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Abstract

In December 2021, the European Commission presented a draft Regulation of the European Parliament and of the Council on the reduction of methane emissions in the energy sector and amending Regulation (EU) 2019/942. The article summarizes the proposed EU rules on methane emissions from coal mines. In addition, it summarizes the figures of anthropogenic methane emissions for the European Union countries from the three main emission sources: agriculture, waste and the energy sector. The volumes of methane emissions from EU and Polish coal mines are also presented and divided into underground and surface mines, as well as active mines, abandoned mines and post-mining activities.

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1. Introduction

The European Green Deal aims to achieve climate neutrality for the European Union by 2050 [1]. Achieving this goal requires undertaking radical measures to reduce greenhouse gas emissions. The document assumes a reduction in greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. Achieving this level requires a reduction in methane emissions from the energy sector of about 58% by 2030 compared to 2020. Currently, the majority of electricity in Poland is produced from fossil fuels, mainly coal. According to [2], in July 2023, the share of hard coal and lignite in Poland's electricity production was about 43.5% and about 21.4%, respectively. Reaching the climate neutrality declared in the European Green Deal is, therefore, a major challenge for countries such as Poland.

The 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) − COP26 − took place in Glasgow in November 2021. Countries that have joined the initiative (the Global Methane Pledge) have committed to a common goal of reducing global methane emissions by at least 30% by 2030 from 2020 levels in all methane-emitting sectors. The pledge requires the use of the best available inventory methods to quantify methane emissions, especially from high-emission sources [3]. More than 100 countries of the world have joined the Global Methane Pledge, accounting for less than half of global anthropogenic methane emissions. China, Russia and India, which are among the world's largest methane emitters, have not joined the pledge. Poland, the Czech Republic and Hungary, which are members of the EU, have also not signed the pledge [4−6].

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In Poland, the most important documents on reducing greenhouse gas emissions and heading towards climate neutrality are:

- Strategy for Responsible Development until 2020 (with an outlook until 2030),
- National Energy and Climate Plan for 2021–2030,
- Poland's Energy Policy until 2040 (PEP2040).

The following indicators were adopted as a global measure of the PEP2040 target [7–10]:

- a maximum of 56% of the electricity produced in 2030 will be generated from coal,
- at least 23% of RES will be used in gross final energy consumption in 2030,
- nuclear power will be implemented in 2033,
- greenhouse gas emissions will be reduced by 30% by 2030 (compared to 1990),
- primary energy consumption will be reduced by 23% by 2030 (relative to 2007 consumption projections).

In the context of such ambitious targets, the implementation of a hydrogen economy in Poland will also be of great importance. Hydrogen is seen as a new, environmentally friendly energy carrier. It is predicted that its role will increase as we move away from fossil fuels. Poland faces the challenge of developing competitive methods of hydrogen production, storage, and distribution. For this purpose, the Polish Hydrogen Strategy until 2030 with a perspective until 2040 (PHS) was developed, which defines the directions and goals for the development of the hydrogen economy. The document assumes an increase in the share of electricity obtained from renewable energy sources, where hydrogen plays a significant role. PHS's perspective includes obtaining hydrogen from new installations, including using coal gasification technologies. Poland aims to obtain low-emission hydrogen, mainly from renewable sources and using emission-free technologies. The goals set in the PHS are consistent with the overarching goal adopted by the European Union, which is to achieve climate neutrality by 2050 [11]. On December 15th, 2021. The European Commission has introduced a draft Regulation of the European Parliament and of the Council on reducing methane emissions in the energy sector and amending Regulation (EU) 2019/942 [3], which will enter into force on the twentieth day after its publication in the Official Journal of the European Union. The regulation is based on the EU's 2030 Climate Target Plan (2030 Climate Plan) and its impact assessment. The aim of the regulation is to improve the condition of the environment by reducing sources of methane emissions. The regulation contains provisions for the accurate measurement, reporting and verification of methane emissions in the energy sector in the Union, as well as for the reduction of these emissions, including, among others, leak detection and repair as well as reductions in venting and flaring. The regulation also refers to the provisions on tools to ensure transparency of methane emissions associated with fossil fuel energy imported into the EU. These tools include information requirements for importers, a database to ensure transparency and a global monitoring tool for methane emitters. Data collected under the regulation will be publicly available on an e-platform, including indicators used to monitor progress towards EU energy and climate targets. In the context of one of the main greenhouse gases – methane, the regulation refers to the coal and oil and gas sectors. The coal sector refers to active underground and open-pit coal mines, as well as closed and abandoned underground coal mines. The underground coal mines include coal mines excavating thermal coal (used mainly as an energy source) and coking coal (used as a fuel and reactant in the steel production process). Open-pit mines include lignite mines.

The proposal for a regulation [3] contains six chapters with 35 articles. Chapter 4 deals with methane emissions in the coal sector. This chapter is divided into three sections outlining the obligations of operators (coal companies) and Member States to measure and report methane emissions data, as well as the obligations to reduce methane emissions at relevant locations. These are:

- section I – monitoring and reporting for active mines,
- section II – reducing methane emissions from active underground coal mines,
- section III – methane emissions from closed and abandoned underground coal mines.

For active underground coal mines, methane emissions include "a) methane emissions from all ventilation shafts operated by the mine operator; b) methane emissions from methane drainage stations and from the methane drainage system, whether arising from intentional or unintentional release to the atmosphere or incomplete flaring; c) methane emissions occurring during post-mining activities". For active opencast coal mines, methane emissions

include "a) methane emissions occurring in the coal mine during the mining process; b) methane emissions occurring during post-mining activities" (transport, processing, storage and handling). For abandoned and closed underground coal mines where coal mining has ceased, methane emissions shall include "(a) methane emissions from all ventilation shafts that continue to emit methane; (b) methane emissions from coal mining equipment that has ceased to be used; (c) methane emissions from other specifically identified point sources of emissions, as defined in Annex VII, Part 1".

The purpose of this paper is to synthesize the proposed EU regulations on methane emissions from coal mines. In addition, the figures of anthropogenic methane emissions for the European Union countries from the three main sources of emissions, which are agriculture, waste and the energy sector, are summarized. The volumes of methane emissions from EU and Polish coal mines are also presented, broken down into underground and open-pit mines, as well as into active mines, abandoned mines and post-mining activities.

2. Materials and methods

Methane is a greenhouse gas that has a significant impact on climate change and is responsible for about one-third of present global warming. This gas persists in the atmosphere for a period of 10–12 years and then oxidizes to carbon dioxide (persists in the atmosphere for hundreds of years), which keeps trapping heat. At the molecular level, methane contributes to a more significant greenhouse effect affecting the climate than carbon dioxide (the global warming potential for methane over a 100-year period is 28 times higher than that of carbon dioxide and 86 times higher over a 20-year period). This gas also contributes to the formation of ground-level ozone, a heavy air pollutant [12]. According to the IPCC [13] report, the slowdown of global warming and improvement of air quality requires a drastic and permanent reduction in methane emissions.

The global amount of methane emitted into the atmosphere consists of natural and anthropogenic emissions. Emissions from natural (biogenic) sources account for about 40% and include wetlands or vegetation fires, among others. About 60% of global methane emissions are anthropogenic ones, the largest sources of which are [3]:

- agriculture (about 30%), especially related to intensive production,
- wastes (about 15%),
- production and use of fossil fuels (15%–20%).

