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MANAGING GREENHOUSE GAS AND DUST EMISSIONS IN THE POLISH HARD COAL MINING INDUSTRY

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Purpose: The purpose of this publication is to present the results of an original statistical analysis of the monitoring of environmental parameters of hard coal mining in Poland and to identify the reasons for changes in these parameters.
Design/methodology/approach: Planning safe and efficient hard coal mining requires continuous and ongoing analysis of the environmental parameters of mining operations. The presented analysis of selected environmental impacts of hard coal mining is based on information reported by mining companies. Data was obtained from the reports of mining companies and the website https://polskirynekwegla.pl/.
Findings: The cessation of coal mining will not fully stop greenhouse gas emissions from the previously mined deposit. This article analyzes changes in annual greenhouse gas and particulate matter emissions. The text identifies the most important reasons for the changes in the environmental impact of mining operations.
Research limitations/implications: The analysis was conducted for the period from 2013 to 2024. One small private Polish mining company does not report its indicators, so the data presented in the article only applies to other hard coal producers. However, due to the limited scope of this company's operations, the aggregated picture of the sector differs little from reality.
Practical implications: The presented analysis of selected environmental aspects of hard coal mining in Poland can help prepare a strategy adapting the hard coal mining sector to the dynamic changes in the fossil fuel market and new environmental challenges. Reducing greenhouse gas emissions by the EU, and thus by Poland, is necessary to slow the growth of unfavorable climate change.
Social implications: Halting, or even limiting, the ever-increasing global warming will be possible through the decarbonization transformation of economies.

Originality/value: The collected information on the environmental conditions of mining operations can help prepare potentially effective scenarios for the transformation of hard coal extraction in Poland and can also be used in the restructuring of mining in other countries.
Keywords: greenhouse gases, methane, hard coal mining, mining restructuring, decarbonization of the economy.
Category of the paper: Research paper, Case study.

1. Introduction

Mining is among the oldest and most essential industrial sectors. The sustainable operation of modern economies is inconceivable without uninterrupted access to mineral raw materials. (Hussein Salman, Abdulnbi Nayyef, 2024). Unfortunately, regardless of the mining model, mining always entails a serious environmental impact. Whether open-pit or underground mining, it impacts the atmosphere, hydrosphere, and lithosphere in various ways (Strzałkowski, Strzałkowska, 2023). The exploitation of deposits affects the environment not only during the period of active mining but also after its cessation (Chećko et al., 2022; Schuchová et al., 2023). Extracting raw materials to the surface along with waste rock using mining methods disrupts the integrity of the rock mass, for example, through fractures and the creation of post-mining voids after the selected deposit (Bąk et al., 2024; Shavarskyi et al., 2022). The resulting voids in the rock mass serve as zones for the disruption of previously entrapped gases, released via interconnected excavations, natural fractures, or hydraulic displacement. From these anthropogenic reservoirs, accumulating gases, mostly classified as greenhouse gases, can migrate to the surface through cracks or mine excavations (Wrona, 2017; Wrona et al., 2021). Impact on the atmosphere is usually associated with greenhouse gas emissions, primarily carbon dioxide and methane, released from mines in ventilation air. Greenhouse gas emissions from ventilation shafts are accompanied by continuous emissions of dust and thermal energy, but gases, smoke, and dust emitted from mine dumps and mining areas (e.g., access roads to dumps and storage areas) must also be considered in comprehensive environmental assessments. These factors stimulate the progression of unfavorable climate change (Bluszcz, Kijewska, 2016b). Unfortunately, the impact of mining activities on the environment is not confined to isolated environmental parameters. In practice, mining operations often interact with multiple environmental stressors simultaneously, amplifying their overall effect. (Strzałkowski, Strzałkowska, 2023).

Halting, or even limiting, the ever-increasing global warming will be possible through the decarbonization transformation of economies (Gawęda, 2022; 2024). Decarbonization assumes a gradual shift away from traditional high-emission technologies and aims to reduce greenhouse gas emissions into the atmosphere, including methane. One of the tools is to limit energy production from fossil fuels (Chećko et al., 2024; Khomenko, Jelonek, 2023). It must be emphasized that the cessation of coal extraction activities does not eliminate residual methane emissions originating from previously mined coal seams (Bluszcz, Kijewska, 2016b; Bluszcz, 2019).

2. Methane emissions into the atmosphere

Global industrial activity exerts considerable pressure on climatic and environmental systems. The effects of this pressure are becoming increasingly evident, as climate change processes intensify at an accelerating rate. The global mineral extraction sector, which underpins industrial development, remains one of the principal contributors to environmental degradation (Chmiela, 2023; Du et al., 2024). Regardless of the type of mining activity, its operation is always associated with a serious environmental impact and usually with the unavoidable emission of greenhouse gases, including methane, into the atmosphere. Greenhouse gas emissions are generated primarily by the extraction, transport, and combustion of fossil fuels (Bąk et al., 2024; Korbiel, Czerwiński, 2022). Limiting the increase in average global temperature to 1.5°C above pre-industrial temperatures requires reducing carbon dioxide emissions, as well as emissions of other short-lived climate pollutants, including methane (Bluszcz et al., 2015; Sobczyk et al., 2020). Historically, methane was regarded as a relatively minor contributor to greenhouse warming. However, it is now recognized as a key driver of radiative forcing and short-term climate dynamics (Bazaluk et al., 2021; Biały et al., 2020). Although methane emissions are quantitatively lower compared to CO_2, this gas has a significantly higher greenhouse gas potential. Methane emissions are responsible for at least 25% of global warming (Jevell et al., 2014; Siciński, 2024). Reducing methane emissions can bring rapid climate benefits that cannot be achieved by reducing carbon dioxide emissions alone. Global methane emissions are estimated to have reached approximately 610 million Mg in 2024, of which approximately 60% were anthropogenic. In the global economy, agriculture emits approximately 41% of all emissions, the energy sector approximately 39%, and waste management approximately 18% (ARP, 2025; Skibski, 2025).

