied by methane emissions. Table 6.1 presents the percentage of methane emissions from Polish and JSW S.A. coal mines. The data clearly show that methane emissions from JSW S.A. coal mines accounted for 24% to almost 28% of the energy sector emissions. In the European Union scale, this value decreased and ranged from 6.35% to 7%, and in the scale of Annex I countries, it was only 0.82% to 0.97%.

*Table 6.1. Summary of the methane emissions percentage from Polish and JSW S.A. coal mines against the Polish, European Union and all Annex I countries energy sectors*

| Energy sector methane emissions percentage | | | | |
|---|---|---|---|---|
| **Years** | **2015** | **2016** | **2017** | 2018 |
| | *European Union Energy sector methane emission percentage* | | | |
| Percentage of methane emissions from Polish coal mines | 18,23 | 18,78 | 18,48 | 18,69 |
| Percentage of methane emissions from JSW S.A. | **6,35%** | **7,17%** | **6,39%** | **6,68%** |
| | *Polish energy sector methane emission percentage* | | | |
| Percentage of methane emissions from Polish coal mines | 67,37% | 66,76% | 66,37% | 65,93% |
| Percentage of methane emissions from JSW S.A. | **24,17%** | **27,90%** | **25,76%** | **25,95%** |
| | *Annex I energy sector methane emission percentage* | | | |
| Percentage of methane emissions from Polish coal mines | 1,46% | 1,35% | 1,37% | 1,31% |
| Percentage of methane emissions from JSW S.A. | **0,82%** | **0,97%** | **0,87%** | **0,85%** |

# 7 Methane emissions from the abounded underground coal mines

The Polish hard coal mining industry has undergone significant changes in the last five years. Thirteen mines have been closed and some have been interconnected. In 2019, there were a total of five mines under liquidation[61], including two owned by JSW S.A.: "Jas-Mos" (October 1, 2016) and "Krupiński" (April 1, 2017). Both mines are still actively draining methane at the level of 99.43% and 86.91%, respectively.

In the report submitted to the UNFCCC Greenhouse Gas Inventory Data register[62], it was assumed that the methane emission factor from abounded underground coal mines was 0.652 million $m^3$/mine. *According to this conversion factor, methane emissions from this activity amounted to 72.58 kt$CH_4$ from 2015 to 2018, equivalent to 1.81 Mt$CO_2$eq.* Figure 7.1 shows methane emissions from the underground mining category broken down into mining activities, post-mining activities, and abounded underground coal mines compared to Europe.