According to the communication on the European Union's strategy to reduce methane emissions [14], these three aforementioned sources account for up to 95% of global anthropogenic methane emissions.

According to the European Environment Agency (EEA), the European Union countries with the largest amount of total net methane emissions (expressed in kt CO_2 equivalent), including international transport in 2021, were: France, Germany, Italy, Poland, Spain and Romania. These emissions include emissions from energy, industrial processes and product use (IPPU), agriculture, waste, and international transport. These emissions also include any removal of CO_2 from the atmosphere through land use, land-use change and forestry (LULUCF) [15]. The share of these emissions from the aforementioned countries in percentage terms was: France – 15.10%, Germany – 12.57%, Italy – 11.57%, Poland – 10.44%, Spain – 10.04% and Romania – 6.21%. In the remaining EU countries, the percentage share of these emissions was less than 5%. Figure 1 shows the percentage of total net methane emissions (expressed in kt CO_2 equivalent), including international transport in 2021 from EU countries.

Total net methane emissions (expressed in kt CO_2 equivalent), including international transport in the European Union in 2021, came mainly from three sources, namely: agriculture, wastes and energy [15]. Figure 2 shows the percentage share of each source of these emissions. According to [3], based on data from EU greenhouse gas inventories, the energy sector is estimated to be responsible for 19% of the Union's methane emissions. This figure does not include methane emissions occurring outside the EU from energy based on the Union fossil fuels.

Figure 3 shows the percentage share of total net methane emissions (expressed in kt CO_2 equivalent), including international transport from agriculture, wastes and energy in European Union countries in 2021. The countries with the highest shares of these emissions from the three main sources of methane emissions are [15]:

- agriculture: France – 10.26%, Germany – 8.31%, Spain – 6.26%
- wastes: Italy – 4.46%, France – 3.79%, Spain – 3.11%,
- energy: Poland – 4.53%, Romania – 2.09%, Germany – 1.14%.

There is a trend in the European Union to reduce methane emissions. In accordance with the provisions of Article 4 of the UNFCCC [16], each Party

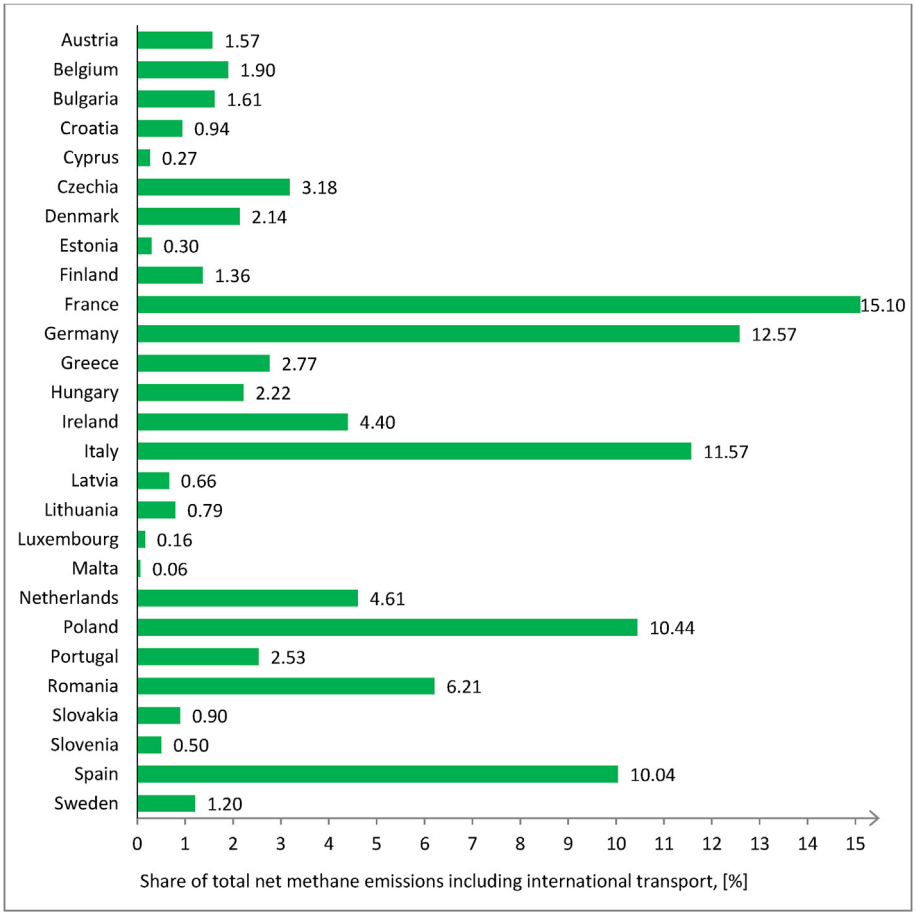

Fig. 1. Share of total net methane emissions (expressed in kt CO_2 equivalent), including international transport from EU countries in 2021; own analysis based on [15].

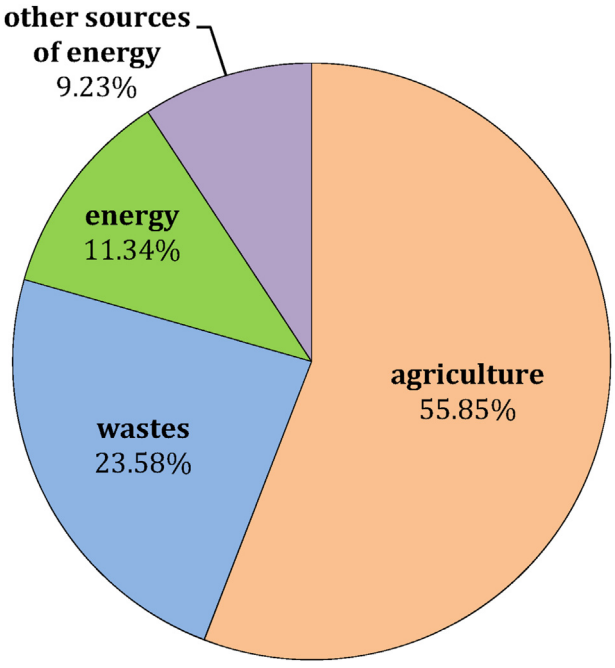

Fig. 2. Share of major sources of total net methane emissions (expressed in kt CO_2 equivalent), including international transport in the EU in 2021; own analysis based on [15].

uses the year 1990 as the baseline in implementing its methane commitments. Figure 4 shows the EU countries with the largest share of total net methane emissions (expressed in kt CO2 equivalent) including international transport for the period 1990–2021. During this period, methane emissions decreased by about 62% in Germany, 56% in Romania, 38% in Poland, 21% in France and 15% in Italy, and an increase in methane emissions of about 1% in Spain [15].