In recent years, both nationally and internationally, there has been increased activity aimed at reducing and monitoring greenhouse gas emissions, with particular emphasis on methane. In 2015, the signatories of the Paris Agreement agreed to achieve climate neutrality in the second half of the 21st century (Gawęda, 2022; 2024). The signatories of the Paris Agreement, responsible for approximately 55% of methane emissions in the global economy, committed to reducing methane emissions by at least 30% below 2020 levels by 2030. Such reductions may contribute to mitigating global warming and facilitate progress toward the objectives of the Paris Agreement, potentially curbing the projected rise in average global temperatures. The urgency of addressing greenhouse gas and methane emissions has been emphasized by the

European Commission, among others, through the adoption of the EU Methane Strategy and the European Green Deal (Bluszcz, Kijewska, 2016a; Sobczyk et al., 2022).

Reducing methane emissions by the EU, and thus by Poland, is necessary to achieve the goals of the Paris Agreement. In 2024, Poland's methane emissions into the atmosphere amounted to approximately 1.9 million Mg, which corresponds to approximately 7.5% of the methane emissions of the entire European Union (Barszczowska, 2024; Dragan, Zdyrko, 2023). The mining sector is the leading source of methane emissions in the national inventory, with emissions from hard coal mines accounting for approximately 51% of the national balance. Agriculture comes second with 32% of the total annual emissions (mainly livestock), and landfills come third with approximately 16% of emissions (Wrona, 2017; Wrona et al., 2021).

Complying with the adopted EU Methane Regulation will be a significant challenge for many Polish businesses, including mines. Despite Poland's relatively small share in global methane emissions into the atmosphere, the hard coal mining sector demonstrates high methane emission intensity (Gomółka, Kasprzak, 2023; Strzałkowski, Maruszczyk, 2024).

Another approach to combating methane hazards, and a way to reduce its potential for atmospheric emissions, is methane drainage and capture from disused mines. Such capture is characterized by marked fluctuations in methane flow rates and concentration levels, influenced by factors such as barometric pressure. Additional methane emissions may originate from decommissioned or abandoned mines that remain historically linked to the surface via networks of inactive shafts and natural geological conduits (Prusek, Turek, 2018; Sobczyk, Kopacz, 2018). Such pathways include decommissioned shafts, adits, old boreholes, faults, outcrops, and natural fractures in the rock mass. Released methane can utilize these migration pathways and enter the atmosphere. It should also be remembered that decommissioned or formerly abandoned mines lack any services capable of minimizing emissions or ensuring their occupational health and safety (Chmiela, 2022; Chmiela et al., 2023).

3. Research methods

The environmental impact of Polish hard coal mining presented in the text is based on information on hard coal mining reported by active mining companies in Poland. The data used for the analysis is available on the website https://polskirynekwegla.pl/ (ARP, 2025) administered by the Katowice branch of the Industrial Development Agency (ARP S.A.). In accordance with statistical obligations, hard coal mining entities report the scope of their mining operations to the Katowice Branch of the Industrial Development Agency (ARP S.A.). Based on the data received, ARP prepares statistical information for the minister on the mining operations of mining companies (Barszczowska, 2024; Prakash Pandey, Prasad Mishra, 2022).

Based on the scope and availability of data, mining companies conduct reporting on a monthly, quarterly, and annual basis. Among Polish mining entities, one privately held company does not disclose its operational data; however, due to its limited scale, this omission does not materially affect the overall sectoral analysis. Consequently, the presented statistical evaluation pertains exclusively to the remaining domestic hard coal producers.

Reported data occasionally reflects anticipated trends associated with sectoral restructuring of the hard coal mining sector and the ongoing energy transformation of the economy, while at other times unexpected and sometimes rapid changes in the assessed parameters occur. The aim of this publication is to present the results of an original statistical analysis of monitoring environmental parameters accompanying the restructuring process of the hard coal mining industry in Poland and to link the observed changes in parameters with the current political and economic situation in the country. The analysis was conducted for the period from 2013 to 2024 and identified the most important factors and events causing major changes in mining operations (Manowska et al., 2024; Schuchová et al., 2023).

Planning the safe and efficient extraction of mineral resources, including hard coal, requires ongoing analysis of the technical and economic parameters of mining operations. Data obtained from studies on environmental and economic conditions can inform the development of viable transformation strategies for domestic hard coal mining and may serve as a reference for restructuring efforts in other national mining sectors (Schuchová et al., 2023).

