Abandoned Mine Methane Development of the Upper Silesian Coal Basin in the Light of the New EU Regulation on Methane Emission Reduction in the Energy Sector

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Abstract. More than 40 coal mines have been abandoned in the Upper Silesian Coal Basin (USCB) since the 1980s. Several of these mines were gassy but only seven have been selected as prospective for abandoned mine methane (AMM) production. The newly developed methodology, which is based on the post-mining emission prognosis, was used to estimate the AMM resource potential of the USCB. Based on this study, conclusions and recommendations for the future development of AMM in the USCB have been formulated. Appropriate changes in the law, proper planning of AMM recovery and estimating AMM resources before closing the mine are considered the most critical factors. Also, AMM development in Poland may be impacted by the new EU Regulation on Methane Emission Reduction. The provisions of this regulation require enormous inventory, record-keeping and logistic work as well as large financial expenditures for measuring methane concentrations for all mines, including non-gassy mines. The regulation applies to all coal mines, as long as 50 years have not passed since their closure, while it is assumed that methane emission from gobs in closed mines lasts approximately 15 years in the USCB mining conditions.

Introduction

When a mine is closed and subsequently abandoned, coal-related gas is a major hazard in terms of public safety (uncontrolled migration of gas to surface) and the environment (methane emission to the atmosphere). However, coal-related gas can also be a valuable energy source if properly and efficiently captured and used. Coal-related gas, commonly referred to as coalbed methane (CBM), includes all types of gas accumulations derived from coal, but, depending on the form of occurrence and gas extraction technology, it can be divided into naturally occurring virgin voalbed methane (VCBM) and anthropogenic gas accumulation that is formed as a result of coal mining, referred to as coal mine methane (CMM) (Fig. 1). CMM is gas released during coal mining, which is partially captured with

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the use of an underground drainage system, while about 2/3 of all gas released is vented into the atmosphere. When a gassy coal mine is closed, the remaining CMM gas is renamed as abandoned mine methane (AMM) (Fig. 1). It is a post-closure methane gas stored and released over many years in the area affected by mining, which can be extracted using surface-to-gob wells or, less frequently, using an existing underground methane drainage system.

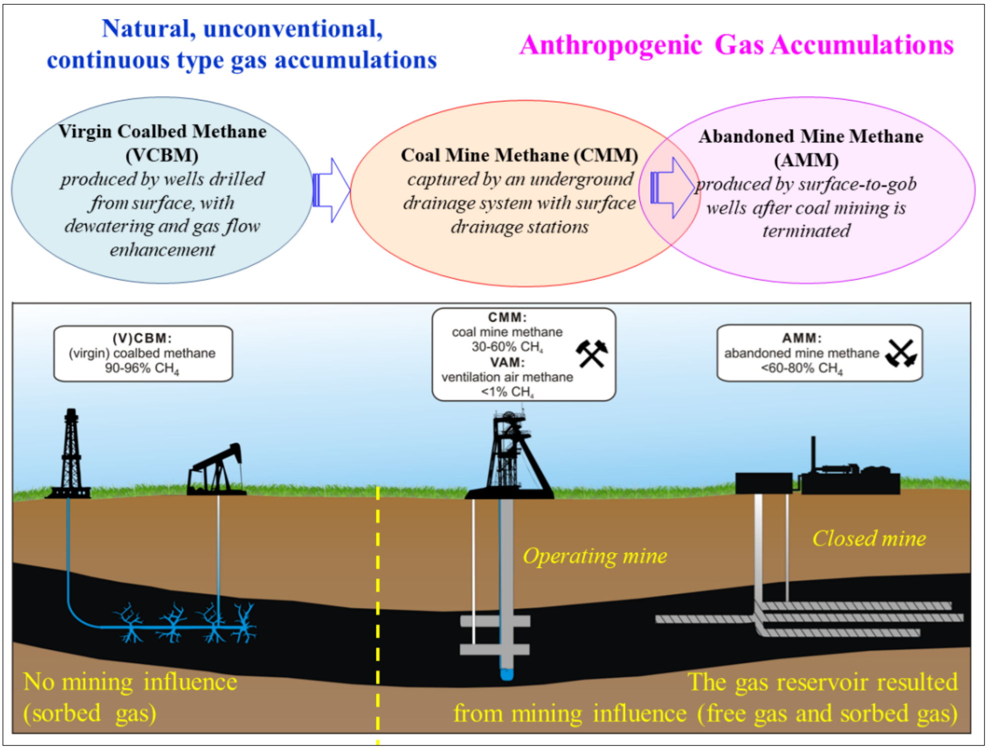

Fig. 1. Coal-related gas accumulations.

