4th International Workshop
on Uncertainty in Atmospheric Emissions
7-9 October 2015, Krakow, Poland

PROCEEDINGS

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About the Workshop

The assessment of greenhouse gases and air pollutants (indirect GHGs) emitted to and removed from the atmosphere is high on the political and scientific agendas. Building on the UN climate process, the international community strives to address the long-term challenge of climate change collectively and comprehensively, and to take concrete and timely action that proves sustainable and robust in the future. Under the umbrella of the UN Framework Convention on Climate Change, mainly developed country parties to the Convention have, since the mid-1990s, published annual or periodic inventories of emissions and removals, and continued to do so after the Kyoto Protocol to the Convention ceased in 2012. Policymakers use these inventories to develop strategies and policies for emission reductions and to track the progress of those strategies and policies. Where formal commitments to limit emissions exist, regulatory agencies and corporations rely on emission inventories to establish compliance records.

However, as increasing international concern and cooperation aim at policy-oriented solutions to the climate change problem, a number of issues circulating around uncertainty have come to the fore, which were undervalued or left unmentioned at the time of the Kyoto Protocol but require adequate recognition under a workable and legislated successor agreement. Accounting and verification of emissions in space and time, compliance with emission reduction commitments, risk of exceeding future temperature targets, evaluating effects of mitigation versus adaptation versus intensity of induced impacts at home and elsewhere, and accounting of traded emission permits are to name but a few.

The *4th International Workshop on Uncertainty in Atmospheric Emissions* is jointly organized by the *Systems Research Institute of the Polish Academy of Sciences*, the Austrian-based *International Institute for Applied Systems Analysis*, and the *Lviv Polytechnic National University*. The 4th Uncertainty Workshop follows up and expands on the scope of the earlier Uncertainty Workshops – the *1st Workshop* in 2004 in Warsaw, Poland; the *2nd Workshop* in 2007 in Laxenburg, Austria; and the *3rd Workshop* in 2010 in Lviv, Ukraine.

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Spatial inventory of GHG emissions from fossil fuels extraction and processing: An uncertainty analysis

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Abstract

This article discusses bottom-up inventory analysis for greenhouse gas (GHG) emissions from fossil fuels extraction and processing in Poland. The approaches to modelling geo-referenced cadastres of emissions from fossil fuels extraction and processing are described as well as methods of uncertainty reduction using the knowledge on spatial greenhouse gas emissions distribution. The results of GHG emissions spatial inventory contain the information on geographical coordinates of emission sources. This information is useful for indication the largest emission sources. In this article we present the obtained results on spatial GHG inventory from fossil fuels extraction and processing in Poland, based on IPCC guidelines taking into account locations of emissions sources, official statistics and digital maps of territories investigated. Monte-Carlo method was applied for a detailed estimation of GHG emissions and results uncertainty in the main categories of analyzed sector.

Keywords: spatial GHG inventory, extraction and processing of fuels, fugitive greenhouse gas emissions, uncertainty

1. Introduction

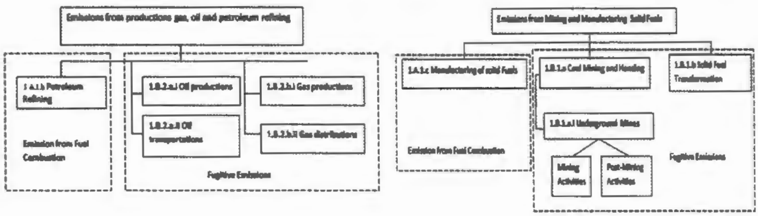
Mankind has faced the most critical global environmental problem – climate changes. These changes are very likely due to increase of the concentration of anthropogenic greenhouse gases (GHG) in the atmosphere, especially for fossil fuel using in the energy sector and emissions in many other categories of anthropogenic activity. Spatial inventory allows us to determine the largest sources of emissions, and it is useful for planning the environmental protection measures on the regional level. Inventory of GHG emissions from fossil fuels extraction and processing in Poland was carried out only at the national level without identification of emissions sources location [3,11]. In this paper we present the mathematical models of emission processes of GHG emissions from fossil fuels extraction and processing at the level of separate emission sources.

The value of emissions we cann`t measure, only evaluate, that is why we talk about uncertainty of the results [5]. The assessment of the uncertainty of GHG inventory at the country level and level of individual emission sources is an important task. It play very big role in the trading of GHG.

2. Spatial GHG inventory

The spatial inventory includes determination of location emission sources and assessment emissions from these sources. Unlike the traditional inventory at the country level, the spatial one takes into account the location and specifics of each source of emission, which makes it possible to build more detailed emission inventories [4, 6 ,10].