4. Restructuring of hard coal mining in Poland

According to official data, the historically highest hard coal production in Poland, just over 200 million Mg, was recorded in 1977. This "record" production level has never been repeated. The green transformation of the economy and the resulting restructuring of the hard coal mining sector have resulted in a systematic decline in hard coal production in Poland for years (Fig. 1) (ARP, 2025; Skibski, 2025). A "shadow of the sector's former glory" is the production of approximately 44 million Mg of thermal and coking hard coal at the end of 2024. Compared to the record mining production in 1977, this is slightly over 20% of that value (Smoliło et al., 2021). In 2024, approximately 4.4 million Mg less was extracted than in 2023 (a decrease of approximately 9% y/y). From 2013 to 2024, global production decreased by 42%, or 32.5 million Mg. On average, the hard coal mining industry reduces production by approximately 2.7 million Mg annually, or 3.5% year-on-year. Only once, in 2022, a steady decline in production was observed, with a slight increase (Fig. 1). This resulted from increased global demand for energy resources during the so-called economic rebound after the "COVID lockdown" period. In Poland, production increased by 0.6 million Mg (1 percentage point) (Górska, 2023; Khomenko, Jelonek, 2023). In 2024, Polish producers satisfied the economy's demand for hard coal by approximately 89%, with the remaining volume obtained from imports (ARP, 2025; Skibski, 2025).

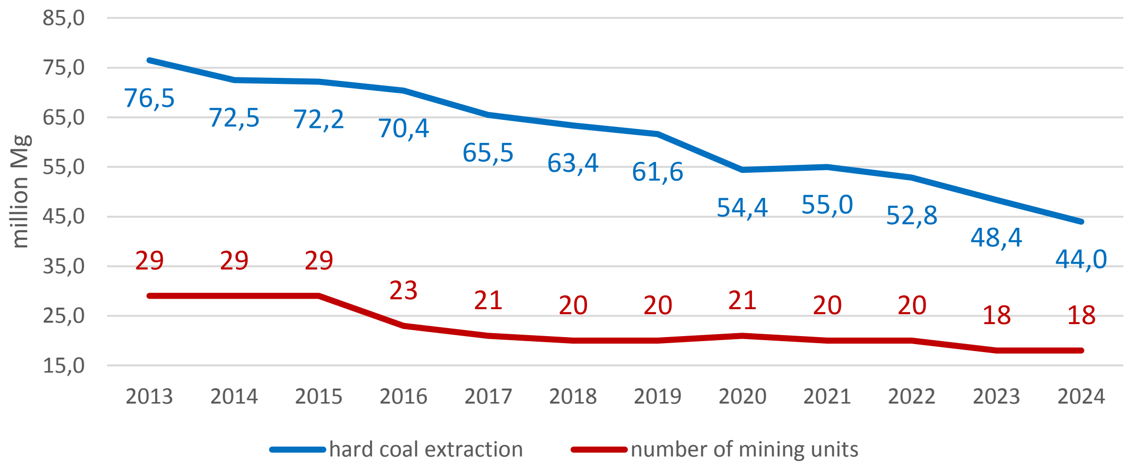

Figure 1. Volume of hard coal extraction in Poland [million Mg] against the background of the number of mining units.

Source: (ARP, 2025).

The Polish energy sector relies primarily on coal combustion for energy generation, for which it has adequate generation and transmission infrastructure. A hypothetical immediate closure of coal-fired units could undermine the country's energy security (Górska, 2023; Remiorz et al., 2025). Basing the energy sector on intermittent renewable energy sources may lead to operational disruptions, including blackouts, as evidenced by recent grid instability events across Europe. A transitional phase is essential to ensure a safe shift toward a low-emission economic model. During this relatively short transition period, traditional coal-fired power generation would stabilize energy supplies. The task of the restructured Polish hard coal mining industry would be to provide the necessary fuel for coal-fired units, with imports merely supplementing domestic production.

Given the expected decline in the domestic energy sector's demand for thermal coal and a similar lack of interest in thermal hard coal by other countries' economies, a reduction in mine production capacity is inevitable (Chećko et al., 2022; Siciński, 2024). Restructuring of the hard coal mining industry has been underway since the end of the 20th century. This process involves reducing the production capacity of active mines and gradually closing those deemed permanently unprofitable (Prakash Pandey, Prasad Mishra, 2022). According to the social contract (Agreement, 2021), the phased reduction of coal mines serving the energy sector will continue until 2049. The most unprofitable mines are to be liquidated first (Act, 2024). Deposits in active mining units are to be extracted efficiently and safely until the limit of their existence resulting from the social contract (Agreement, 2021).

Since 2013, there has been a decline in the number of active mining units. During this time, 12 mining units were closed. The social contract signed in 2021 provides for further reductions in domestic mining and the continued closure of unprofitable mining units (Strzałkowski, Maruszczyk, 2024). In Poland, in 2024 (Figure 1), hard coal mining was conducted by eight state-owned and private mining companies, using 18 mining units (ARP, 2025; Skibski, 2025).

The ongoing restructuring processes and adaptation of the sector to a zero-emission economic model limit mining capacity, which should affect the ecological aspects of mining operations (Abdulnbi Nayyef et al., 2024; Magdziarczyk et al., 2023). Along with the restructuring of hard coal mining, a gradual shift away from traditional high-emission technologies and a reduction in emissions of greenhouse gases, dust and heat into the atmosphere is expected (Bluszcz, 2019; Sobczyk et al., 2020).