The largest source of methane emissions in the energy sector in the European Union are coal mines. In 2020, EU mines generated 943,000 Mg of methane emissions, equivalent to 78 million Mg of CO_2 emissions. In 2020, Polish mines accounted for 61% of EU methane emissions, releasing 576,000 Mg of methane into the atmosphere [17]. According to UNFCCC data [18], EU mines generated 925,828.38 Mg of methane emissions in 2020, including 798,868.07 Mg from underground mines and 126,960.31 Mg from open-pit mines. The share of EU underground and open-pit mines in emissions was 86% and 14%, respectively. Reported

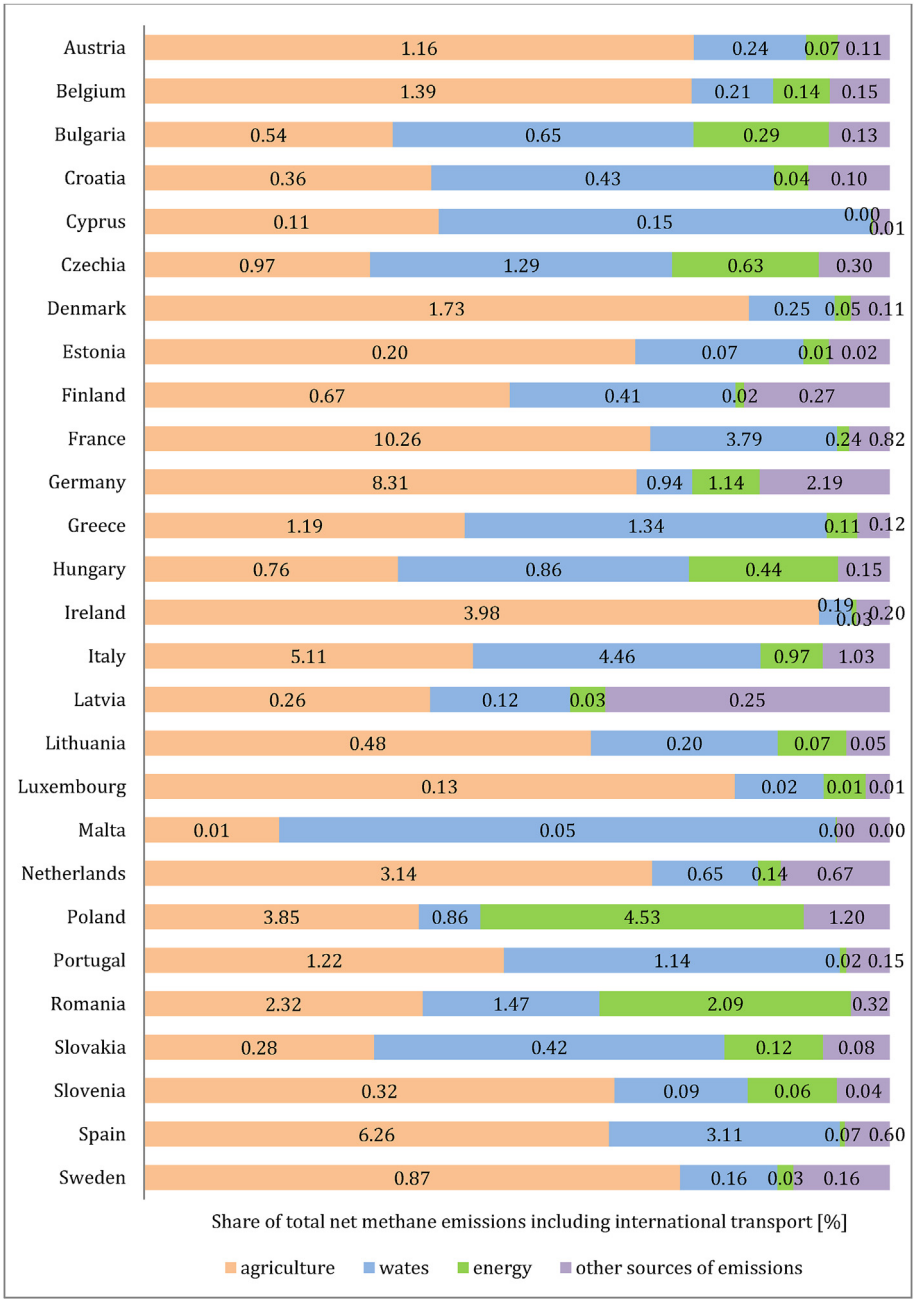

Fig. 3. Share of total net methane emissions (expressed in kt CO_2 equivalent), including international transport from agriculture, wastes and energy in EU countries in 2021; own analysis based on [15].

emissions from underground mines include emissions from active mines, abandoned mines and post-mining activities, while emissions from open-pit mines include emissions from active mines and post-mining activities. The values and shares of component emissions from EU underground mines are: active mines – 458,767.92 Mg (58%), abandoned mines – 241,796.91 Mg (30%) and post-mining activities – 98,303.24 Mg (12%). The values and shares of the components of emissions from EU open-pit mines are: active mines – 119,437.30 Mg (94%) and post-mining activities – 7523.01 Mg (6%). Figure 5 shows the share of EU underground and open-pit mines in methane emissions in 2020, as well as the values of these emissions, broken down by active mines, abandoned mines and post-mining activities. The share of emissions from underground and open-pit mines in the European Union was, respectively: active mines – 62%, abandoned mines – 26% and post-mining activities – 12%.

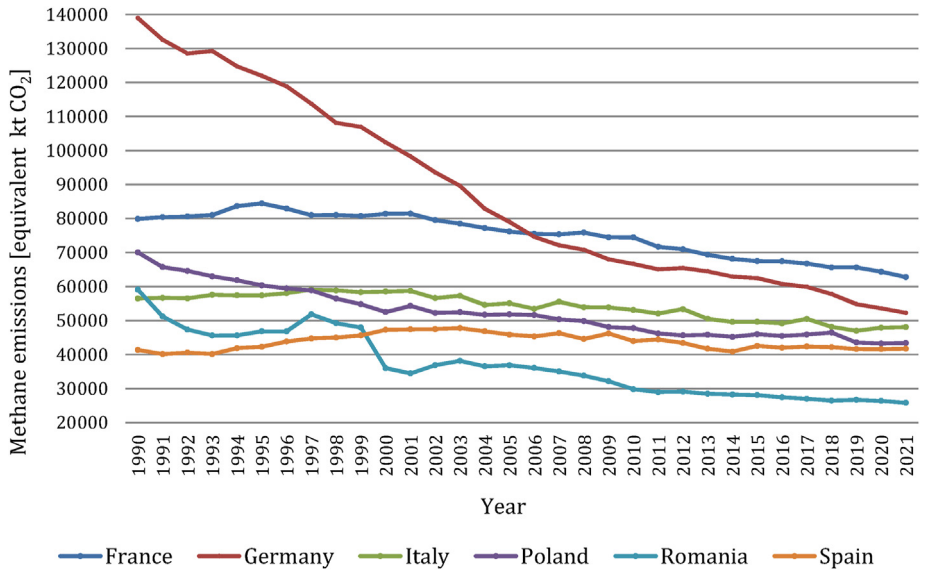

Fig. 4. EU countries with the largest share of total net methane emissions (expressed in kt CO_2 equivalent) including international transport in 1990–2021; own analysis based on [15].

According to the UNFCCC data [18], EU mines generated 907,629.48 Mg of methane emissions in 2021, including 768,773.42 Mg from underground mines and 138,856.06 Mg from open-pit mines. The share of EU underground and open-pit mines in emissions was 85% and 15%, respectively. The values and shares of component emissions from EU underground mines are: active mines – 434,808.76 Mg (56%), abandoned mines – 235,225.10 Mg (31%) and post-mining activities – 98,739.56 Mg (13%). The values and shares of component emissions from EU open-pit mines are: active mines – 130,319.49 Mg (94%) and post-mining activities – 8536.57 Mg (6%). Figure 6 shows the share of EU underground and open-pit mines in methane emissions in 2021, as well as the values of these emissions, broken down by active mines, abandoned mines and post-mining activities. In both 2020 and 2021 in the EU, the largest methane emissions came from active and abandoned underground mines, followed by active open-pit mines and post-mining activities. The share of emissions from underground and open-pit mines in the EU was, respectively: active mines – 62%, abandoned mines – 26% and post-mining activities – 12%. Based on UNFCCC data [18], methane emissions in 2021 compared to 2020 from active EU underground and open-pit mines decreased and increased by about 1%, respectively (Figs. 5 and 6). Methane emissions from EU abandoned mines and post-mining activities remained at comparable levels.