AMM of the Upper Silesian Coal Basin (USCB)

Golden age of the coal mining industry in the USCB came in the late 1970s and the early 1980s with coal production of more than 200 million tons. At that time, the number of operating mines reached its peak of around 80. Currently, there are 29 mines and coal production is less than 50 million tons. Between 1980 and 2020 more than 40 mines have been closed, and most of them were closed in the late 1990s and the early 2000s.

Since gas content of coal seams in the USCB largely depends on coal seams depth, early mine closures were associated with shallow coal seams which were non-gassy or slightly gassy. Of the total number of mines abandoned so far, only several were very gassy with an operating methane drainage system in place. Overall, nearly half of all abandoned mines are non-gassy (Fig. 2). Another important feature of the Upper Silesian mining conditions is the fact that the majority of mines are adjacent to one another (Fig. 2). Therefore, when a coal mine is closed, the gas released from coal seams in this mine is taken over by the ventilation and drainage system of an adjacent mine or mines. This way, the methane hazard of the closed mine is substantially reduced while its AMM becomes CMM transferred to another mine.

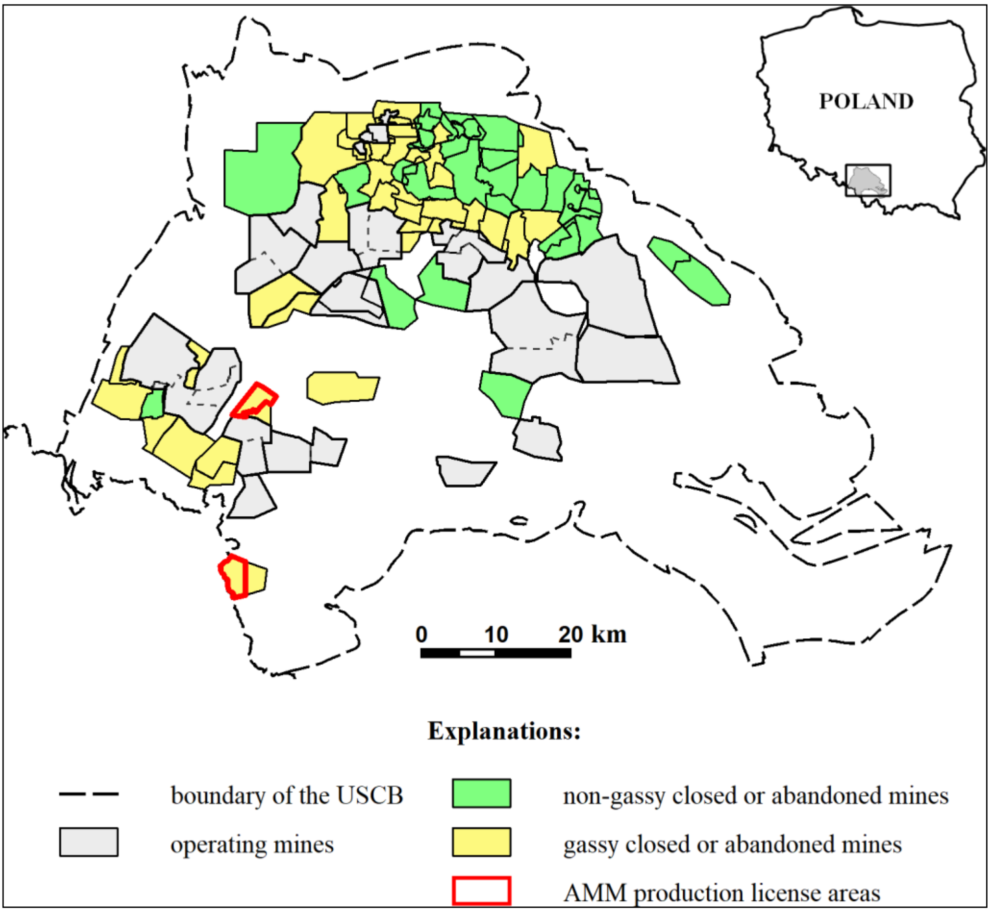

Fig. 2. Abandoned mines and operating mines in the USCB as well as license areas with documented AMM production.