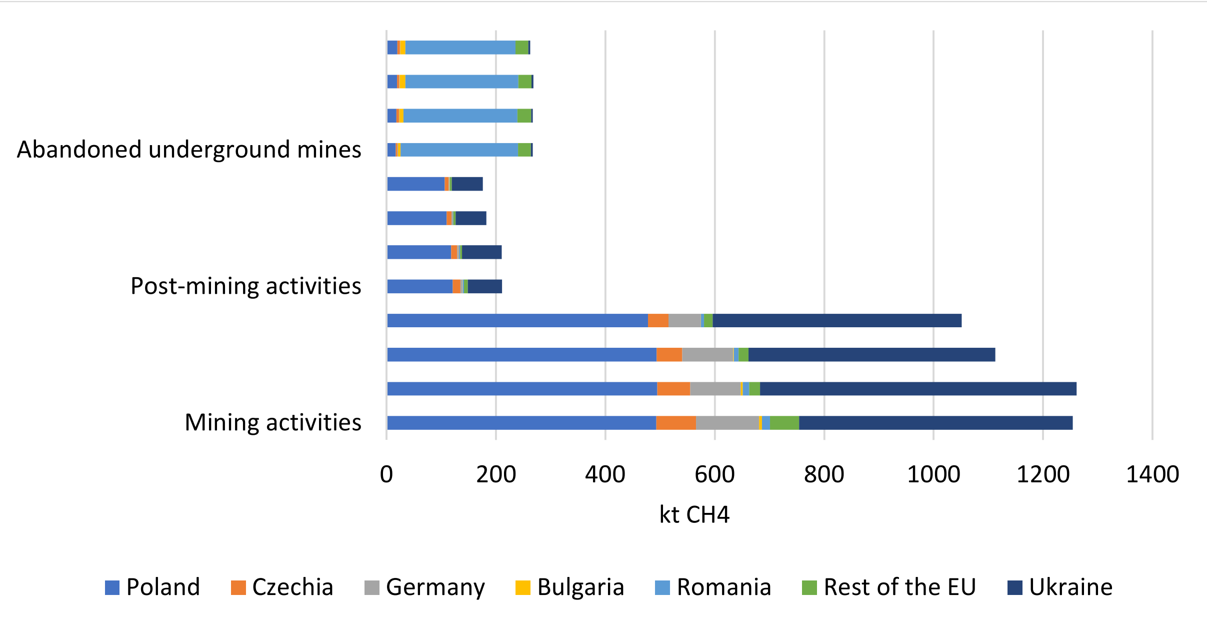


Fig. 7.1. Methane emissions from the underground mining category, broken down by mining activities, post-mining activities, abounded underground mines in the period from 2015 to 2018 in Europe

*In Poland, the highest amount of methane emitted in the underground mining category comes from mining activities (78% of total emission), then from post-mining activities (19%), and abounded coal mines accounted for 3% of emission.* Compared to Europe, Poland is

[61] WUG, 2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach
[62] UNFCCC Greenhouse Gas Inventory Data, https://di.unfccc.int/detailed_data_by_party

characterized by high emissions from the mining activities category (about 42% in this category in Europe) and post-mining activities (about 58%). The abounded mines' emissions represented on average 7% of the total methane emissions from the abounded mines category. The highest emissions in this category can be attributed to Romanian mining, where the average emissions are 78%.

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

Methane emissions from the coal mines formerly owned by JSW S.A. in 2019 were ranging 1.88 million $m^3$, which corresponds to 1.35 $ktCH_4$ (0.03375 $MtCO_2eq$).

Compared to the Annex I countries, methane emissions in Poland in the mining activities category were 10%, in the post-mining activities category 17%, and the emissions from abounded coal mines accounted for an average of 3% of the total methane emissions from this sector (rys.7.2).