5. Results and discussion

Due to the volume of hard coal production, Poland is the largest methane emitter in the European Union. In 2024, Polish mining produced approximately 96% of the total hard coal production in the EU, followed by Romania and the Czech Republic. In Polish hard coal mining, methane emissions are primarily related to mining operations. Combating methane hazards in mines involves ventilation dilution of gas released into the excavations and methane drainage of coal seams and adjacent rocks (Biały et al., 2020; Bluszcz, Kijewska, 2016b). Unfortunately, for safety reasons for the crew and the mining plant, methane released into the excavations is diluted through ventilation and released into the atmosphere through a network of ventilation shafts. Its capture is difficult or even technically impossible due to its low concentration, up to 0.75% in mine exhaust shafts (Abdulnbi Nayyef et al., 2024; Khomenko, Jelonek, 2023). In rock mass methane drainage, most often achieved by creating negative pressure, methane drainage systems capture methane through a system of special pipelines or excavations and direct it to the surface for management. It is assumed that for Polish mining, the proper efficiency of methane drainage from coal seams and adjacent rocks using drainage systems should be at least 50%, while the economic utilization of the captured methane should be at least 95%.

Hard coal deposits are typically mined from the top down. According to this principle, seams located closer to the surface are first selected (Strzałkowski, Strzałkowska, 2023). Due to their proximity to the surface, the deposit undergoes spontaneous degassing over time. Progressive mining reaches deeper and deeper, where the deposits are characterized by higher gas content. Typically, as the deposit is mined and the resulting depth increases, the amount of greenhouse gases released during extraction increases. In hard coal mines, the deposit most often releases carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), hydrogen sulfide (H_2S), sulfur oxides (SO_x), and nitrogen oxides (NO_x). These gases are released from the deposit and originate from natural oxidation processes or are a result of technological processes related to mining. Greenhouse gas emissions from mines are primarily based on two gases: carbon dioxide (CO_2) and methane (CH_4). It is estimated that virtually all of the methane emitted into the atmosphere is released from coal and adjacent rocks, originating from natural processes in deposit formation (Wrona, 2017; Wrona et al., 2021). CO_2 emissions result primarily from the release of gas trapped in the rock mass, but also from the natural oxidation of coal upon contact with ventilation air. Although the concentrations of other gases are relatively low, the large volumes of ventilation air circulating through mines result in substantial absolute emissions. Sulfur oxides (SO_x) and nitrogen oxides (NO_x) emitted into the atmosphere by mines, most often result from blasting operations using explosives and the combustion of liquid fuels by mine equipment. CO emissions may result from incomplete combustion of coal in goaf or liquid fuels with insufficient oxygen supply. Hydrogen sulfide emissions typically originate from the decay of organic substances, such as wood. Hydrogen sulfide also occurs in aquifers, where, in addition to organic matter decomposition, microbial conversion of sulfates can occur. The possibility that this process may be enhanced by the presence of ammonia cannot be ignored (Bazaluk et al., 2021).

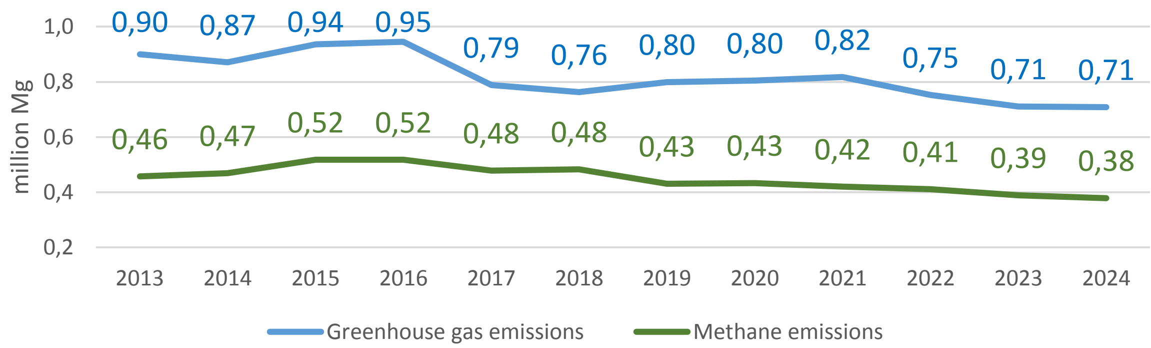

Figure 2. Greenhouse gas emissions (including methane) and methane emissions from hard coal mining in Poland [million Mg].

Source: (ARP, 2025).

Greenhouse gas emissions have been declining since 2013. During the analyzed period, a decrease was recorded from approximately 0.9 million Mg in 2013 to approximately 0.71 million Mg in 2024 (Figure 2). As illustrated in Figure 2, the analyzed period saw an absolute decrease in greenhouse gas emissions by approximately 21%. In 2015 and 2016, a temporary increase in hard coal mining emissions was observed. This increase resulted from mines exploring new gas-bearing, yet not yet degassed, seams. Appropriate prevention led to a return to the previous downward trend. During the same period, absolute methane emissions to the atmosphere (Figure 2), after initially stabilizing at approximately 0.47 million Mg and increasing in 2015 and 2016 to approximately 0.52 million Mg, have been gradually declining. In 2024, emissions amounted to approximately 0.38 million Mg, approximately 19% lower than in 2013. The increase in greenhouse gas discharge in 2021 to 0.82 million Mg/year is difficult to explain. The increase in greenhouse gas emissions is certainly partly due to increased extraction, but the growth rate of greenhouse gas emissions (2.5% year-on-year) significantly exceeds the growth rate of extraction (1.1% year-on-year). A partial explanation may be the fact that, for COVID-19 prevention reasons, within the limits of available technical capabilities, some mines increased the intensity of excavation ventilation in the second half of 2020 and early 2021. However, the question remains whether even increased mine ventilation could increase greenhouse gas emissions sufficiently without increasing methane emissions. Additionally, unlike the increase in global greenhouse gas emissions from hard coal mining, no increase in methane emissions into the atmosphere was observed in 2021. Paradoxically, methane emissions into the atmosphere decreased by 2.3% year-on-year in 2021.