At the same time, the Polish regulatory regime of coal-related gas has not been favorable for AMM development. AMM is treated on the same ground as VCBM which, unlike CMM, is considered petroleum, and, consequently, is governed by the same provisions as conventional oil and gas. Therefore, obtaining an AMM production license is complicated, time consuming and costly [1].

Considering all the above factors, there has not been a strong incentive to develop AMM resources in the USCB. So far, AMM development on a commercial scale has been marginal in the USCB. AMM gas has been produced in two abandoned mining areas (Fig. 2), on the basis of a production license, and its total annual production has amounted to 5 million m^3, which is less than 2% of all CMM captured by the methane drainage systems of operating mines.

Although very little of AMM resources has been used so far, some geological and mining data suggested that a considerable AMM potential may still exist in the USCB and can be a valuable source of energy.

Assessment of the AMM potential in the USCB

To assess the AMM potential of the USCB, the Upper Silesian branch of Polish Geological Institute – National Research Institute (PGI-NRI) was commissioned by the Polish government to conduct a research project entitled "Assessment of resource potential and feasibility of gas production from coal seams in the abandoned hard coal mining areas"

After a multi-stage analysis of nearly 50 abandoned coal mining areas, 11 of them were initially selected, whereas only 7 mining areas were considered prospective for AMM development in the USCB (Fig. 3).