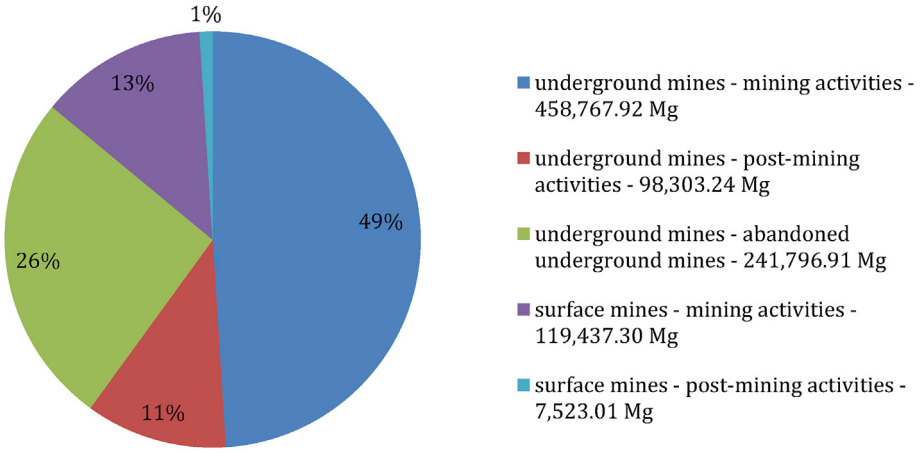

Fig. 5. Share of EU underground and open-pit mines in methane emissions in 2020 by active mines, abandoned mines and post-mining activities; own analysis based on [18].

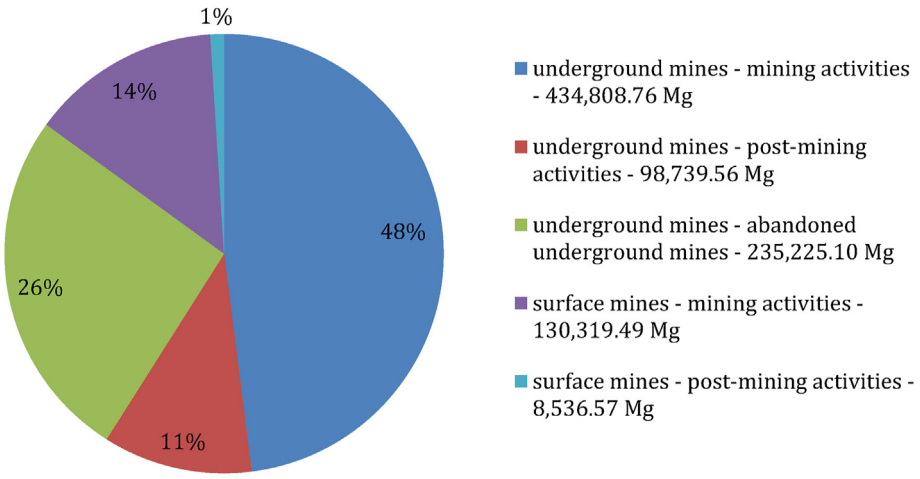

Fig. 6. Share of EU underground and open-pit mines in methane emissions in 2021 broken down by active mines, abandoned mines and post-mining activities; own analysis based on [18].

According to [19], Poland's methane emissions in 2020 amounted to about 44.34 million Mg of carbon dioxide equivalent, of which nearly 33% came from underground mines. According to UNFCCC data [18], in 2020 Polish mines generated 575,792.14 Mg of methane emissions, including 535,740.59 Mg from underground mines and 40,051.55 Mg from open-pit mines. The share of Polish underground and open-pit mines in emissions was 93% and 7%, respectively. The values and shares of the components of emissions from Polish underground mines are: active mines – 423,239.00 Mg (79%), abandoned mines – 21,405.16 Mg (4%) and post-mining activities – 91,096.43 Mg (17%). The values and shares of the emissions' components from Polish open pit mines are: active mines – 36,970.66 Mg (92%) and post-mining activities – 3080.89 Mg (8%). Figure 7 shows the share of Polish underground and open-pit mines in methane emissions in 2020, as well as the values of these emissions, divided into active mines, abandoned mines and post-mining activities. The share of emissions from underground and open-pit mines in Poland was respectively: active mines – 79%, abandoned mines – 4%, and post-mining activities – 17%. Based on UNFCCC data [18], in 2020 the total share of Polish underground and open-pit mines in methane emissions in the European Union was 62%. Considering emissions from underground mines as emissions from active mines, abandoned mines and post-mining activities, and emissions from open-pit mines as emissions from active mines and post-mining activities, the share of Polish underground and open-pit mines in methane emissions in the European Union was 67% and 32%, respectively.

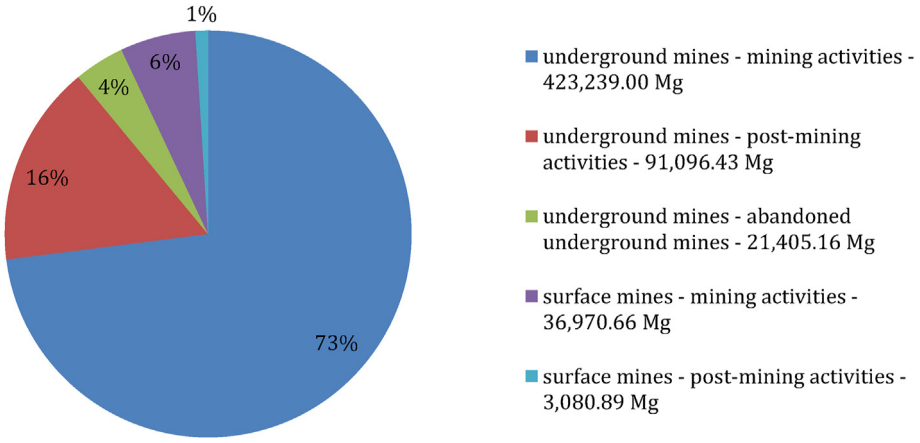

Fig. 7. Share of Polish underground and open-pit mines in methane emissions in 2020 broken down by active mines, abandoned mines and post-mining activities; own analysis based on [18].