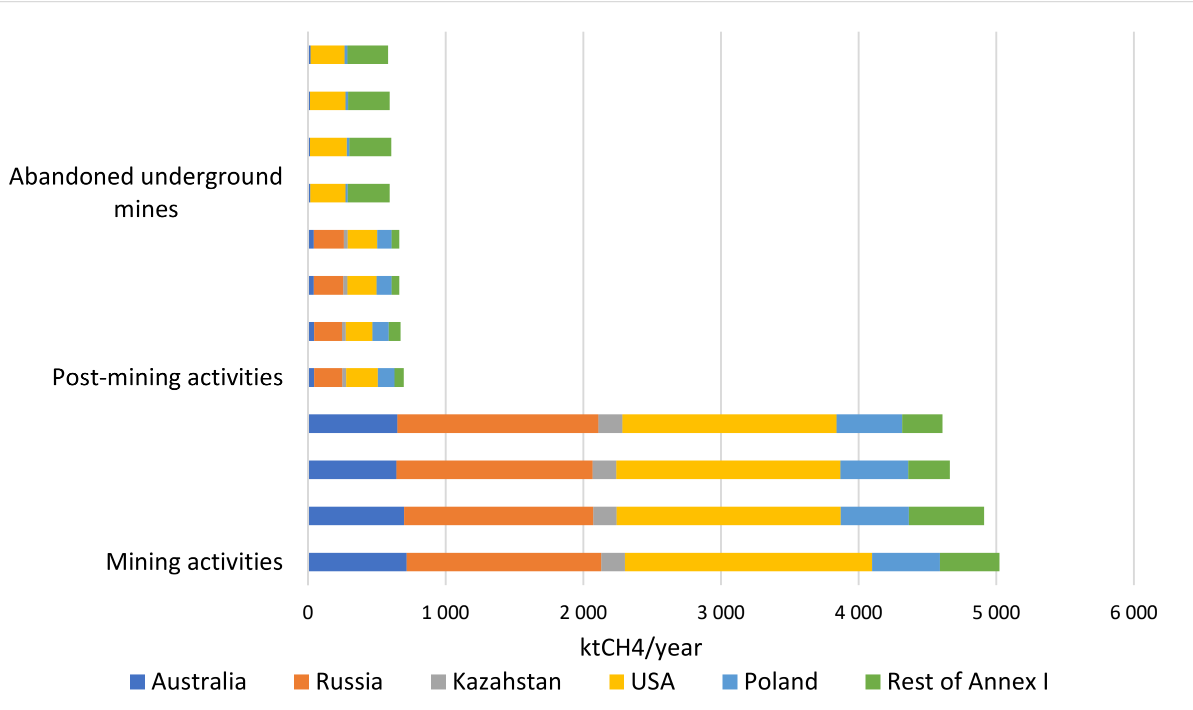


*Figure 7.2. Methane emissions from the underground mining category, broken down by mining activities, post-mining activities, abounded coal mines in the period from 2015 to 2018 in Annex I countries*

Polish hard coal mining is characterized by a very low permeability of the rock mass. Methane emissions occur as a result of its decompression under the influence of mining activities. Most often, this is when the emission of methane from the rock mass is increasing, and there is a need to drain it. Ending the exploitation causes rock mass pressure to equalize, manifested by an increase in stresses and decreased permeability. As a consequence, methane emission is disappearing over time. Considering the above, methane's emissions from abounded coal mines over a longer period should not significantly impact the underground mine category's total value.

# 8 Possible directions for reducing methane emissions from coal mines, including JSW S.A.

Polish coal mines, including those owned by JSW S.A., reduce atmospheric methane emissions by capturing and utilizing methane. Chapter 3.3.2 presents possible methods of drained methane utilization. Despite numerous attempts made, the drainage efficiency in all coal mines is about 34.6% to 36.3% (Chapter 2), and its utilization is at the level of 57% to almost 64%. In JSW S.A., the methane drainage efficiency is 38.28%, and its utilization 57.51%. The conclusion is that measures aimed at reducing atmospheric methane emissions should be based on:

- increasing the methane drainage efficiency,
- increasing the methane utilization.

Because methane drainage in Poland is carried out mainly for safety reasons, it is not commonly used in workings with a low forecasted total methane capacity. As a result, it is removed via ventilation directly into the atmosphere. Therefore, it seems necessary to introduce an obligation to conduct drainage in all exploitation areas in methane-prone coal mines and reduce the permissible value of methane concentration in the collective methane drainage pipelines below 30%.

Additionally, more modern methane capture technologies should be sought, such as:

- drainage galleries,
- methane drainage of post-mining goaves with boreholes from mine workings or the surface,
- use of directional boreholes.

Increasing the efficiency of methane drainage is key to reduce the ventilation air methane of workings and coal mines. Still, it is also important to increase the efficiency of methane utilization. JSW Group undertakes several activities aimed at the effective use of methane, described in chapter 4. Also, it researches the possibility of applying the mine gas concentration technology to the methane content at the network gas level[63]. This process (CMM) leads to a mixture with a methane content of 95% -98% $CH_4$, which is suitable for industrial use and injection of high-methane fuel gas into the network. The project aims to conduct a preliminary analysis of the feasibility and profitability of processing a methane gas stream (CMM) of 40 $Nm^3$/min obtained from the methane drainage system at Shaft VI of the

[63] www.cmm-energy.EU

Budryk coal mine in Ornontowice, that contains an average of 53% methane, to gas with properties acceptable for high-methane fuel gas injection into the grid.

The scientific research assumes that the methane drainage station's gas will be directed through the buffer tank to the compressor suction, where it will be compressed. However, it will contain saturated water vapor and must be cooled to remove most of the water. Then it will be directed to a set of two adsorption columns working alternately, in which final drying will take place. The dried oxygen-containing gas will be directed to the vacuum pressure swing adsorption (VPSA-1) and (VPSA-2) systems, where in the adsorption phase approx. 95% methane and 100% $CO_2$ will be adsorbed, while nitrogen, approx. 5% of methane and the remaining oxygen will be removed under reduced pressure as exhaust gases. It is assumed that pressure swing adsorption will play an essential role in enriching gas streams with methane in the near future, enabling its greater use, thus reducing the negative impact on global climate change.