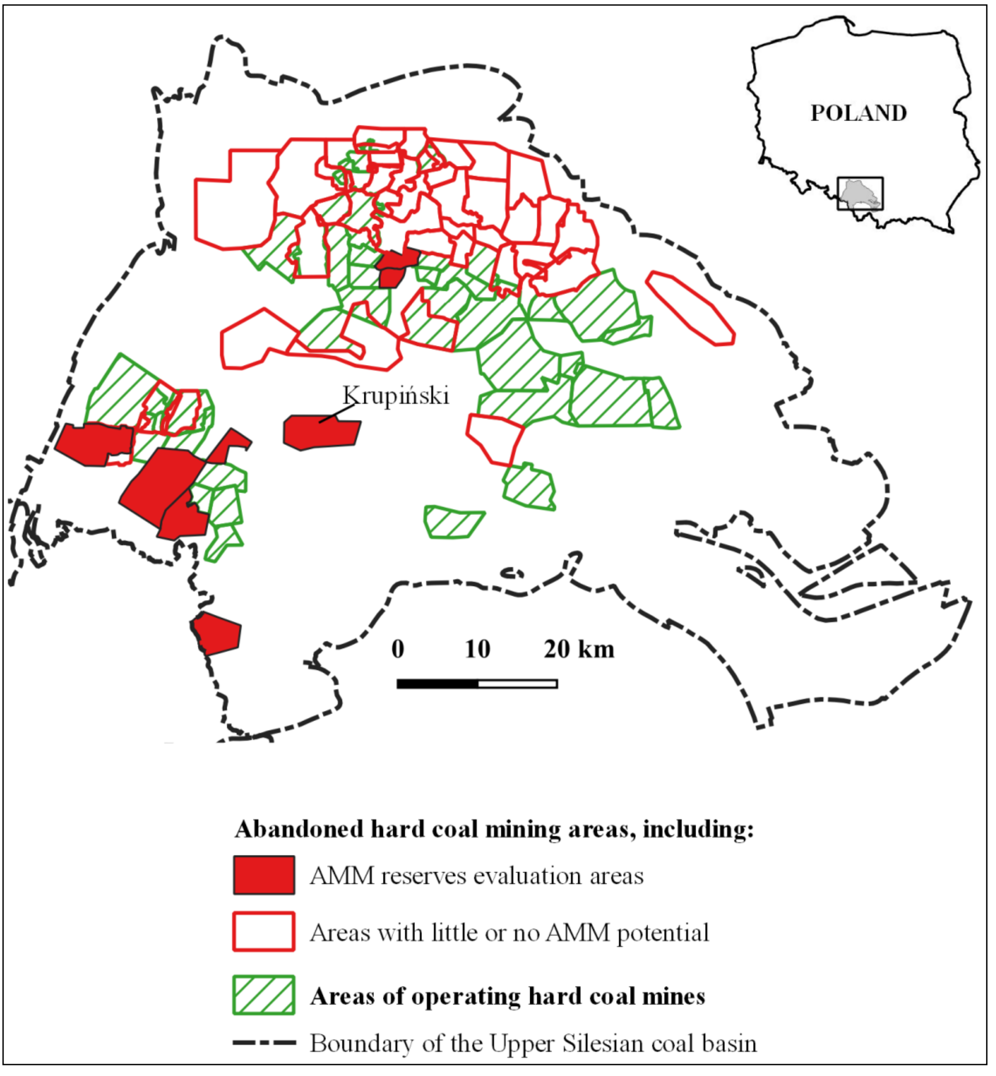

Fig. 3. Location of abandoned mining areas which are prospective for AMM development.

A significant technical barrier to economical utilization of the AMM potential is the uncertainty of AMM resource estimation. Therefore, while conducting the AMM assessment project, most of the efforts were spent on developing a proper methodology for AMM resource and reserves evaluation. Initially, it was found that the existing approach to AMM resource estimation in Poland, using a standard volumetric method adopted from the virgin coalbed methane (VCBM) resource evaluation, may result in a significant estimation error due to poor definition of an AMM reservoir.

In the first phase of the project, the existing estimation methodology has been adjusted in such a way as to limit AMM reservoir boundaries only to the coal seam drainage space which is equivalent to the post-mining relaxation zone. However, this did not bring the expected results, as it turned out that the extent of the coal seam drainage space cannot be unambiguously defined due to additional geological factors (secondary methane accumulation zone, presence of tectonic fractures) which strongly impacted the geometric model of determining the extent of the post-mining relaxation zone. Therefore, the estimation of resources using a volumetric method was dropped, and a new approach was proposed using a dynamic method, which gives approximate, but much more reliable results in the geological and mining conditions of the USCB.

The new methodology for AMM resource estimation, which draws from the experience in forecasting methane emissions to the atmosphere from closed mines in the United States, entails total post-mining methane emission prognosis based on a hyperbolic decline curve against time [2], [3]. The methane emission at the end of coal mining is assumed as the starting point of the decline curve, and then the curve fit is calibrated using the measured post-mining methane emissions. Assuming the time of the expected AMM production (30 years is used), the total recoverable resource of AMM is estimated.

Due to the geological and mining conditions as well as the quality and availability of data, the Krupiński mine was treated as a case study, on the basis of which the new methodology for AMM resource estimation in the USCB was developed. In this particular case study, the decline curve fit was performed for the 5-years post mining emission data from the starting point - methane emission rate at the end of mining. The estimated initial recoverable resource volume of methane was 249 million m^3 (Fig. 4). However, the mine was planned to be flooded, so the post-mining emission prediction had to be corrected for flooding. Therefore, the actual emission prediction (potential AMM reserves) amounts to 139 million m^3 (Fig. 4). Taking into account the actual post-mining emission of methane by the year 2021, the remaining AMM reserves amount to 60 million m^3 (Fig. 4).

The complete assessment of the AMM resource potential also included the estimation of the initial coal-related gas volume (CMM and AMM combined) within the anthropogenic reservoir of this coal mine and how all historical methane emissions developed with time. The total methane gas actually released while coal mining, which is referred to as CMM, was estimated at 1.9 billion m^3 (Fig. 5). Only about 1/3 of CMM gas was captured and used, while the remaining gas volume is vented into the atmosphere. After coal mining was terminated, methane emission continued and was measured for 5 years during the process of mine closure. These data were used to predict the post-mining methane emission using a decline curve fit (Figs 4 and 5). The result of post-methane emission prediction is the total recoverable resources or the initial AMM reserves, while the remaining AMM reserves continuously change with time depending on the date from which the AMM production is planned to commence.

As a result of the multi-stage study of all gassy abandoned mines in the USCB, the newly developed methodology was used to estimate methane resources and reserves for the seven coal mining areas considered prospective for AMM development. The total initial AMM reserves for all the prospective areas amounted to 833 million m^3, of which 604 million m^3 was already released prior to the date of estimation (the end of 2020) and indicates the total depleted AMM resource or past methane emissions (Tab. 1).