In 2021, Poland accounted for 96% of the EU's hard coal output (55 million Mg) and was the second largest lignite miner (52 million Mg) [1720]. According to [21], Poland's methane emissions in 2021 amounted to 1525.17 thousand Mg, i.e., 42.7 million Mg of CO_2 equivalent. The share of methane in total national greenhouse gas emissions was 10.7%. The share of methane emissions from mines was 37.1% of total CH_4 emissions. According to UNFCCC data [18], in 2021 Polish mines generated 561,879.50 Mg of methane emissions, including 516,277.85 Mg from underground mines and 45,601.65 Mg from open-pit mines. The share of Polish underground and open-pit mines in emissions was 92% and 8%, respectively. The values and shares of component emissions from Polish underground mines are: active mines – 402,737.00 Mg (78%), abandoned mines – 21,405.16 Mg (4%) and post-mining activities – 92,135.69 Mg (18%). The values and shares of the emissions' components from Polish open-pit mines are: active mines – 42,093.83 Mg (92%) and post-mining activities – 3507.82 Mg (8%). Figure 8 shows the share of Polish underground and open-pit mines in methane emissions in 2021, as well as the values of these emissions, broken down by active mines, abandoned mines and post-mining activities. In both 2020 and 2021, Poland's largest methane emissions came from active underground mines and post-mining activities, followed by open-pit mines and abandoned underground mines. The share of emissions from underground and open-pit mines in Poland was, respectively: active mines – 79%, abandoned mines – 4% and post-mining activities – 17%. Based on UNFCCC data [18], methane emissions in 2021 relative to 2020 from active Polish underground and open-pit mines decreased and increased by about 1%, respectively (Figs. 5 and 6). Methane emissions from Polish abandoned mines and post-mining activities remained at comparable levels.

Methane emissions from Polish mines have been in decline since 2016. In 2021, methane emissions from Polish coal mines were 425 thousand Mg. The four most emitting Polish coal companies emitted a total of 388 thousand Mg of methane. The share of these companies in methane emissions is 91% (Fig. 9). The remaining 9% (37 thousand Mg of methane) is the difference in the share between the mentioned companies and the total emissions assigned to the companies in the coal mining sector according to the KOBiZE. These are mainly mines belonging to the Company for the Restructuring of Mines [21,22].

In Poland, the reduction of methane emissions in the coal sector requires investments, including in diligent monitoring of these emissions and the economic use of methane. According to the European Commission [23], methane has an economic value, which results, among other things, from the possibility of selling it on the market. In most cases, methane can be recovered and used as an energy source. According to [17], based on data from Eurostat [20] and the UNFCCC [18], there is an average of 9.4 Mg of methane emissions per thousand Mg of coal mined in Poland. In addition, per thousand Mg of coal mined in the EU, there is an average of 1.6 Mg of methane emissions for lignite and 9.5 Mg of methane emissions for hard coal. According to [19,24], in 2021 Polish mines emitted 815.3 million m^3 of methane, which, with 55.0 million Mg of coal output, gives 14.8 m^3 of methane per Mg of coal. 341.0 million m^3 of methane were

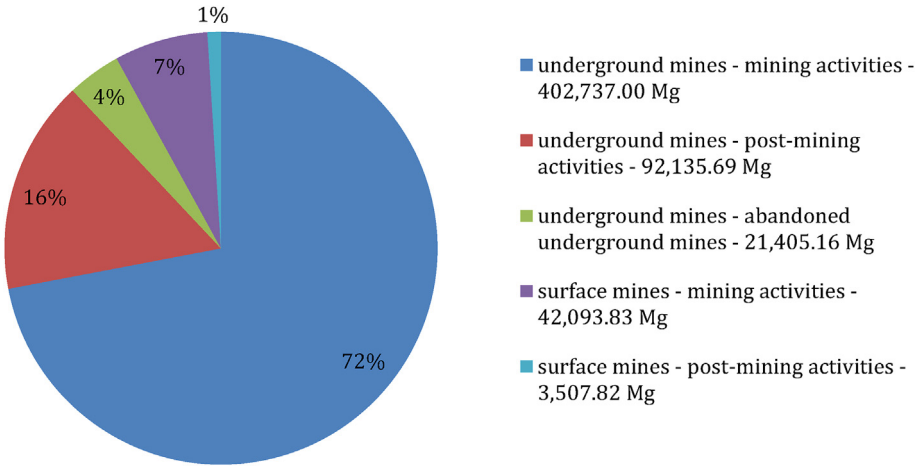

Fig. 8. Share of Polish underground and open-pit mines in methane emissions in 2021 broken down by active mines, abandoned mines and post-mining activities; own analysis based on [18].

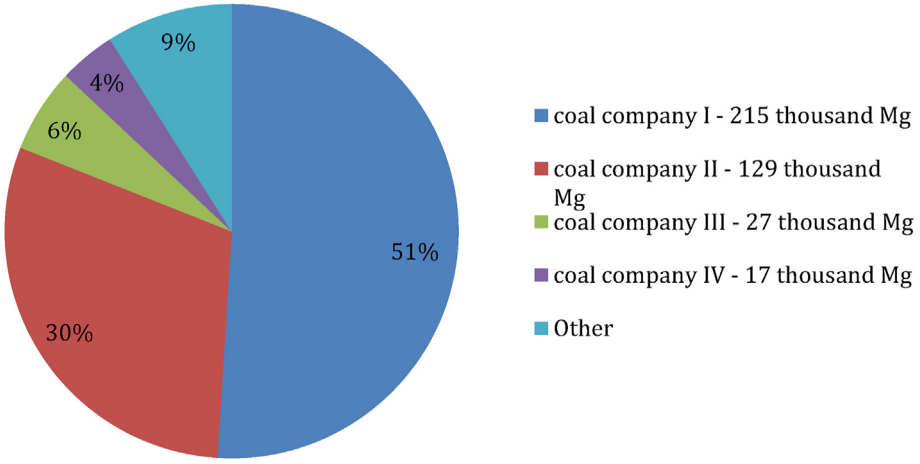

Fig. 9. Share of the most emitting Polish coal companies in 2021 in methane emissions; own analysis based on [22].

captured in the methane drainage systems, of which 214.2 million m^3 were used economically. Thus, the efficiency of methane drainage was 41.8%, and the efficiency of utilization was 62.8%. In 2022, Polish mines emitted 779.0 million m^3 of methane, which, with the extraction of 52.8 million Mg of coal, gives 14.8 m^3 of methane per Mg of coal. The methane drainage systems captured 303.5 million m^3 of methane, of which 206.1 million m^3 were used economically. Thus, the efficiency of methane drainage was 39.0%, and the efficiency of utilization was 67.9%. According to [25], the efficiency of methane drainage in mines in Poland does not exceed 40%. Economically, only about 60% of this is used effectively. The goal for Poland should be to strive to improve these indicators. It should be emphasized that gas from methane drainage stations is not suitable for every use. In addition, VAM technologies for managing gas from ventilation shafts are very expensive.

3. Results and discussion

According to an IPCC report, fossil fuels have been a significant contributor to methane emissions since at least 2007 [13]. Based on the impact assessment of the 2030 Climate Targets Plan [3], it was concluded that in the EU, reducing methane emissions in the energy sector is the most cost-effective. Attention was drawn to the need for a functioning unified energy market in the EU. This is a result of, among other things, the cross-border extent of emissions and the lack of a coordinated regulatory approach between EU countries and sectors. In many countries, operators are not under regulation to reduce methane emissions from their energy sectors. Most emissions of methane from fossil fuel energy consumed in the EU occur outside its borders. There is a lack of reliable information on the scale, origin and nature of these emissions. Methane emissions from the energy sector are of differing significance in member countries and their regions, depending on their energy mix and natural resources, including active or closed underground coal mines. Currently, in many countries, the primary strategy of action for quantifying and reducing methane emissions is based on voluntary industry-led initiatives. At both the EU and international levels, there is no standard for monitoring, reporting and verification for coal. At present, there are no specific regulations at the Union level for reducing methane emissions from active, closed or abandoned coal mines [3]. Flooding of closed or abandoned underground mines could prevent these emissions, but it involves environmental risks. According to [26], rising water levels due to mine flooding cause a decrease in the intensity of methane desorption due to the effects of hydrostatic pressure and the filling of gas migration pathways with water. In addition, there is the so-called piston effect, i.e., an increase in the pressure of free gas in the workings above the water level, which facilitates the migration of methane toward the surface. The Effort Sharing Regulation (EU) 2018/842 [27] outlines targets for binding annual reductions in greenhouse gas emissions, including methane, in member countries over the period from 2021 to 2030, including parts of the energy sector. As a part of this regulation, the Commission checks national policies and the measures member states use to achieve their targets every five years.