As previously discussed, greenhouse gas emissions, including methane, depend on two key factors. One is the steadily declining global hard coal production which theoretically contributes to lower emission volumes. The other is the increasing gas content of mined deposits due to greater mining depths, which tend to elevate emission levels. To evaluate the specific emissions, the total gas and methane emissions reported by the sector were divided by the annual mining production also reported by mining companies (Fig. 3). During the analysis period from 2013 to 2024, specific greenhouse gas emissions per unit of coal extracted have shown a consistent upward trend. There was an increase from 11.8 kg/Mg in 2013 to 16.1 kg/Mg in 2024, which corresponds to a 27% increase. In the analyzed period, the Polish hard coal mining industry emitted on average 13.4 kg of greenhouse gases per Mg of hard coal extracted (ARP, 2025; Skibski, 2025).

During the analyzed time period, the average methane emission per Mg of hard coal mined in Poland was 7.4 kg/Mg, and the variability also showed an upward trend. From 2013 to 2024, specific methane emission increased from 6.8 to 8.6 kg/Mg (ARP, 2025; Skibski, 2025). The increase in specific methane emission is attributable to the exploitation of increasingly deeper and more methane-rich coal seams.

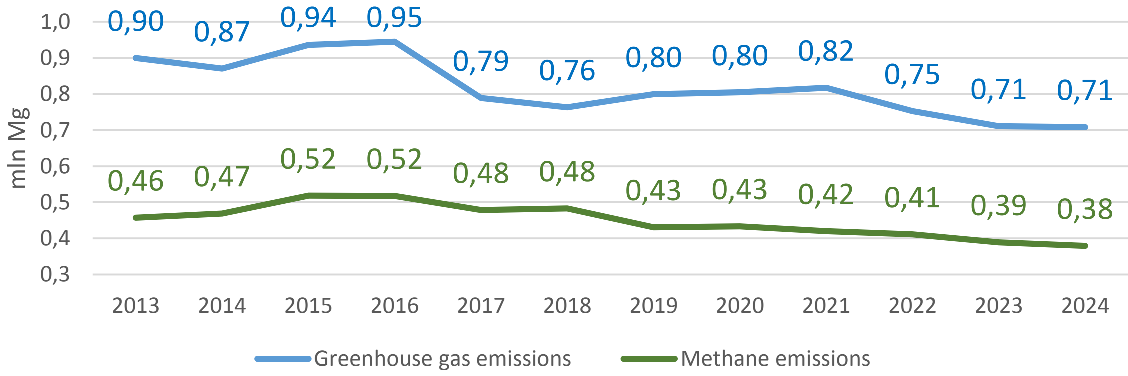

Figure 3. Unit greenhouse gas emissions (including methane) and methane emissions alone from hard coal mining.

Source: (ARP, 2025).

To better illustrate the emissions intensity of hard coal mining, the specific greenhouse gas and methane emissions per mining unit were calculated (Bluszcz, 2019; Górska, 2023). Emissions and the number of mining units were obtained from data reported by coal companies. The number of mining units reported by coal companies is imperfect for direct comparisons. Among the mining units reporting their data, there are single- and multi-unit mines, which are treated equally in this comparison (Prusek, Turek, 2018; Sobczyk et al., 2022). Bearing in mind that different numbers of operations, or component mines, may distort the comparison, some analysis of the trends can be achieved.

In the first years of the assessed period, from 2013 to 2024, greenhouse gas emissions per active mining unit were around 30,000 Mg/year (Fig. 4). Due to the early decommissioning of several mining units, a significant increase in greenhouse gas emissions per mining unit has occurred since 2016, reaching approximately 39,000 Mg/year, a level that has persisted to this day (ARP, 2025; Skibski, 2025). This significant increase can be explained by the fact that the decommissioned mining units had relatively low production and were exploiting a deposit that was already largely degassed. Notably, a significant increase in emissions per mining unit was observed in 2021. Greenhouse gas emissions reached approximately 40,900 Mg/mining unit/year, 6% more than in 2020 and 8% more than in 2022 (Fig. 4). As mining operations extend to greater depths and deposits become increasingly unfavorable for extraction, it is statistically expected that emissions per unit may rise. Merely limiting extraction volumes may not be sufficient to reverse this trend.

In the case of average methane emissions by a mining unit, apart from the varying number of movements within a mining unit, the analysis may be complicated by the fact that some units emit negligible amounts of methane, resulting in significant deviations between actual and average values. Under these assumptions, from 2013 to 2015, the average mining unit emitted approximately 17,000 Mg CH_4/mining unit/year (Fig. 4). Due to the closure of several non-methane mines, average mining unit emissions have been increasing since 2016 to approximately 23,000 Mg CH_4/mining unit/year. In subsequent years (from 2019), methane emissions have decreased to approximately 21,000 Mg CH_4/mining unit/year, which is still maintained (Fig. 4) (ARP, 2025; Skibski, 2025). This decline may be due to the sector's reduction in hard coal production and mines preparations for implementing the provisions of the EU methane regulation. Due to the restrictive provisions of the aforementioned regulation, it should be expected that emissions from mining units should decrease or at least not increase.