The remaining 229 million m^3 of the initial AMM reserves indicates the remaining AMM reserves or future emissions that can be captured and used from 2021 onwards (Tab.1). It is worth noting that of this 604 million m^3 of AMM already released only 170 million m^3 was officially captured and used, while 426 million m^3, i.e. 70% of the past emissions, has not been captured in a controlled manner, but has been taken over by the ventilation and methane drainage systems of the adjacent active mines and/or dispersed in the rock mass. This represents a lost resource potential of methane that was to a large extent emitted into the atmosphere.

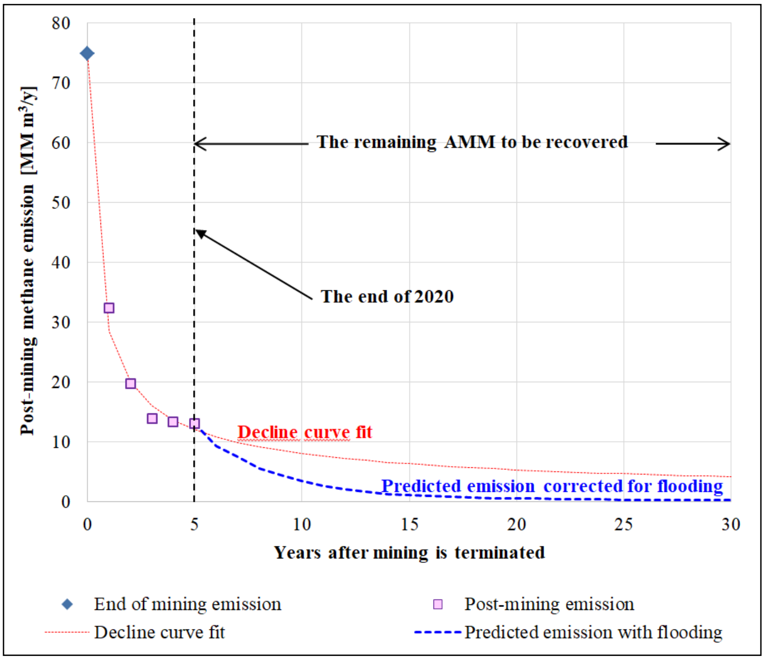

Fig. 4. Post-mining methane emission prediction for the Krupiński mine case study.

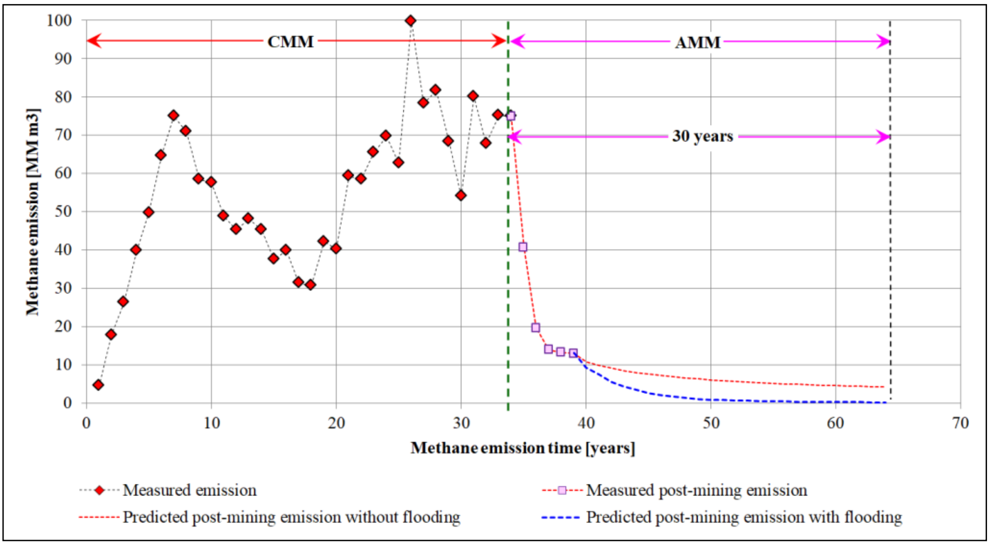

Fig. 5. Methane emission during mining and post-mining emission prediction showing the total coal-related gas potential (CMM+AMM) within the anthropogenic gas reservoir of the Krupiński mine.