In Polish hard coal mines, ventilation air methane (VAM) is a huge problem. It is released into the air during the coal mining process and is diluted, creating a methane-air mixture due to the air stream regulation. Its capturing is highly problematic due to the low concentration of methane ranging from 0.1 to 0.75% - (0.75% is the upper limit of methane concentration in ventilation shafts specified in Polish mining safety regulations). The annual methane content in the ventilation air of hard coal mines in Poland in 2019 amounted to approx. 502.2 million $m^3$, while in the JSW S.A. coal mines, it was about 246 million $m^3$.

Numerous research and development work carried out in the world in recent years has led to the development of many technologies and devices that allow the use of methane from ventilation air as a fuel, and the most important of them include:

- thermal reverse flow reactor (FTRR),
- Catalytic Flow Reversing Reactor (CFRR),
- methane concentrator,
- gas turbines (CGT and CCGT),
- microturbines,
- hybrid turbines.

Most of these technologies allow the use of ventilation air methane; however, the main problem is to provide a methane-air mixture with a methane concentration of at least 0.5 to 1.0%. It will allow the devices - methane-burning reactors -to be economically efficient.

The installation used to utilize methane from the ventilation air of hard coal mines consists of the following elements[64]:

- devices for collecting the methane-air mixture from the ventilation shaft - devices for transporting the mixture,
- methane-burning reactors (they produce fumes and heat),
- water-gas heat exchangers (possibility of using natural Energy),
- flue gas chimneys.

In Polish mines, the main barrier to methane's effective energy use from the ventilation air is the low concentration of methane, ranging on average from 0.01% to 0.30%. Additionally, the installation performance is an issue. A capacity of 3000 $m^3/h$ characterizes the developed technologies. Considering that the air stream in the ventilation shafts reaches values above 22,000 $m^3/min$, this technology would be highly ineffective.

[64] Nawrat S.: Możliwości wykorzystania metanu z powietrza wentylacyjnego podziemnych kopalń węgla. Miesięcznik WUG, nr 5, 2006, s. 16–20
Nawrat S., Gatnar K.: Ocena stanu i możliwości utylizacji metanu z powietrza wentylacyjnego podziemnych kopalń węgla kamiennego. Polityka Energetyczna, t. 11, z. 2, 2008. s. 69–83
The United States Environmental Protection Agency: Assessment of the Worldwide Market Potential for Oxidizing Coal Mine Ventilation Air Methane. 2003, EPA 430-R-03–002

# 9 Summary

The Intergovernmental Panel on Climate Change has recognized methane as the second most important greenhouse gas, i.e., substances that absorb infrared radiation and contribute to global warming. Methane emissions accompany exploitation of coal, and Poland is the tenth largest producer of this mineral. In Poland, 88% of methane is released from underground mining activities and only 12% from opencast mines.

In Poland, the highest amount of methane emitted in the underground mining category comes from mining activities (78% of total emissions), then from post-mining activities (19%), and abounded coal mines account for 3% of emission.

Considering the total methane emissions from the underground mining category in Europe, the release of methane from abounded coal mines in Poland accounts for approximately 1.16% of the total emissions, mining activities for an average of 30%, and post-mining activities for 7%.

In 2019, 803.8 million $m^3$ of methane was released from the rock mass affected by mining. That corresponds to the value of 1,530.9 $m^3$ per minute[65]. In 2015–2019, this amount per tonne of coal mined (relative methane capacity) ranged from 12.9 to 14.5 $m^3$.

*The drainage efficiency in Polish coal mines in 2015-2019 ranged from 34.6% to 36.3%. Utilization efficiency in 2018 was varying between 57% to almost 64%. In 2019, this value slightly decreased. In turn, the percentage of atmospheric methane emissions in this period ranged from 63.7% to over 65.0% in 2019.* However, these data were calculated concerning the total methane bearing capacity, which means that they include only ventilation air methane. *Including not utilized methane in the calculations will increase the atmospheric methane emissions percentage to 76%.*

In Poland, one of the largest coal producers is Jastrzębska Spółka Węglowa S.A. The Company's mining activities are accompanied by the emissions of considerable amounts of methane, which obliges it to take pro-environmental actions to minimize its harmful impact on the atmosphere. This report analyzed the data provided by JSW S.A. concerning the state of emissions, drainage, and utilization of methane in the period from 2015 to 2020. The results were compared with the data from the WUG and E-PRTR register and from Europe and Annex

[65] WUG, 2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach.

