Greenhouse gas emissions inventory in a coal mining region

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Abstract. The estimate of greenhouse gas (GHG) emissions at the regional level was carried out. The volumes of greenhouse gas emissions were set aside by sectors “Power generation”, “Industrial processes and products use”, “Agriculture, forestry and other options of land use”, “Wastes”. The possibilities of reducing GHG emissions in the “Power generation” sector by replication of coal mine methane (CMM) processing technologies in modular boiler-houses and gas-generating container type stations aimed for thermal and electric power production are considered.

1. Introduction
In the process of underground coal mining, direct GHG emissions – coal mine methane – are emitted into the atmosphere. The main source of them are coal mine methane (CMM) emissions [1, 2]. Various technologies for utilization methane from coal mines exist, including thermal and electric power generation [3, 4, 5, 6]. In the coal industry, an important factor contributing to the GHG emissions reduction technologies implementation is the assessment of projects economic efficiency of [7, 8, 9]. The creation of additional economic benefits for the project initiator will facilitate the introduction and replication of approved GHG emissions reduction technologies in coal industry.

2. Main part
The GHG emissions management system is a multilevel one: enterprise – region – macreregion – federal level. At the enterprise level, the inventory of GHG emissions is regulated by regulatory documents of the Russian Ministry of Natural Resources. At the same time, each enterprise contributes to the greenhouse gas emissions amount at the regional level. The ministry approved guidelines for conducting an annual inventory of greenhouse gas emissions at the regional level too. At the Russian Federation level, a national inventory report of anthropogenic emissions from sources and their removals by GHG sinks is compiled annually.

The GHG inventory at the regional level includes the assessment method selection, the collection of activity data, emission factors and other parameters, emission estimates, monitoring and ensuring the quality of work performed, validation (verification) of the undertaken calculation, estimate of their uncertainty and, finally, preparation of the record in the form of GHG inventory report and a set of standardized reporting tables. The inventory of GHG emissions at the regional level is carried out in four sectors, combining relevant processes, sources and sinks:

- “Power generation”;
- “Industrial processes and products use”;
- “Agriculture, forestry and other options of land use”;
“Wastes” [10].

Calculation of emissions volume is done for the following greenhouse gases:
- carbon dioxide (CO₂);
- methane (CH₄);
- nitrous oxide (N₂O);
- nitrogen trifluoride (NF₃);
- hydrofluorocarbons (HFCs);
- perfluorocarbons (PFCs).

Each economic sector consists of separate categories and subcategories of sources. The category that has a significant impact on the cumulative greenhouse gas emissions by the absolute value (emission level), trends, or uncertainties in estimates of its magnitude in the Inventory is called the key (main) category. When vehicles burn various types of motor fuels, they produce direct greenhouse gases of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O).

Fugitive emissions include emissions from the production, storage, primary processing, transportation and consumption of oil, coal and gas, as well as from fuels combustion in cases when the released energy is not used (for example, during coal mining and transportation, etc.) In the Russian Federation, coal is one of the main energy resource.

The record of methane emissions accompanying coal mining and processing is important for developing measures to improve the coal mines degasification efficiency, as well as for estimating cumulative coalbed methane emissions (CBM), the data of which should be included in the National reports on GHG emissions.

Geological processes of coal formation lead to the emerging of methane (CH₄), and also carbon dioxide (CO₂) may be present in some coal strata. Coal seams contain relatively small volumes of free CH₄, that are mainly absorbed in a solid carbon-gas solution or adsorbed on the surfaces of macromolecules and micro fractures. There is a dynamic equilibrium between free and bound methane in in-situ coal seams conditions, which is disturbed when coal seams are uncovered and mined. [10].

CH₄ is the main greenhouse gas that is released during coal mining and subsequent handling of coal.

Fugitive GHG gas emissions from underground and opencast coal mining occur as a result of the following processes:

1. Coal mining. Coal deposits development leads to the gaseous CH₄ release from the developing coal seam and from the surrounding strata, as a result of which gas migrates into underground mining workings (the underground mining method) or directly into the atmosphere (the open cast mining method). CH₄ is the main greenhouse gas that liberates during coal mining and its subsequent handling. The amount of CH₄ released is characterized by the term total methane emissions. Absolute methane emissions is a CH₄ flow rate per time unit, and relative methane emissions is a ratio of gas released volume over a given time period to a ton of coal mined over the same period. Being derivatives of the methane content of a particular coal seam, methane emissions indices are quite constant in time. Each coal basin has certain values of coal seams methane content, which increases with the depth of coal seams bedding due to the growth in sorption ability of coal and variation in its porosity [11]. The coal seams methane content and methane emissions indices of coal mines are under constant instrumental control by engineering services that ensure the underground work safety.