Additionally, the total amount of methane emissions during coal mining for the prospective areas was estimated, which represents the depleted CMM resource amounting to a total of over 9 billion m^3 (Tab. 1). Thus, the total emission of CMM and AMM combined, which represents the total resource of these anthropogenic methane reservoirs, amounts to almost 10 billion m^3.

Table 1. AMM reserves and CMM gas volume for the prospective abandoned mining areas of the USCB estimated using the new methodology.

Mine (coal deposit)	Mining period	Total CMM released	Initial AMM reserves (as per prognosis)	Total AMM released by 2020 (as per prognosis)	AMM Reserves (remaining)
	from - to	MM m^3	MMm^3	MMm^3	MMm^3
Krupiński	1983 - 2017	1870	**139**	78	**60**
Śląsk (+Śląsk Pole Panewnickie)	1974 - 2017	488	**19**	5	**14**
Anna (Anna+Anna 1)	1955 - 2012	422	**45**	22	**23**
1-Maja (Marcel-Ruch 1 Maja)	1960 - 2000	2676	**198**	153	**45**
Moszczenica	1964 - 2000	3159	**286**	222	**65**
Morcinek (Kaczyce)	1987 - 1998	195	**76**	63	**14**
Żory	1980 - 1996	259	**69**	60	**9**
Total		9070	**833**	604	**229**

Prospects for the development of AMM in the USCB

The results of this comprehensive research project on the AMM resource potential in the USCB, conducted by the Upper Silesian Branch of PGI-NRI, demonstrated that the estimated recoverable resource volume of existing AMM is significant and AMM development has to be expedited. At the same time, future AMM development in the USCB is also worth considering. Currently, there are 29 operating mines in the USCB and most of them are gassy with the use of methane drainage systems because the depth of mining in the USCB gradually increases contributing to the increase in gas content of coal seams. Within the next 20 years, in accordance with the current climate policy, at least half of the currently operating mines in Poland will be closed. Therefore, there will be a necessity and a good opportunity for AMM development.

Based on the PGI-NRI project findings, important conclusions and recommendations were formulated for the rational and effective use of the existing and future AMM resources. These conclusions and recommendations are aiming at improving the efficiency of AMM utilization and removing barriers in AMM development. The most important conclusions and recommendations are as follows:

1. Planning of AMM production should be started well in advance. It is necessary to conduct constant monitoring of methane emissions during mining. While preparing the mine decommissioning plan, the future AMM resources should be estimated and the AMM development plan should be made. This plan should include: estimating the extent of the de-stressed zone, delineating potential methane reservoirs for a future AMM production, and, if possible, adaptation of the existing methane drainage system for a future AMM production.
2. Considering a rapid decrease in methane emissions over time, and, as a consequence, a significant depletion of AMM reserves in the first few years of the AMM potential production (after the cessation of coal mining), it is advisable that potential investors

obtain an AMM production license and start methane extraction immediately after the termination of coal mining.

3. A significant technical barrier to economical utilization of the AMM potential is the uncertainty of AMM resource estimation. Although the new approach to AMM resource evaluation has been developed by PGI-NRI, the existing evaluation procedures can still be officially used. It is advisable that the existing approach to AMM resource evaluation is thoroughly revised and newly developed procedures for evaluating and estimating methane resources from coal deposits are implemented.
4. Most of recommendations stated above, require appropriate changes to the existing Polish regulations, including the separation of two different types of methane accumulation: VCBM and AMM. AMM, as a distinct type of gas accumulation, should be excluded from hydrocarbon jurisdiction and be subject to separate regulations which will facilitate AMM development.

The impact of the new EU regulation on the AMM development in the USCB

New circumstances that start to play a significant role and may have a considerable impact on the AMM development appeared together with the draft Regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector, announced in December 2021 [4].

For the first time at the EU level, this regulation, being a single legal framework, is applied to monitoring, reporting and mitigation of methane emissions in the energy sector, including the coal sector. The methane emissions reduction procedures to be implemented in underground coal mines covers all operating mines as well as closed and abandoned mines. The regulation also provides for a strict package of sanctions in the event of non-compliance with its provisions.