The Union, as a party to the United Nations Framework Convention on Climate Change and the Paris Agreement, is obliged to submit an annual

report summarizing data from inventories of anthropogenic greenhouse gas emissions from all member states. The report follows a best practice methodology recognized by the Intergovernmental Panel on Climate Change. Based on data from the EU greenhouse gas inventory, it was found that the largest single source of methane emissions in the energy sector in the Union is methane emission from coal mines. In 2019, direct methane emissions from the coal sector accounted for 31% of methane emissions, while those from the oil and gas sector accounted for 33%. In the Union, reports on the volume of methane emissions from the coal sector are a component of Member State reports on the volume of greenhouse gas emissions. In addition, in accordance with Regulation (EC) No. 166/2006 [28], data on methane emissions from mines are included in the European Pollutant Release and Transfer Register. A National Pollutant Release and Transfer Register, maintained by the Chief Inspector of Environmental Protection in the form of a publicly accessible electronic database, has also been established.

Regulation (EU) 2018/1999 [29] commits member states to establish national inventories of anthropogenic emissions of all greenhouse gases for the purpose of their estimation and reporting of national projections. Reports containing data from these inventories and national projections are submitted to the Commission. The reports, prepared in accordance with UNFCCC guidelines, often use the default emission factors rather than direct measurements at the source level. This creates uncertainty about the source, frequency and magnitude of emissions. Reports are submitted to the UNFCCC secretariat according to three available reporting levels in accordance with IPCC guidelines. Moving from tier 1 to tier 3 means greater methodological complexity and greater certainty in measuring methane emissions. In general, tier 1 methods are based on IPCC default emission factors, with activity data being the most basic and least disaggregated. Tier 1 reporting of coal methane emissions is still very common in several EU countries. The methods used in Tiers 2 and 3 tend to be more extensive, specific emission factors tend to be based on measurements and specific to the source, technology, region or country, and activity data tend to be more disaggregated. Tier 2 obliges the use of country-specific emission factors, while Tier 3 uses facility-specific data or measurements. Reporting at Tier 2, considered a higher-level method, for large sources of methane emissions is consistent with IPCC reporting guidelines. If emission sources have a significant impact on a country's overall greenhouse gas inventory in terms of either absolute levels, trends or uncertainties, then the IPCC proposes to apply higher-level methods to those sources. Both the estimation and reporting methods for methane emissions in the energy sector differ among EU countries. Data on international methane emissions are only marginally accurate. There are still many fossil fuel exporters who have not submitted full greenhouse gas inventory data to the UNFCCC [3].

The European Commission has held a stakeholders' consultation on the implementation of the Monitoring, Reporting and Verification (MRV) regulation based on the Oil and Gas Methane Partnership (OGMP). In the public consultation, 96% of respondents supported the introduction of MRV regulations for coal, with support from the coal industry. A number of methods and tools were used, including a public online consultation, in-depth interviews and three webinars with stakeholders, as well as a targeted consultation on the costs of implementing the MRV regulation. This was to ensure that data on the costs, social impacts and potential benefits of the initiative were included. As part of the public consultation, 80% of respondents expressed approval for the inclusion of measures to reduce methane emissions from coal mines in EU regulations. Support was expressed for the inclusion of Leak Detection and Repair (LDAR) obligations in EU regulations. 72% of respondents believed that Union regulations on methane emissions in the energy sector should also apply to companies importing or exporting fossil fuel energy to the EU. The regulation and its basic assessment are based on evidence from stakeholders during consultations held in the subject area, as well as special workshops, a literature review, analysis and modelling. To achieve the initiative's goals, variants, including preferred ones, have been defined in three policy areas.

The objectives of the variants in Policy Area 1 for coal are [3]:

- improving the accuracy of both monitoring and reporting of methane emissions in the energy sector,
- requiring operators to measure emissions in detail at the asset level,
- reporting of direct methane emissions from coal in the EU power sector,
- monitoring, reporting and verification obligations for coal, including indirect emissions.

The objectives of the options in Policy Area 2 for coal are:

- to mitigate methane emissions from coal in the EU power sector using leak detection and repair measures,
- banning atmospheric release and flaring of the gas.

The objectives of the options in Policy Area 3 for coal are:

- measuring, reporting and reducing methane emissions associated with fossil fuel consumption in the EU but occurring outside its borders,
- measuring and reporting, and achieving a certain amount of reduction in all methane emissions associated with fossil fuel consumption in the EU across the value chain,
- using diplomatic action to encourage countries to reduce methane emissions,
- creating a database to ensure transparency on methane emissions,
- using a tool to monitor high methane emissions globally.

In all EU countries, competent authorities will be responsible for monitoring and enforcing the application of the regulation, a list of which will be made public by the Commission [3]. At least one competent authority should be designated in each member state to supervise operators in effectively fulfilling the obligations established by the regulation. Union countries should inform the European Commission of the designation of such an authority and of any changes to it. Cooperation between competent authorities and with the Commission, possibly with authorities of third countries, is aimed at enforcing the application of the regulation. The Commission and all competent authorities should form a network of public authorities that work closely together and exchange information and best practices, as well as provide opportunities for consultation. Competent authorities should have the authority to conduct regular inspections to verify the enforcement by operators or mine operators of the requirements of the regulation. Inspections can be conducted on site or in the field and involve the examination of documentation and records for compliance with the requirements of the regulation, which document, among other things, the detection of methane emissions and measurements of methane concentrations. Mine operators and operators are obliged to enable or facilitate the performance of tasks by the competent authorities, especially in terms of providing access to facilities, documentation and records, as well as submitting emission reports to these authorities. If an inspection identifies a serious violation of the regulation's requirements, the operator or mine operator should be requested by the competent authorities to take remedial action. Operators, in order to ensure that all necessary actions assigned to them by the competent authorities are carried out within the designated or other agreed timeframe, should provide all necessary assistance to these authorities [3]. The relevant data from the inspection register should be made public according to Directive 2003/4/EC of the European Parliament and of the Council [30]. The competent authorities shall draw up programs of routine inspections after the first inspection, i.e. 18 months after the entry into force of the regulation. The interval between inspections may not exceed a period of two years. If the inspection finds a serious violation of the requirements of the regulation, the next inspection will be carried out before the expiration of one year. Additional inspections may be carried out, including in cases of non-compliance or justified complaints (a written complaint may be made to competent authorities by any natural or legal person claiming to have suffered damage as a result of violations of the Regulation's requirements by operators or mine operators). A report prepared by the competent authorities after each inspection shall be submitted to the operator concerned and, in the case of a complaint, to the complainant, and shall be made public within two months of the inspection (some information may not be disclosed for confidentiality reasons) in accordance with Directive 2003/4/EC. The report includes information on the legal basis of the inspection, the procedural actions performed, as well as the findings and recommendations for further action by the operator or mine operator. In order to implement the requirements of the regulation, operators and competent authorities should be given adequate time to take the necessary preparatory actions [3].