I countries' energy and mining sectors. Based on that, it was possible to recognize the percentage of methane emissions the Company's coal mines are responsible for.

*Among the Polish underground coal mines, JSW S.A. Group's average ventilation air methane was 182 kt/year (483 m$^3$/min). The total atmospheric methane emissions ranged from 198.5 to 264 kt/year, but from 2016 it were systematically decreasing. The amount of drained methane in the discussed period was 683 kt in total and 113.83 kt on average. The Company's average methane drainage efficiency throughout the period was 38.28%, and the average methane utilization efficiency was 57%.*

When analyzing the available emission registers, such as WUG or E-PRTR, the Company's coal mines with the highest methane emissions were "Budryk" and "Pniówek"[66]. In the case of the first one, the highest ventilation air methane amounted to 66 kt (175.51 m$^3$/min for 2018), and on average, during the entire research period, it was 53.17 kt/year (140.08 m$^3$/min). In "Pniówek", the average ventilation air methane was 51.7 kt/year (137.38 m$^3$/min).

*The data presented in the report show that the Company drained from 94 to 150 kt of methane, which in the entire adopted period gives the amount of 683 kt*. The highest value corresponds to the "Budryk", i.e., 234.12 kt in total. In 2016 this number increased by 22 kt compared to 2015 and remained at a level of 41.1 kt to 49.4 kt (for 2020). Then it decreased to 24.2 kt. Also, coal mine "Pniówek" captured large amounts of methane - 163.3 kt in total. Active drainage was also carried out in the "Borynia-Zofiówka-Jastrzębie" coal mine, where 98 kt of methane was captured during the period under consideration. It is worth noticing that the least amount of methane (3.3 kt to 7.25 kt) from all Fronts in this combined coal mine was captured by the "Borynia" Front.

By far, "Knurów" Front drained the smallest amount of methane, mainly because until 2016, no drainage was conducted, and in following years its level ranged from 0.3 kt to 3.7 kt. On the other hand, in “Szczygłowice" Front, almost 93 kt of methane was captured, but with a significant drop in 2018 (to 2.9 kt from 14 kt) compared to the previous year. In total, both Fronts have drained almost 113 kt of methane as a combined coal mine.

The efficiency of methane drainage for individual mines owned by JSW S.A. based on the WUG register indicates that the "Budryk" coal mine achieved its highest value - 44% on average and the next was "Knurów-Szczygłowice" - 33% on average. The entire Company's

[66] WUG, 2015-2020. Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo- geologiczną w 2017 roku. Wyższy Urząd Górniczy w Katowicach
European Pollutant Release and Transfer Register (E-PRTR): https://prtr.eea.europa.eu/#/home

average methane drainage efficiency for five years was 34.7%. This value differs slightly from the data from JSW S.A. (data from JSW S.A. cover the year 2020).

*In total, in the period under consideration, the Company's coal mines utilized 391.40 kt of methane, which corresponds to 9,785.23 kt of $CO_2$ equivalent (assuming $GWP_{100} = 25$). Over the entire period, this value ranged from 53.6 kt (2018) to 82.4 kt (2016). From the total amount utilized methane, 181.51 kt was used in internal combustion engines.*

The "Pniówek" coal mine utilized the highest amount of methane (142.3 kt) with an efficiency of 76% to 96%. In "Zofiówka" Front utilization efficiency reached 64% to 95%. The "Budryk" coal mine used up a total of 97 kt of methane (from 8.0 kt//year to 21.33 kt/year). Despite the high methane capture, this coal mine managed to achieve utilization efficiency between 28% and 52% (2019). It is worth noting that in 2020 this value increased to 72%, which is the result of the modernization of the methane drainage station and the start-up of the ECOMAX gas engine with a total capacity of $2MW_{el}$ from July 2020, which in combination with the already installed JMS624GS-SL $2x4MW_{el}$ engines gives overall power 10 $MW_{el}$.

The "Knurów" Front did not carry utilization between 2015 to 2019. It was not until 2020 when launching CAT CG 260-16 gas engines with a total capacity of 12 MWel (3x4 MWel) allowed burning 5.75 kt of methane, increasing the utilization efficiency to 48%.