According to the IPCC Guidelines [9] we indicated emissions from extraction and processing oil and gas, and extraction and processing of sold fuels. Figure 1 presents the classification of emission categoriesin this sector. Here take place two types of emissions: the fugitive emissions, and emissions from fuel combustion [7-9].



a) b)

Figure 1. The classification of GHG emissions, which arise from extraction and processing: a) gas and oil; b) coal [8, 9]

For cerrying out the GHG spatial inventory from fossil fuels extraction and processing industry, all places with extraction of coal, gas, and oil, coke plants and refineries are presented as point emission sources (their sizes are small in comparison to the size of the country and we can ignore area of them). The digital maps of point sources for emission categories under investogation were built.

We have developed the special models for disaggregation of official statistical data (activity data) from the national level (data at the level of mine or plant are confidential) to the level of separate sources. Then, using created digital maps and mathematical models we calculated emissions for each elementary object.

3. Mathematical model

For GHG spatial inventory we adapted the mathematical description of emission process in investigated area. As write before, we estimate separately fugitive GHG emissions and emissions from burning fuels. As an example, we present below the mathematical model of emissions from coal industry (the models for oil and gas industry are similar and depend on available of statistical data at corresponding level). According to this mathematical model the methane fugitive emissions we can calculate using formula:

$$E^{g_l}_{coal,}(\xi_n) = E^{g_l}_{coal,m}(\xi_n) + E^{g_l}_{coal,p}(\xi_n), \qquad (1)$$

$$\xi_n \in \Xi_{coal},\ n = \overline{1, N},$$

where $E^{g_l}_{coal,}(\xi_n)$ is the amount of annual fugitive emissions from ξ_n coal mine, $g_l \in (CO_2, CH_4)$; $E^{g_l}_{coal,m}(\xi_n)$ is the amount of fugitive emissions from mining process; $E^{g_l}_{coal,p}(\xi_n)$ is the fugitive emissions which appear after mining process (keeping, transportation and other); Ξ_{coal} is the set of coal mines; N is the number of coal mines from Ξ_{coal} set.

Emissions from burning fuels at separate coke plant we calculate by formula:

$$E^{g,f}_{coke}(\eta_k) = D^{f}_{stat,coke} \cdot K^{f}_{coke}(\eta_k) \cdot K^{g,f}_{em,coke}(\eta_k), \qquad (2)$$

$$\eta_k \in \mathrm{N}_{coal},\ k = \overline{1,K},$$

where $E^{g,f}_{coke}(\eta_k)$ is the amount of annual emissions from burning fuels at η_k coke plant, $g \in \{CO_2, N_2O, CH_4\}$, f is the type of fuel, which are used at η_k coke plant; $D^{f}_{stat,coke}$ is the national data about using fuels in all coke plants; $K^{f}_{coke}(\eta_k)$ is the disaggregation factor, which depends on available of statistical data for η_k coke plant; $K^{g,f}_{em,coke}(\eta_k)$ is the emission factor for the f-th type of fuel, and different GHG; N_{coal} is the set of coke plants; K is the number of coke plants.

4. Results of spatial inventory

Coal is the main source of energy in Polish industry. That is why in the energy sector dominates the production of solid fuels, mostly coal. Poland ranks 8th place on the extraction of coal in the world (176 mln. t. in 2010). All coal mines are disposed in Silesian and Lublin voivodeships. There are 9 coke plants in Poland. They are located in Silesian (Śląskie) and Lesser Poland (Malopolskie) voivodeships. The largest metallurgical plants are in these voiwodeships and coke is a main fuel in this industry.

Using a geographic information system the geoinformation technology has been developed, in which the above mentioned models (1) and (2) are used to estimate the emissions of GHG emissions from fossil fuels extraction and processing.

Statistical data have been collected, and an input geospatial database has been formed (separately for each source category) [1]. The database contains information on names and locations of emission sources, their production capacities, and the specific emission factors.

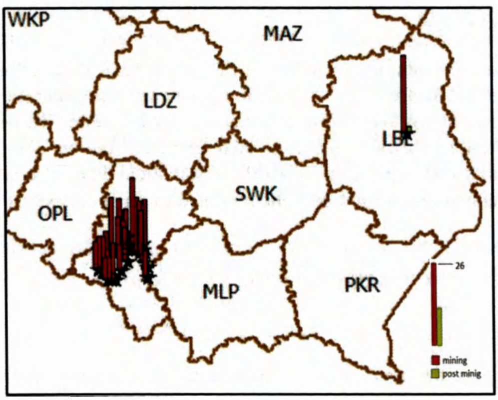


Figure 2. Fugitive emissions of CH_4 from coal mining for separate coal mines (th. t, Poland, 2010)

The results of inventory are obtained on the level of separate emission sources. In this paper we present the assessment of emissions in coal industry (see Figure 2 and

Figure 3). The similar spatial inventories are performed for oil and gas extraction and processing in Poland.