2. Subsequent handling of coal. Not all gas is released during the coal seam mining process: as a rule, coal continues to liberate gas after being mined, but more slowly than during the process of mining. Emissions from the subsequent coal processing and its transportation are called emissions from subsequent handling of coal.

3. Low temperature oxidation. These emissions occur as a result of coal natural oxidation by atmospheric oxygen, which results in a negligible amount of CO₂.
4. Coal spontaneous combustion. The process of low-temperature oxidation occurs with the formation of a certain amount of heat (self-heating). When critical temperatures are reached, spontaneous combustion of coal occurs. Spontaneous combustion is characterized by a rapid oxidation (combustion) reaction and a high rate of \( \text{CO}_2 \) formation, sometimes visible fire is observed. The spontaneous combustion of coal can be both natural and man-made, i.e. associated with activities in coal industry. It should be noted that within the framework of Methodological Recommendations, only anthropogenic spontaneous combustion is considered.

After the deposit depletion, closed coal mines may continue to release methane. For safety reasons, in order to prevent methane formation and its release into the atmosphere from closed mines when coal mining process is terminated, non-operating underground coal mines in Russia are flooded. According to the IPCC, flooded coal mines are not sources of methane emissions and, accordingly, are not considered in the Methodological Recommendations.

The determination of fugitive greenhouse gas emissions associated with coal mining was carried out in accordance with Level 2 of the Methodology that considers regional emission factors [10]. Calculation of fugitive emissions initiated by mining, processing, storage and transportation of coal in the framework of compiling regional inventories was made for two categories of greenhouse gases sources related to surface and underground coal mining methods (table 1).

| Year | Underground coal mining | Subsequent handling of coal | Surface coal mining | Total \( \text{CH}_4 \), (thou t) | \( \text{CH}_4 \) emissions aimed for Cadastre entry (thou t) |
|------|-------------------------|-----------------------------|---------------------|-------------------------------|-------------------------------------------------|
| 1990 | 851.799 167             | 162.764 172                 | 226.384 290         | 1240.947 62                   | 1240.947 6                                    |
| 2014 | 840.409 193 6           | 160.587 744                 | 482.400 770 5      | 1483.397 708                   | 1483.397 7                                    |
| 2015 | 802.485 042 9           | 153.341 091                 | 514.061 553 5      | 1469.887 687                   | 1469.887 7                                    |
| 2016 | 855.981 521 2           | 163.563 348                 | 534.942 974 5      | 1554.487 844                   | 1554.487 8                                    |
| 2017 | 892.910 574 5           | 170.619 855                 | 576.940 919 5      | 1640.471 349                   | 1640.471 3                                    |
| 2018 | 940.990 819 7           | 179.807 163                 | 611.041 541         | 1731.839 524                   | 1731.839 5                                    |

Greenhouse gas emissions in the “Power generation” sector are represented by \( \text{CO}_2 \), \( \text{CH}_4 \), \( \text{N}_2\text{O} \) emissions from fuel resources combustion to generate heat and electricity, as well as from motor fuels burning by transport, \( \text{CO}_2 \) and \( \text{CH}_4 \) from fugitive emissions (figure 1).

![Figure 1. The structure of greenhouse gas emissions in the region by sector “Power generation”.](image-url)
Time lines of emission inventory are an important part of GHG inventory of the Russian Federation constituent entity, as they show historical trends in emissions and indicate the effectiveness of mitigation strategies.

The GHG emissions inventory results and sinks in Kemerovo region are presented in table 2.

| Year | Power generation (thou tСО₂) | Industrial processes and products use (thou tСО₂) | Agriculture (thou tСО₂) | Waste (thou tСО₂) | Total GHG emissions (thou tСО₂eq) | Forest land sinks (thou tСО₂) | Cumulative GHG emissions with regard of sinks (thou tСО₂eq) |
|------|-----------------------------|-----------------------------------------------|------------------------|-----------------|-------------------------------|--------------------------|---------------------------------|
| 1990 | 136 669.28                  | 32 721.21                                     | 23 396.54              | 355.12          | 193 142.15                   | -                        | 193 142.15                      |
| 2014 | 94 301.28                   | 26 259.93                                     | 11 605.94              | 734.7           | 132 901.87                   | 10 976.23                | 121 925.62                      |
| 2015 | 94 500.82                   | 25 793.36                                     | 11 975.24              | 744.13          | 133 013.55                   | 11 108.97                | 121 904.58                      |
| 2016 | 95 876.27                   | 24 568.92                                     | 11 930.49              | 752.07          | 133 127.76                   | 11 206.88                | 121 920.87                      |
| 2017 | 97 477.99                   | 25 406.06                                     | 11 768.01              | 756.26          | 135 408.32                   | 11 454.61                | 123 953.71                      |
| 2018 | 97 376.16                   | 24 532.72                                     | 11 537.23              | 761.58          | 134 207.69                   | 11 534.80                | 122 672.89                      |

The sector “Industrial processes and products use” includes the estimate of the following GHG emissions: CO₂ in products production from mineral raw materials, as well as glass cement, ceramic products; CO₂ and N₂O in the chemical industry and CO₂, CH₄ and PFCs (CF₄ and C₂F₆) in the metallurgical industry.