Due to the incomplete utilization of the captured methane, it is released into the atmosphere. "Budryk" and "Knurów-Szczygłowice" coal mines registered the highest methane emissions in the analyzed period - a total of 117.58 kt and 65 kt, respectively. For each of them, JSW S.A. conducts activities aimed at increasing the use of methane. In the first one, the installation of an additional gas engine significantly contributed to reducing methane emissions in 2020 by 13 kt compared to 2019 (by 20% compared to 2019) and by 20 kt compared to 2018 (by 32%). The installation of engines in the Front "Knurów's methane drainage station in July 2020 caused a reduction in atmospheric methane emissions by 48%, i.e., by almost 144 $ktCO_2eq$ ($GWP_{100} = 25$).

*In the analyzed period, the Company's coal mines emitted 1,383.73 kt of methane into the atmosphere, which corresponded to 34.59 $MtCO_2eq$. The use of an increased value of $GWP_{100}$ (28) results in an increase in the total emissions from JSW S.A. by 12% (38.74 $MtCO_2eq$) but should not impact the long-term climate change trend. On the other hand, the GWP metric choice for a 20-year horizon increases the value of emissions by 244% (119.0 $MtCO_2eq$). This ratio significantly increases the share of the mining sector represented by JSW S.A. in the context of total methane emissions on a global and European scale.*

Under the obligations of the UNFCCC, Poland reports national emissions under the adopted reduction targets in five categories in the so-called Joint Reporting Boards[67]. The emissions of individual greenhouse gases are presented in $CO_2$ equivalent, and the $GWP_{100}$ metric is used as a conversion factor, which for methane is 25, according to the IPCC guidelines[68]. It is assumed that the use of an increased $GWP_{100}$ value would result in a higher total annual greenhouse gas emission as a result of the increased share of methane (approx. 20%) but would not significantly affect the long-term trend of changes[69]. The choice of other metrics, e.g., $GWP_{20}$, may significantly increase the mining sector's share in total methane emissions, which could influence government policy choice regarding the methods used to mitigate climate change. This applies to industries and enterprises with high levels of non-$CO_2$ emissions, as is the case with JSW S.A. *The metric adopted in the report of the "EMBER Coal to Clean Energy Policy think tank" is inconsistent with the IPCC guidelines and misleads the public opinion regarding the volume of methane emissions from the mining sector, particularly from JSW S.A.*

*Compared to all Annex I countries, the Polish energy sector is responsible for approximately 3.3% of the emitted methane, and on the European scale for 18.5% (23.3 $MtCO_2eq$ on average).*

According to the analysis prepared by the International Energy Agency[70], Poland ranks sixth in terms of methane emissions from the mining sector. *The global (Annex I countries) underground mining sector against the total methane emissions is a source of 6.0 Mt of methane on average. Polish mines release 0.62 Mt. Note that these figures do not include emissions from China and India.*

A closer look at the underground mining sectors of the individual Annex I countries indicate that the United States of America dominates and is responsible for 35.03% of total methane emissions (in the underground mines sector). The following countries are Russia (23.5%), the other Annex I countries, including Ukraine (15.7%), Australia (12.18%), Poland (10.28%), and Kazakhstan (3.31%). In Kazakhstan, the majority of methane emissions (77.74%) come from opencast mining. *JSW S.A. coal mines are responsible for around 4% of total methane emissions from the underground mine sector.*

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[67] National Inventory Report, 2020. Inventory of Greenhouse Gases in Poland for the Years 1988–2018 A Synthesis Report. IEP-NRI, written in response to the requirements of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Warsaw, polish text

[68] IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

[69] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[70] Source: IEA World Energy Outlook 2019 https://www.iea.org/reports/methane-tracker-2020

Including the literature data on methane emissions from the mining sector for China (550 $MtCO_2eq$) and India (24.6 $MtCO_2eq$) changes the ranting slightly. *The Polish underground mining ranks seventh, accounting for 2% of the total global methane emissions in this category, while the emissions from JSW S.A. are 0.8%.*