Verification of emission data will be the responsibility of independent accredited verifiers. Accreditation should be granted by a national accreditation body according to Regulation (WE) No. 765/2008 [31]. Reports submitted to verifiers by operators or mine operators will be evaluated for their compliance with the requirements of the regulation, including the amount of emissions. Verifiers will review the data sources and methods used, and may conduct on-site inspections to determine their reliability, credibility and accuracy.

The activities of verifiers will improve the reliability, independence and transparency of reported methane emission data, as well as the proper verification of such data given the level of detail and technical complexity of emission measurements. Until the Commission adopts European and international standards for quantifying methane emissions, verifiers shall base their activities on existing European and international standards for quantifying and verifying greenhouse gas emissions. If the assessment proves that the emission report meets the requirements of the regulation, verifiers shall issue a verification statement. When the assessment finds that the emission report does not meet the requirements of the regulation, the operator or mine operator shall be informed of this fact by the verifier, to whom he shall promptly submit a corrected report. Verifiers shall operate separately from mine operators and operators, among other things, verifiers shall not have relationships with mine operators and operators that would affect their independence and neutrality. Verifiers should obtain all assistance from mine operators and operators regarding verification activities, including access to facilities, documentation or records. The verifiers are independent of the competent authorities. The verification role for methane emissions data will be assigned to the International Methane Emissions Observatory (IMEO), especially with regard to the tasks outlined in Article 10 of the Regulation. The International Methane Emissions Observatory (IMEO) was established by the European Union in cooperation with the United Nations Environment Programme, the Climate and Clean Air Coalition and the International Energy Agency in October 2020. The IMEO is a body independent from the Union and is not subject to Union law. It was inaugurated at the G 20 summit in October 2021. The IMEO's activities are focused on collecting, determining, verifying and publishing methane emissions data in the energy sector. The Commission may provide the IMEO with methane emission data obtained from competent authorities. The IMEO will have the ability to compare this data with other sources, such as satellite data [3,32]. One of IMEO's tasks will be to establish a methane supply index, providing data on methane emissions from various fossil fuel energy sources from around the world [14]. Data would be obtained from estimates, source-level measurements, as well as satellite monitoring. This would allow conscious decision-making on fossil fuel energy purchases based on methane emissions from sources of such energy. Based on the publicly available information prepared by the IMEO, the Commission should address all deficiencies in the measurement, reporting and verification of methane emission data [3].

In active underground mines, the concentration of methane in the air is under constant monitoring due to the threat to human health and safety. Methane emissions from underground coal mines come mainly from ventilation and methane drainage systems, which are the two main ways of reducing methane concentrations in ventilation workings. In underground coal mines, mine operators carry out continuous measurement of methane emissions from ventilation shafts, using equipment with a methane concentration sensitivity threshold of at least 100 parts per million. In addition, monthly measurements are carried out on a sample basis. In the case of methane drainage stations, operators continuously measure the volume of methane released into the atmosphere and burned in the flare. If some of the equipment used for continuous measurement is out of service for a certain period of time, it is possible to estimate the data for this period proportionally on the basis of readings taken during their periods of operation. These devices must operate for more than 90% of their useful life for emission monitoring, except for downtime for recalibration. To estimate post-mining emissions, mine operators use post-mining emission factors, updated annually, based on coal samples specific to the deposits in concern and in accordance with relevant standards. Mine operators and operators of methane drainage stations are required to submit to the competent authorities a report containing annual data on methane emissions at the source level in accordance with the provisions of Article 24 of the Regulation. Operators shall ensure that these reports have been previously evaluated by verifiers and include a verification statement issued in accordance with Articles 8 and 9 of the Regulation. The report shall contain the information specified in Annex V, with Parts 1, 2 and 3 covering active underground coal mines, active open-pit coal mines and methane drainage stations, respectively. The report shall be prepared 12 months from the date of entry into force of the regulation, and thereafter by March 30 of each year. The competent authorities shall make the reports available to the public and the Commission within three months of their submission by operators in accordance with Article 5(4) of the Regulation [3].

In the case of abandoned mines, methane emissions come from ventilation shafts or pressure relief valves, among others. According to [33], even 10 years after closure, methane emissions from unflooded mines account for about 40% of the

emissions found during closure. In addition, differences in ownership and operation rights in the EU contribute to the patchy treatment of methane from abandoned mines. Member states are obliged to establish and make public a list of all closed and abandoned coal mines on their territory or under their jurisdiction by 12 months after the regulation enters into force. The list must contain at least the information specified in Annex VII, Part 1 of the Regulation. For closed and abandoned coal mines that ceased operations 50 years before the date of entry into force of the Regulation, methane concentration measuring equipment shall be installed on all elements listed in Annex VII, Part 1(v) until 18 months after the date of entry into force of the Regulation. If methane emissions are found at any of these elements, methane concentration measurements shall be taken at least once an hour in accordance with relevant standards. Measuring devices must have a sensitivity threshold of at least 10,000 parts per million and must operate for more than 90% of their useful life for emission monitoring, excluding downtime for recalibration. Reports on estimates of annual methane emission data at the source level, including the information contained in Annex VII, Part 3, shall be submitted to the competent authorities by 24 months from the date of entry into force of the regulation and thereafter by March 30 of each year. Prior to that, they shall be evaluated by verifiers and shall be accompanied by a verification statement issued in accordance with Articles 8 and 9 of the regulation. The reports are made available to the public and the Commission up to three months after their submission by operators. Conducting methane concentration measurements and preparing reports is the responsibility of mine operators for closed mines and of member states for abandoned mines. In order to mitigate methane emissions from abandoned coal mines, Member States shall draw up and implement a plan to reduce emissions. This plan shall be submitted to the competent authorities by 36 months from the date of entry into force of the regulation. The emission reduction plan must provide at least the information specified in Part 4 of Annex VII of the regulation [3].

As of January 1, 2025, there will be a ban on the release into the atmosphere and flaring of methane from the methane drainage stations. In the event of an emergency or malfunction, as well as necessary maintenance of the methane drainage system, operators will release methane into the atmosphere, provided that flaring is technically not feasible or threatens the safety of operations or personnel. Operators must notify the competent authorities of all cases of methane release into the atmosphere and flaring. The notification shall be made immediately after the occurrence of the event and no later than 48 h from the start of the event or from the moment the operator became aware of it. The notification must contain the information specified in Annex VI of the regulation. The relevant authorities shall make this information available to the public and the Commission on an annual basis. Venting of methane through ventilation shafts in coal mines emitting more than 5 Mg of methane/thousand Mg of coal mined, other than coking coal mines, shall be prohibited from 1 January 2027. Originally, the regulations specified emissions of more than 0.5 Mg of methane/thousand Mg of coal mined. Restrictions on the release of methane into the atmosphere from ventilation shafts in coking coal mines will be introduced on the basis of the Commission's adoption of a delegated act in accordance with Article 31 to supplement the regulation on this issue until three years after its entry into force. As of January 1, 2030, a ban will be imposed on the release into the atmosphere and flare of methane for the elements listed in Annex VII, Part 1(v). The exceptions to the use or reduction of emissions are their technical unfeasibility, a threat to environmental safety or operations or personnel. Mine operators or member states, in reports submitted to the competent authorities, must prove the necessity of the decision to release into the atmosphere or flare methane [3]. A regulation [28] for underground mining and related activities imposes an obligation to report releases of methane, among other things, if a threshold of 100,000 kg/year is exceeded.