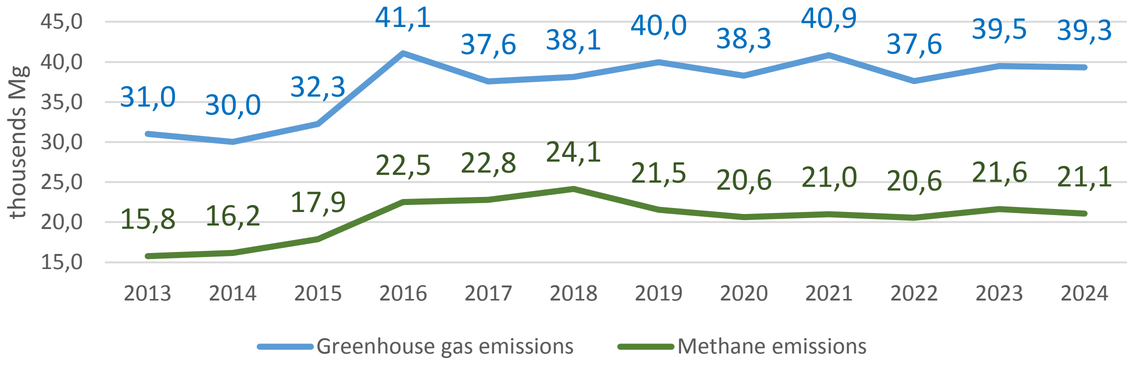

Figure 4. Greenhouse gas emissions (including methane) and methane emissions per hard coal mining unit.

Source: (ARP, 2025).

Due to their utility and independence from energy sources, modern underground mining often employs mining machinery powered by engines burning liquid fuels. While the specific emissions of a single machine are relatively low, the total amount of diesel fuel consumed can be a significant source of greenhouse gases. Until 2017, approximately 9500 Mg/year of diesel fuel was burned in the Polish hard coal mining industry (Fig. 5). Since 2018, average diesel fuel consumption in hard coal mines has increased to over 11,000 Mg/year. This level has remained constant. In 2024, the total diesel fuel consumption across all hard coal mining units was approximately 655,000 Mg, used to power combustion-driven mining machinery. As with the analysis of hard coal mining emissions, the increase in diesel fuel consumption in 2021 to approximately 11,900 Mg is difficult to explain (Fig. 5) (ARP, 2025; Skibski, 2025). This could be explained by the significant dispersal of workers to various tasks temporarily suspended in 2020 due toCOVID-19 restrictions. Performing various mining or repair tasks scattered throughout the mine by small groups of workers could have required the consumption of increased volumes of diesel fuel by combustion-powered means of transport, such as suspended monorails. Another contributing factor may have been less stringent fuel management practices following the lockdown period, resulting in inefficient fuel utilization.

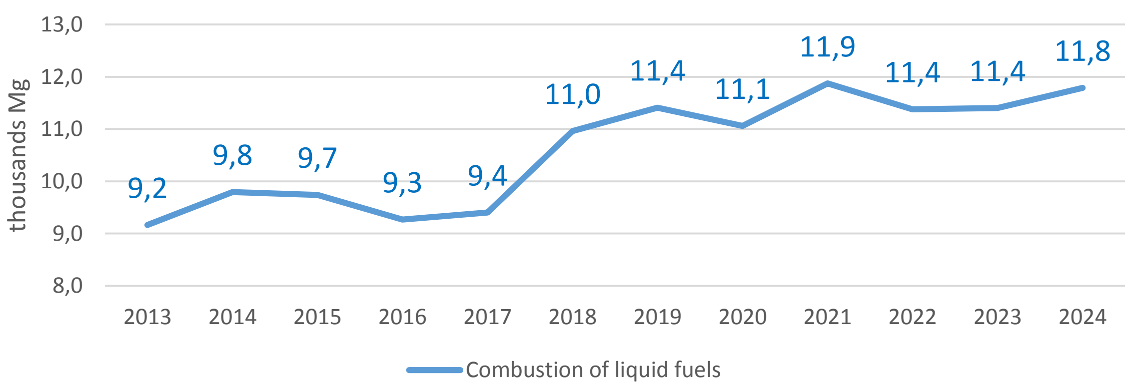

Figure 5. Combustion of liquid fuels (diesel oil) by mining machines.

Source: (ARP, 2025).

The carbon footprint of diesel fuel combustion in engines, which is the amount of carbon dioxide (CO_2) emitted into the atmosphere during operation, is approximately 2.68 kg of CO2 per liter of fuel. In addition to direct CO_2 emissions, diesel fuel combustion also generates other pollutants such as sulfur oxides (SO_x/SO_2), nitrogen oxides (NO_x/NO_2), carbon monoxide (CO), total particulate matter (TSP), and soot. The maximum sulfur content in diesel fuel in the European Union is 10 mg/kg (10 ppm). This limit is intended to reduce harmful sulfur oxide emissions into the atmosphere and limit corrosion in engines. According to the data from liquid fuel producers on the emission intensity of diesel oil combustion and assuming that 1 Mg of diesel oil is approximately 1220 liters, it can be calculated that in 2024, as a result of the operation of combustion engines in hard coal mines, 38,500 Mg of carbon dioxide (CO_2), 71 Mg of nitrogen oxides (NO_x/NO_2), 5.7 Mg of carbon monoxide (CO), up to 0.3 Mg of sulfur oxides (SO_x/SO_2), and 14.2 Mg of suspended particulate matter (TSP) were emitted (ARP, 2025; Skibski, 2025).