*In the European context, Poland and Ukraine are the largest emitters of methane from underground mines. They are responsible for the emissions at the average level of 38.3% and 34.38%, respectively.* Other European countries are responsible for the remaining 27.32% of emissions, including Romania (5.48 $MtCO_2eq$), Germany (2.32 $MtCO_2eq$), and the Czech Republic (1.72 $MtCO_2eq$). *JSW S.A.'s coal mines are responsible for approximately 15% of total methane emissions.*

*JSW S.A.'s mines, in the period from 2015 to 2018, accounted for only 1.29% of total methane emissions in Europe. The remaining underground mines in Poland accounted for 2.03%. The most significant amount of methane was released from the Agriculture sector - 51.32%, then Waste - 27.14%, and Energy - 19.91%.*

Compared to the Annex I countries, these values are significantly lower, and for JSW S.A. amounted to 0.31% and for other Polish mines 0.49%, respectively. The dominant sector was *Agriculture* - 38.10% and *Energy* - a total of 36.83%.

On the national level, the structure of emissions is a little bit different. *From 2015 to 2018, JSW S.A. coal mines accounted for 12.3% of total methane emissions, and the remaining mines for 19.26%.* Poland's highest methane emissions fell in the *Energy* category, approximately 47.38%, followed by *Agriculture* - 28.63% and *Waste* - 23.83%.

*In the Polish energy sector, methane emissions from JSW S.A. coal mines amounted from 24% to almost 28%. On the European Union scale, this value is decreasing and ranges from 6.35% to 7%. On the other hand, among the Annex I countries it is only 0.82% to 0.97%.*

Because the emission of methane accompanies the activities carried by JSW S.A., the Company tries to capture and utilize it as much as possible. Still, for safety reasons, it is impossible to avoid emissions along with the ventilation air entirely.

Actions aimed at minimizing methane's harmful effect on the atmospheric air are carried out through the maximum use of the captured methane. Currently, methane is used in cogeneration engines to produce electricity and heat. The ongoing program of "economic use of methane" (GWM) involves investments in the "Budryk" and "Knurów - Szczygłowice" coal mines, consisting of additional gas-engines installation with a total target capacity of 48 $MW_{el}$. By 2022, the Company plans to implement activities to obtain the installed capacity in both mines at the level of 43.9 MWel[71]. The annual production potential of "Green Electricity" in both coal mines will amount to 330 thousand tonnes MWh, covering 33% of JSW S.A.'s electricity demand. It is assumed that pro-ecological activities will reduce atmospheric methane emissions by 80 million $m^3$ of $CH_4$, which gives about 1.6 million $MgCO_2eq$. The Company's investments will allow from 2025 to use the entire drained methane economically. In 2020, the first effects of the investments were noticeable by reducing methane emissions. In Front "Knurów" and coal mine "Budryk", the drainage efficiency increased by 48% and 32% compared to 2018, respectively. Both coal mines utilized a total of 32 million $m^3$ of $CH_4$.

The JSW Group conducts activities aimed at reducing greenhouse gas emissions. Since 2017, it has been making integrated calculations and reporting the organization's and individual products' carbon footprint to meet the new guidelines for disclosing climate change information. In 2019, the Company's carbon footprint was 7.9 million MgCO2eq.

By analyzing the threats related to the activities carried by JSW S.A., it is essential to mention the possibility of including methane in the E.U. Emissions Trading System (EU ETS). This program is a critical element of the European Union's policy to combat climate change and its primary tool to reduce greenhouse gas emissions cost-effectively. It introduces a limit of total emissions of certain greenhouse gases emitted by installations covered by the system. Until now, methane was not included in the system, but the announcement of its inclusion will require the purchase of emission allowances. Considering higher $GWP_{100}$ for methane (28) than for CO2, the charges for its emission will be much higher than for $CO_2$. If we assume that methane emission from JSW S.A. in the coming years will remain at a similar level as in 2020 (198.47 ktCH4) and the price for a EUA unit raise from 25 to 55 euro in 2040, it will result in an increase in fees from 642 million PLN to 1.4 billion PLN (Fig. 8.1).

The inclusion of methane in the EU ETS will entail enormous costs for the coal companies, leading to their bankruptcy. Therefore, it seems necessary to eliminate methane emission from coal mines. In the case of methane captured with the drainage system, the situation would require increased financial outlays for its complete utilization. When it comes to VAM, it is not very realistic. The utilization technology of ventilation air methane is costly and is not designed to the air flux flowing in the shafts.