Currently, the most favourable reduction in methane emissions can be achieved in active, closed or abandoned underground coal mines. For active, closed or abandoned open-pit mines, effective reductions in methane emissions are hampered by technological considerations. According to the EU greenhouse gas inventory, in 2019 active open-pit lignite mines emitted 166 thousand Mg of methane, while underground coal mines emitted 828 thousand Mg of methane, a difference of about 20%. Methane emissions from open-pit mines are rarely measured despite available technology. This is due to the difficulty of dispersing these mines over a wide area. Mine operators should measure methane emissions using basin-specific carbon emission factors in accordance with IPCC guidelines for national greenhouse gas inventories [3]. More precise results can be obtained by using methane emission coefficients specific to either the mine or the deposit, which is a result of the different methane content of

deposits in coalfields. These coefficients, which take into account methane emissions from surrounding layers, are determined by mine operators on a quarterly basis based on relevant standards. Proven recoverable balance resources of coalbed methane in Poland in 2021 amounted to 106,660.94 million m^3 [34].

Fossil fuel energy importers to the EU will be obliged to inform the competent authorities of member states of measures used by exporters to measure, report and reduce methane emissions. The information to be provided is contained in Annex VIII of the regulation. The information shall be submitted by nine months after the entry into force of the regulation and then by December 31 of each year. EU countries shall submit this information to the Commission by 12 months from the date of entry into force of the regulation and then by June 30 of each year, after which the Commission shall make this information public in accordance with Article 28. The Commission is authorized to amend the regulation with regard to the information to be submitted by importers. On or before December 31, 2025, the Commission will examine the enforcement of the requirements for importers in Article 27, taking into account, in particular, the provisions of paragraph 3. The information requirements for measurement and reporting levels will be the same for importers as for EU operators. The information will be submitted by EU countries to the Commission and will be used by the Union to establish and manage a database to ensure transparency on methane emissions until 18 months after the regulation enters into force. This database will contain the information given in paragraphs 1 and 2 of Article 28 of the regulation, including on fossil fuel energy imports into the Union (to be updated quarterly). This database should include detailed information on compliance with the scope of the standard adopted at the international or EU level by exporting coal companies. This information should express the degree of involvement of these companies in measuring, reporting and verifying methane emissions according to UNFCCC Tier 3 reporting methods. This database should represent the activities undertaken in measuring, reporting and reducing methane emissions by both companies in the Union and exporting companies. In addition, the database should include information on regulatory actions on measuring, reporting and reducing methane emissions taken by fossil fuel energy-producing countries. The database would serve as a source of information for importers, as well as other stakeholders and the public in deciding whether to purchase fossil fuel energy into the Union. The database will be available to the public free of charge on the Internet, at least in English [3].

In addition, the Union will establish a global tool for aerial monitoring of methane emitters from energy sources based on satellite data and input from several certified data and service providers, including the EU's Copernicus space program. The tool will be used to obtain information on the location, scale and repeatability of high-emitting methane sources. The global methane monitoring tool will be established by two years from the date of entry into force of the regulation. The tool will be publicly available and updated monthly. The increasing spatial and temporal resolution of satellite data will allow this tool to be used to monitor the effects of the regulation, as well as to catch shortcomings in its implementation. This tool will be used as a basis for bilateral dialogues between the Commission and interested countries. The scope of these dialogues would address possible scenario options for policies and measures on methane emissions. The Commission will alert a country when the tool detects a major new source of emissions, with the goal of raising awareness and promoting remedial action [3].

Measures concerning, among other things, obliging importers to report on exporters' measures to measure, report and reduce methane emissions, as well as the establishment of a database to ensure transparency on fossil fuel energy imports into the Union and the introduction of a global monitoring tool for methane emitters will form the basis of a method for gradually tightening measures on imports. The Commission, taking into account the work carried out by the IMEO, including the methane supply index, the database and the global monitoring tool for methane emitters, should evaluate the implementation of these measures. If necessary, the Commission should present the conclusions of the review with the aim of imposing more rigorous measures on importers and ensuring a comparable level of effectiveness in the monitoring, reporting, verification and reduction of methane emissions measures used in the third countries [3].

Member States should undertake to apply effective, proportionate and discouraging penalties for violations of the regulation and take all measures to implement them. Member states shall notify the Commission of the established penalty provisions by 3 months from the date of entry into force of the regulation, and shall immediately inform the Commission of any subsequent amendments to them. Penalties are devoted to Article 30 in Chapter 6 of

the regulation. A list of types of violations and criteria for the application of penalties, examples of which are provided in paragraph 2 of Article 30, should be established. Penalties may be in the form of fines and periodic penalty payments, as referred to in paragraph 2 of Article 30. Penalties should be appropriate to the type of violation, as well as the nature, seriousness and duration of the violation in question, the possible benefit to the operator, and the type and seriousness of environmental damage. The imposition of penalties by Member States should be made public, and in accordance with Union and national law, together with the applicable procedural guarantees and the principles of the Bill of Fundamental Rights [3].

The implementation of the obligations contained in the regulation [3] will likely oblige regulated operators to make investments. The costs resulting from these investments are to be taken into account when setting tariffs subject to efficiency rules. Therefore, based on the provisions in the Regulation [3], Regulation (EU) 2019/942 [35] should be amended. The amendment concerns the imposition of a requirement on the European Union Agency for Cooperation of Energy Regulators (ACER) to establish and make publicly available a set of indicators and relevant benchmarks. The set, which is to be updated every three years, is intended to compare the unit investment costs of similar projects for measuring, reporting and reducing methane emissions. The EC claims that most of the measures proposed under the regulation [3] are cost-effective for companies. In addition, the EC does not expect a significant impact of the proposed regulation on fossil fuel energy prices.

4. Conclusions

The European Green Deal aims to achieve climate neutrality for the European Union by 2050. Achieving this goal requires, among other things, a significant reduction in methane emissions from its three largest anthropogenic sources, namely agriculture, waste and the energy sector. In the European Union, the largest source of methane emissions from the energy sector are coal mines. For Poland, where most electricity is currently produced from fossil fuels, mainly from coal, reducing methane emissions from the power sector is a serious challenge. In the European Union, the largest methane emissions in the mining sector come from active and abandoned underground mines, followed by active open-pit mines and post-mining activities. In Poland, the largest methane emissions in the mining sector come from active underground mines and post-mining activities, followed by open-pit mines and abandoned underground mines. Methane can be recovered and used as an energy source. However, technologies for managing gas from ventilation shafts are very expensive and there are still some technical obstacles that have so far prevented their implementation in the mining sector.

On December 15, 2021 the European Commission introduced a draft regulation that contains provisions for the accurate measurement, reporting and verification of methane emissions in the energy sector in the Union, as well as the reduction of these emissions. Currently, there are no specific regulations in this regard for coal mines at the EU level. The regulation addresses, among other things, the need for a single energy market in the European Union, which is due to the transboundary extent of emissions and the lack of a coordinated regulatory approach between EU countries and sectors. Most methane emissions from fossil fuel energy consumed in the EU occur outside its borders. There is a lack of reliable information about the scale, origin and nature of these emissions. The draft regulation is still under discussion. A number of amendments have been submitted, including from Poland, taking into account the reality of the Polish mining industry.

During the publication work of this paper, the Council of Ministers adopted the Methane Regulation, which will be published in the Official Journal of the EU and will enter into force 20 days later.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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Conflict of interest

The authors declare no conflict of interest.

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