During the extraction of mineral deposits, including hard coal, dust is generated. Some dust remains in the mine, but some is released to the surface with ventilation air. In addition to dust resulting from mining, ventilation air also carries away types of dust The largest fraction of these is limestone dust (commonly referred to as stone dust), which is used to prevent coal dust explosions. Since 2013, dust emissions from hard coal mines have been decreasing (Fig. 6). During the analyzed period, dust emissions decreased from 1603 Mg in 2013 to 685 Mg in 2024. This represents a total reduction of 918 Mg, or 57%, with an average annual decrease of approximately 83 Mg (ARP, 2025; Skibski, 2025).

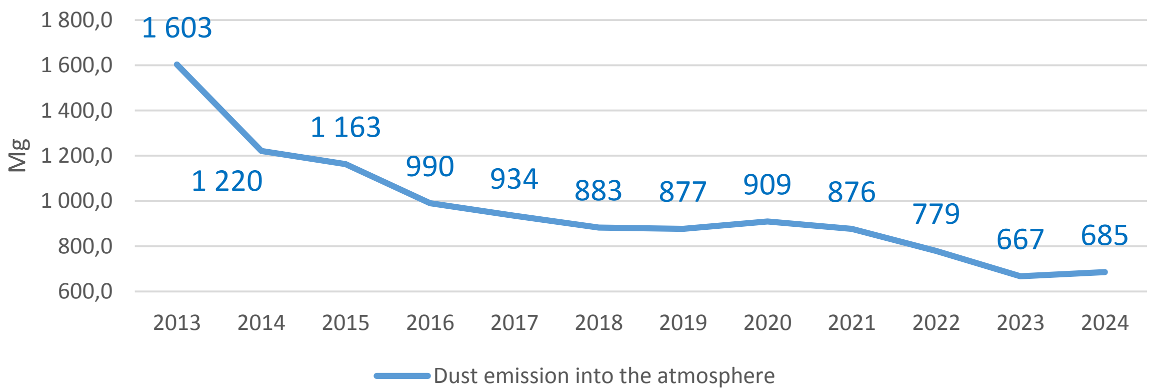

Figure 6. Dust emission into the atmosphere by hard coal mining.

Source: (ARP, 2025).

Mechanization of mining and the expansion of mines into increasingly thinner seams may increase dust levels in mines relative to production volume, but reduced production will reduce total dust emissions into the atmosphere (Fig. 7). Between 2013 and 2016, there was a rapid decline in specific atmospheric dust emissions, most likely due to the closure of the least efficient mines. Following this period, dust emissions stabilized at approximately 15 Mg per million Mg of hard coal produced. Notable exceptions occurred in 2020 and 2021

(Mozharovskyi et al., 2025; Redziuk, 2022; Shekhunova et al., 2023), when specific dust emissions to the environment increased (ARP, 2025; Skibski, 2025).

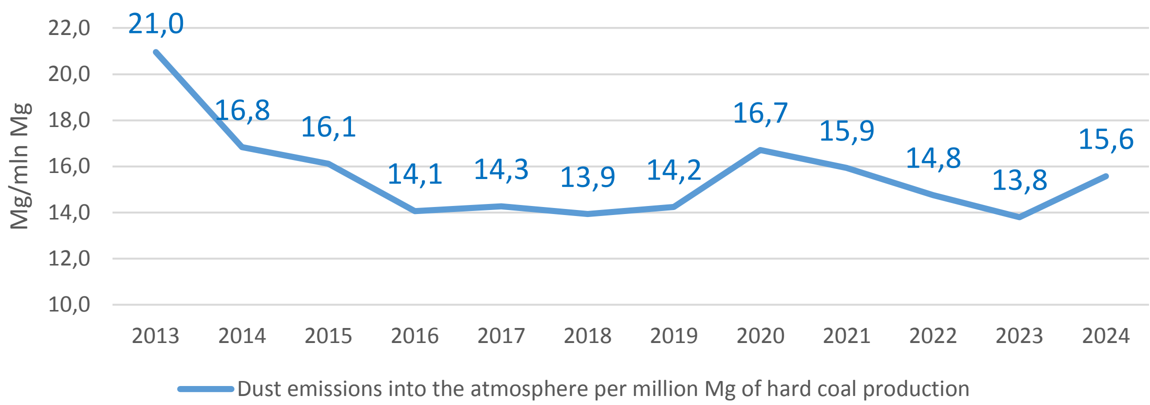

Figure 7. Dust emissions into the atmosphere per million Mg of hard coal production.
Source: (ARP, 2025).

The average dust emission into the atmosphere resulting from mining operations conducted by a mining unit remained at a level of approximately 43 Mg until 2021. Following the closure of two mining units in 2022, the situation stabilized, and currently the average hard coal mining unit emits approximately 38 Mg of various dust annually (Fig. 8) (ARP, 2025; Skibski, 2025).

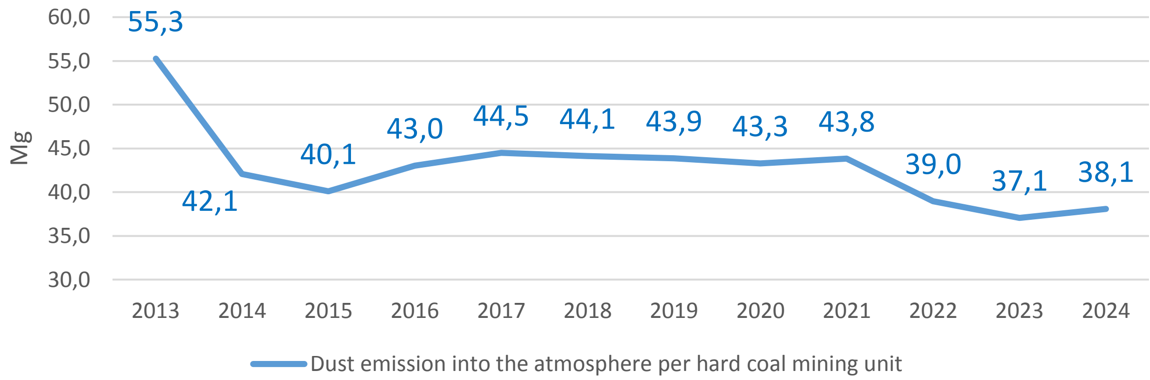

Figure 8. Dust emission into the atmosphere per hard coal mining unit.
Source: (ARP, 2025).