5. Uncertainty analysis

In the Polish national report on GHG emissions [11] the total uncertainty of GHG emission estimates is only in the energy industries sector (fuel combustion) without division by the types of anthropogenic activity. The simplified approach is used, which is based on the assumptions that every value is independent and probability distribution is symmetric. In general the uncertainty in the energy industries is 3,4% for carbon dioxide, 18,4% for methane, and 11,6% for nitrous oxide, uncertainty of fugitive emissions from fuels is 48,8% for methane (extraction of coal), and 5,4% for methane (extraction of gas and oil) [11].

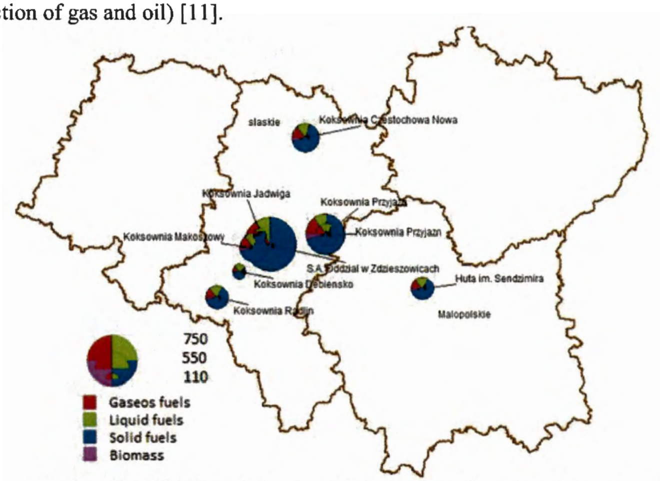


Figure 3. Result of GHG emissions spatial inventory from burning coal, oil, natural gas and biomass by type of fuel for separate coke plants (th. t.,CO_2-equivalent, Poland, 2010)

Uncertainty of emission factors for fuel combustion is low for carbon dioxide (or rather is considered a small) compared with other greenhouse gases, as the emission of this gas is mainly dependent on the carbon content in the fuel, which is very easy to identify. The uncertainty of CO_2 emissions is symmetric. The high level of uncertainty for methane and nitrous oxide can be explained by a lack of studies to establish national emission factors that take into account the specifics of individual processes and the lack of understanding of the formation of these emissions reductions [2,6].

Based on the results of modelling GHG emissions from burning coal in coke plants, the uncertainty is 3,76% for total emissions in CO_2 equivalent (symmetric normal distribution for CO_2 emission coefficient and lognormal for CH_4 and N_2O emission coefficient are used). The results of modelling of GHG emissions from burning coal and their uncertainties for separate coke plants are presented in Table 1. We also estimate uncertainties for separate coal mines. Table 2 presents results of modelling fugitive GHG emissions for ten the biggest coal mines (on data of 2010).

Table 1 The results of modelling GHG emissions and their uncertainties for separate coke plants

Name of coke plant	CO_2 emissions,t; uncertainty, %	CH_4 emissions, t; uncertainty, %	N_2O emissions, t; uncertainty, %	Total emissions, t; uncertainty, %
Coke plant Przyjaźń	464,408.5	2,756.6	603.8	466,722.0
	±3.687	-37.335..+49.308	-45.438..+68.080	-3.689..+3.767
Coke plant Jadwiga	50,018.4	968.5	65.0	50,154.675
	±3.689	-37.334..+49.308	-45.438..+68.080	-3.689..+3.767
Coke plant Dębieńsko	53,585.6	1,037.7	69.8	54,731.6
	±3,686	-37.335..+49.308	-45.438..+68.080	-3.687..+3.767
Coke plant Radlin	133,964.0	2,594.2	174.2	136,328.9
	±3.687	-37.335..+49.309	-45.439..+68.080	-3.689..+3.767
Coke plant Przyjaźń	133,964.0	2,594.2	174.2	136,328.9
	±3.687	-37.335..+49.309	-45.438..+68.081	-3.687..+3.768
Coke plant Częstochowa Nowa	232,204.2	4,496.6	301.9	236,936.8
	±3.687	-37.335..+49.308	-45.438..+68.080	-3.687..+3.767
Coke plant Makoszowy	206,434.0	4,150.7	268.4	210,996.3
	±3.689	-37.335..+49.308	-45.439..+68.080	-3.689..+3.767
S.A. Oddział w Zdzieszowicach	722,518.0	1,4527.5	939.5	724,486.3
	±3.689	-37.335..+49.308	-45.439..+68.080	-3.689..+3.768
Ironworks im. Sendzimira	137,623.0	2,767.1	178.9	139,997.9
	±3.689	-37.335..+49.308	-45.438..+68.080	-3.689..+3.767