Absolute indicators for reducing greenhouse gas emissions for each sector of the economy are calculated for each category of emissions and are measured in tons of CO₂ equivalent. When calculating the listed indices, the level of GHG emissions in 1990 should be taken as a base level.

Reducing greenhouse gas emissions in “Power generation” sector is possible due to the introduction of technologies for utilization degasification systems methane and ventilation air methane (VAM) from exhaust air jets with its subsequent use to generate electric and thermal power.

When implementing measures to reduce coal mine methane (CMM) emissions, it is necessary to take into account that for a coal mining company, in addition to environmental, the economic component is also important when utilization technology is introduced. First of all, the decision must be based on availability of specified methane (conditioned methane) in the coal rock massif. The mines operating in the south of Kuzbass are characterized by significant CH₄ resources, for example: at “Yerunakovskaya-VIII” mine (JSC “OCC Yuzhkuzbassugol”) it is possible to introduce a container type heat power station (CHPS) and block-modular boiler houses (BMBH), at LLC “Alardinskaya Mine” (JSC “OCC Yuzhkuzbassugol”) it is possible to implement a CHPS, on LLC “Yubileynaya Mine” (JSC “TopProm” it is possible to install CHPS and block-modular boiler houses, at the mine “Raspadskaya” (PJSC “Raspadskaya”) the possibility exists for CHPS installation.

The presence of methane collectors within the mining allotment is not always the absolute basis for the successful use of CH₄ utilization facilities. It is also important to consider that distant location of methane collectors from the consumer does not lead to the loss of economic effect from project realization, due to undertaken construction and technological works to ensure conditions for gas transportation or generated energy supply to the power grid. In addition, the potential of individual reservoirs, mining development plans, and operating conditions on the surface should be considered. The ability to take these factors into account in the planned technological process becomes evident thanks to possessed experience in implementing coal mine methane utilization projects.
On the basis of actual experience of CH4 use on JSC “SUEK-Kuzbass”, implying the operation of CHPS and BMBH at “N.a. C.M. Kirov” and “Komsomolets” mines, the introduction of new installations is possible at production units of this company. For example, at “After C.M. Kirov” mine the installation of additional cogeneration plants is possible, for the mine “V. D. Yalevskogo” it is also possible to introduce a CHPS, for the “Polysaevskaya” mine options with conversion of boiler houses to methane use are possible.

In general, considering the above said, the definition of sites for implementation of measures to reduce CMM emissions requires a separate set of scientific and technical work, including a comprehensive analysis of mining allotment parameters of coal mines under consideration.

The GHG emissions estimate was undertaken for four sectors: “Power generation”, “Industrial processes and products use”, “Agriculture, forestry and other options of land use” and “Waste”.

3. Conclusion

According to the inventory results of GHG emissions and sinks, excluding sinks amounted to 193 142.15 thousand tons of CO2eq in 1990; in 2014 – 132 901.87 thousand tons of CO2eq; in 2018 – 134 207.69 thousand tons of CO2eq.

The largest volume of GHG emissions for the reporting period in the whole for the region was made by the «Power generation» sector (1990 – 70.76%; 2014 – 70.96%; 2015 – 71.05%; 2016 – 72.02%; 2017 – 71.99%; 2018 – 72.56%), and the smallest – by the “Waste” sector (1990 – 0.18%; 2014 – 0.55%; 2015 G. – 0.56%; 2016 – 0.56%; 2017 – 0.56%; 2018 – 0.57%).

In 2018, GHG emissions excluding sinks in the “Power generation” sector amounted to 97 376.16 thousand tons of CO2eq, including: “stationary fuel combustion” – 47 131.39 thousand tons of CO2eq; “Emissions from transport” – 5 962.27 thousand tons of CO2eq; “Fugitive emissions” – 44 282.51 thousand tons of CO2eq.

According to the inventory results, actual emissions in 2018 are 69.49% of the 1990 level, which indicates the implementation of the Russian Federation Government recommendations on reducing greenhouse gas emissions by 2020 to 75% of the 1990 level in the region in compliance of the Decree of the President of the Russian Federation as of September 30, 2013 No. 752 “On reducing greenhouse gas emissions”.

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