With regard to methane emissions from closed and abandoned underground mines, the most important requirements of the Regulation are as follows [4]:

- within 1 year – setting up an inventory of all closed and abandoned coal mines where operations have ceased within the last 50 years; the inventory shall contain: mine boundaries, schemes of mine workings, results of methane concentration measurements at all emission sources (including: inoperative shafts, all unused methane capturing installations);
- within 2 years – installation of measuring equipment on all of the above-mentioned elements in closed or abandoned mines where operations have ceased within the last 50 years and where methane emissions were found to exceed 0.5 tons of methane per year;
- within 3 years – development and implementation of a mitigation plan to address methane emissions from closed and abandoned coal mines, which is submitted to the competent authorities;
- after 2030 – prohibition on methane emissions to the atmosphere from closed and abandoned coal mines.

The monitoring and reporting of methane emissions in the hard coal sector, as part of the EU legal framework, is in principle adequate and can bring benefits both from the point of view of environmental and climate protection, public safety, and can also be beneficial for the development of AMM. In this sense, the provisions of the Regulation are reasonable, as long as they do not generate a burden which may bring some adverse effects.

The EU regulation will bring some challenges, especially for the Polish government, which may affect the development of AMM in the USCB. However, it is difficult to predict the real outcome of these challenges at this moment. Some major challenges for the Polish government will include:

- The regulation is applicable to all closed and abandoned mines, whereas half of the abandoned mines of the USCB were non-gassy and thus should be excluded;
- Bearing in mind that most of abandoned mines were decommissioned more than 20 years ago and the Regulation is applicable to all mines closed within the last 50 years, the period of 50 years may be too long for the USCB mining conditions because some scientific evidence show that methane emission from gobs lasts approximately fifteen years [5].
- Setting up an inventory for such a large number of closed and abandoned coal mines will be a difficult task to perform because of scarcity of reports and data as well as frequent changes of mining area boundaries, operators' names etc.; this procedure may also be superfluous for non-gassy mines;
- Installation of appropriate measurement equipment and performing regular measurements with required accuracy for all potential emission sources will be costly and may last far too long – at least 6 or 12 years depending on the mine status: flooded or dry respectively.

Summary

Abandoned mine methane (AMM) can be distinguished as a separate type of coal-related gas accumulations, which is contained within a post-mining anthropogenic gas reservoir with CMM being its precursor.

A large number of mines that have been abandoned for the last 40 years in the Upper Silesian coal basin (USCB) may indicate a considerable AMM potential in this basin. However, AMM has been recognized as a mining hazard (rather than an energy source), which can be easily reduced when taking over by the methane drainage and ventilation systems of adjacent operating mines and thus its development has been marginal in the USCB. Moreover, neither AMM resources nor feasibility of AMM production has been assessed until recently. Therefore, the Upper Silesian branch of PGI-NRI conducted a comprehensive research project in order to evaluate AMM potential in the USCB and assess the feasibility of AMM development. In this study, after a multi-stage analysis, 7 abandoned coal mining areas were considered prospective for AMM development.

Based on the initial finding of the AMM estimation process, it was demonstrated that the existing approach to AMM resource estimation in Poland using a standard volumetric method, may result in significant estimation errors. A new methodology for estimating AMM recoverable resources was proposed based on a hyperbolic emission decline curve as a function of time after the end of coal mining. This approach was applied for the AMM resource estimates of the prospective abandoned coal mining areas in the USCB. The total recoverable resource of AMM, estimated for the seven prospective areas, amount to 833 million m^3, while the total remaining AMM reserves, as of the end of 2020, is 229 million m^3.

Also, this study was used to formulate important conclusions and recommendations with a view to prompting the rational use of AMM. Appropriate changes in the law, proper planning of AMM recovery and estimating AMM resources before closing the mine are considered the most critical factors.

The recent introduction of the draft Regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector may also have a considerable impact on the AMM development in the USCB. The regulation in principle can bring benefits both from the point of view of environmental and climate protection, public safety, and can also be beneficial for the development of abandoned mine methane. On the other hand, it may bring some adverse effects and challenges which may pose a threat to AMM development.

The provisions of the regulation concerning closed and abandoned mines require enormous inventory, record-keeping and logistic work as well as large financial expenditures for measuring methane concentrations for all coal mines, including non-gassy mines. The regulation applies to all coal mines, as long as 50 years have not passed since their closure. In the USCB mining conditions, it is assumed that methane emission from gobs in closed mines lasts approximately fifteen years.

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