The Polish economy, and especially the energy sector, is largely based on hard coal combustion. Transforming both the economy and the energy sector is a long-term process. An immediate shift away from hard coal combustion would undermine the foundations of energy security. A transition period will be necessary, during which the Polish coal mining industry will continue to supply the necessary fossil fuels. Unfortunately, mining will be accompanied by ongoing emissions of greenhouse gases and particulate matter into the atmosphere, and even an immediate cessation of mining operations would not bring about rapid improvement.

6. Conclusions

Efforts to limit global warming to 1.5°C or 2°C above pre-industrial levels will require rapid and sustained reductions in emissions of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), and other greenhouse gases. This includes electrifying the economy, deploying renewable energy sources, improving efficiency, and using negative emissions technologies such as CCUS. These climate mitigation measures rely on technologies that reduce emissions at source as well as those that remove greenhouse gases already present in the atmosphere.

Conducting any mining activity always entails a significant environmental impact. The scale of ecological changes most often depends on the type of mineral being extracted and the scope of its extraction. The decline in economic demand for fossil fuels, including thermal coal, resulting from the industry's adaptation to climate and energy policies and the decarbonization of the energy sector, is reflected in the restructuring of the hard coal mining sector as a whole, and thus in its environmental impact. Hard coal production is adjusted to the needs of the economy. An immediate cessation of mining is impossible, as the Polish energy sector relies on coal combustion. A transition period is necessary to ensure the country's energy security. It is estimated that coal will be present in the Polish energy sector until at least 2050. The Polish hard coal mining industry, based on a support system, is tasked with providing the necessary volumes of hard coal.

A new hard coal mining policy and the resulting legal regulations should be part of a broader policy of transforming the fossil fuel sector. Forecasts assume a decline in demand for thermal coal, which necessitates the integration of climate, energy, and industrial policies into a unified strategy. Mitigating the effects of rising average global temperatures resulting from broader climate policy requires reducing greenhouse gas and particulate matter emissions into the atmosphere. Carbon dioxide is typically understood as a greenhouse gas, but methane plays a significant role in atmospheric warming mechanisms. Reducing production capacity in the Polish hard coal mining industry lowers greenhouse gas emissions. In 2024, hard coal mining released approximately 0.71 million Mg of greenhouse gases into the atmosphere, including approximately 0.38 million Mg of methane.

Due to the reduction in production capacity in the hard coal sector, absolute emissions of greenhouse gases, including methane, resulting from mining operations are decreasing. Unfortunately, the decline in production and the decreasing number of mining units do not correspond to the reduction in gas emissions. Due, among other things, to the exploration of ever deeper deposits, their gas content is increasing. The exploitation of more gas-rich deposits translates into higher specific greenhouse gas emissions per extraction volume. Since 2013, greenhouse gas emissions per extraction unit have increased by approximately 33%, and methane emissions by approximately 43%. Since 2016, greenhouse gas and methane emissions per extraction unit have remained more or less constant at 39.3 thousand Mg of greenhouse gases, including 21.1 thousand Mg of methane.

Airborne dust emissions from hard coal mine ventilation shafts are declining, with a decrease of approximately 57% recorded between 2013 and 2024. The decline in total dust volume was greater than the decline in extraction volume. From 2014 to 2024, dust emissions per extraction volume remained more or less constant at approximately 15 Mg/million Mg of extraction. However, emissions per mining unit, after remaining stable for a long time, fell to approximately 38 Mg per mining unit in 2022, a level that remains unchanged.

The end of coal mining will not fully halt greenhouse gas and methane emissions from the previously mined deposit. Emissions will remain directly from the once-mined deposit through the system of fractures and faults, and indirectly from the abandoned mine infrastructure. At least residual emissions should be expected for many years after mining ceases. In contrast, in the case of dust, the end of mining will be equivalent to the end of dust emissions into the atmosphere, provided that the landfills where secondary dust emissions occur are reclaimed.

Methane emissions are a significant component of the global greenhouse effect. The potential for methane (CH_4) to rapidly impact the climate and the potential technical feasibility of reducing its atmospheric emissions make it one of the most effective short-term climate policy goals. For Poland, this means accelerating the implementation of EU regulations. In the Polish mining industry, methane has traditionally been perceived as an unwanted gas co-occurring in coal seams, posing a threat to the safety of both people and mines. The potential for reducing methane emissions should not be viewed as a cost, but through the possibility of its management under favorable conditions, as a tool enabling sustainable restructuring of the sector.

The greenhouse gas emission rates analyzed in this study in Polish hard coal mines are only partially due to the restructuring of the sector and the shift to more difficult-to-extract deposits. Urgently addressing the escalation of the presented problems in greenhouse gas emissions into the environment could improve the efficiency of the hard coal mining sector.

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