Table 2 The results of modelling GHG emissions and their uncertainties for the main coal mines

Name of coal mine	Volumes of coal extraction; 10^3 tons/year	CH_4 emission factor; tons/t	CH_4 fugitive emissions, Gg	Uncertainty, %
KWK Murcki Staszic	3.875	4.90	18.977	48.49
KWK Mysłowice-Wesoła	3.229	4.91	19.029	48.49
KWK Wujek	4.982	4.91	24.466	48.49
Oddział KWK Jankowice	2.759	4.91	13.547	48.49
Oddział KWK Knurów-Szczygłowice	3.792	4.91	18.622	48.49
Oddział KWK Sośnica-Makoszowy	3.285	4.91	16.13	48.49
Oddział KWK Ziemowit	4.097	4.91	19.912	48.49
Oddział KWK Piast	4.613	4.87	22.423	48.49
KWK Wieczorek	3.405	4.9	16.548	48.49
KWK Bogdanka	5.351	4.91	26.011	48.49

The total uncertainty of emissions depends on uncertainties of all input parameters of emission model, such as uncertainty of statistical data, uncertainty of CO_2, CH_4 and N_2O emission coefficients. Figure 4 graphically shows results of sensitivity analysis of the total uncertainty of emissions estimates to improvement of uncertainty of input parameters on *P* percent. Results demonstrate that relative uncertainty of total emissions in CO_2-eqv. largely depends on uncertainty of statistical data and uncertainty of CO_2 emission coefficient. Uncertainty of total emissions stays almost unchangeable with the change of uncertainty of N_2O and CH_4 emission coefficients. For example, the reduction of uncertainty ranges of CO_2 emission factor into 50% causes the decreasing of total emission uncertainty from 3.76% to 2.63%.

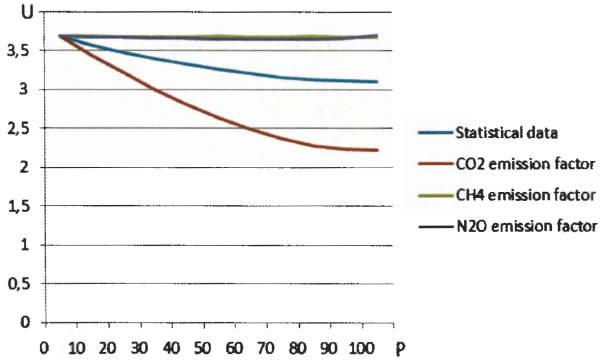


Figure 4. Dependence of total uncertainty of GHG inventory from burning coal in the coke plants of Poland (U) from decreasing uncertainty of input data into P percent (Monte Carlo simulations).

6. Conclusions

The mathematical models of GHG emissions resulting from fossil fuels extraction and processing were adapted to spatial inventory. The specialized geoinformation technology for spatial assessment of GHG emissions, which is based on elaborated mathematical models and uses the created geospatial database of input data was developed. The fugitive GHG emissions, that arise from extraction coal, gas and oil, as well as emissions from burning coal, oil, natural gas and biomass in the coke plants and refineries, and the fugitive emissions that arise during coking coal and processing oil, were examined.

The digital maps of the locations of extraction coal, gas and oil, the locations of coke plants and refineries in Poland were created, the layers with geospatial data about the structure of GHG emissions in the fossil fuels extraction and processing industry in Poland, taking into account specific emission factors for these objects, were formed. Based on performed numerical experiments the geospatial database and digital map of GHG emissions in Poland were obtained. The results of the inventory of greenhouse gas emissions were visualized by digital maps.

Spatial inventory of GHG emissions is useful to the authorities for making informed decisions to reduce GHG emissions. Estimation of uncertainty of GHG inventories can be helpful to comply the obligations on emission reduction. The sensitivity analysis demonstrates, that relative uncertainty of total emissions in CO_2-equivalent largely depends on uncertainty of statistical data and uncertainty of CO_2 emission coefficient. At the same time the uncertainty of total emissions stays almost unchangeable with the change of uncertainty of N_2O and CH_4 emission coefficients.

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