[71] www. cmm-energy. E.U

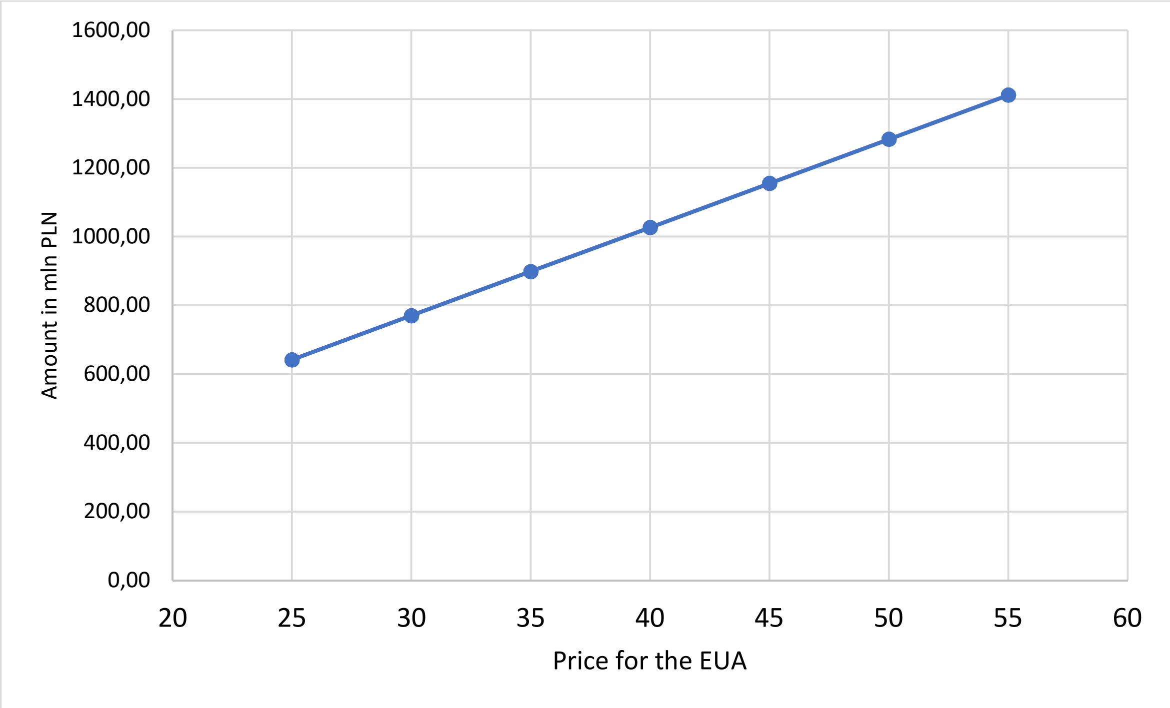


Figure 8.1. Projected increase in the fees for the JSW S.A. methane emission to the year 2040

The solution seems to be the co-financing of the development and modernization of the methane drainage technology and the introduction of the obligation to use it regardless of the safety condition (capturing from post-mining goaves). Legislative solutions are also necessary, e.g., treating the drained methane as a renewable energy source or as a primary source for producing "environmentally friendly electricity". The lack of such regulation significantly reduces the attractiveness of methane energy use, as it does not allow for a preferential price for the sold electricity. The solution could be treating the methane utilization investment as preferential (due to environmental protection). However, this would require introducing changes to the Polish legislation allowing for an unequivocal "inclusion of electricity and/or heat from the processing of methane mine gas in the support system on the same terms as energy from renewable sources is supported, regardless of the amount of installed power in the source - giving the status of environmentally friendly energy".

Due to the harmfulness of atmospheric methane emissions, each road limiting their presence in the Earth's atmosphere should be supported by law, promoted, and subsidized to the possible extent and the country's ecological regulations in force. It is one of the ways of intensifying the fight against atmospheric methane emissions while at the same time significantly increasing the safety of mining crews and reducing the costs of hard coal mining.

Recognition of the electricity produced from mine gas as the fulfillment of the obligation to purchase energy from renewable sources will allow for:

- intensification of investment processes in the mine gas utilization by encouraging investors,
- significant improvement in the safety of hard coal mining.