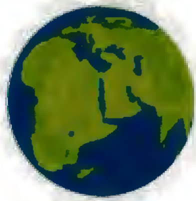

4th International Workshop on Uncertainty in Atmospheric Emissions

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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Uncertainty analysis of GHG spatial inventory from the industrial activity: A case study for Poland

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Abstract

Taking into account the global climate change problem, an urgent task is greenhouse gas (GHG) emissions reduction, and associated with this problem the uncertainty analysis of input data and results of GHG inventory. The main purpose of this investigation is the assessment of inventory uncertainty at the level of separate company, region and even country in the industrial sector (including emission processes caused by chemical and physical transformation of materials, as well as by burning of fuels). We discuss the obtained results of spatial GHG inventory in the Industry sector in Poland, by usage of the bottom-up approach, based on IPCC guidelines, official statistics and digital maps of territories investigated. Monte-Carlo method was applied for estimation of inventory uncertainty in main categories of analyzed sector, taking into account the small and large variation of parameters in cases of symmetric and asymmetric distributions. We determined emission sources that have the greatest impact on overall uncertainty in the industrial sector, and evaluated the relative uncertainty depending on uncertainty in activity data and emission factors. The additional knowledge on spatial distribution of emissions and their structure, supports the processes of decisions making on emission reduction.

Keywords: GHG emission, spatial GHG inventory, uncertainty analysis, Monte-Carlo method.

1. Introduction

Nowadays climate change is one of the most urgent ecological problem. Systematic atmospheric measurements show that the concentration of carbon dioxide (CO_2), as the most important anthropogenic greenhouse gas (GHG), has increased more than 20% compared to 1958 year. Apart from the energy sector, a significant share in terms of greenhouse gas emissions belongs to industrial production.

The national inventories of GHG emissions are the key element of the global system of monitoring and control of climate change. For enhancement of the assessment accuracy of GHG emissions inventory it is necessary to improve the inventories by developing new mathematical and software tools. The development of mathematical models of emission processes for GHG inventory is an important task in estimation of emissions, since only for a small number of emission sources experts may make direct measurements.

The assessment of the uncertainty of GHG inventory at the country level as well as individual emission sources is an extremely important problem due to the fact that incorrect estimates may have a significant impact on the process of GHG trading. The results of GHG inventory have a special value only with estimates of uncertainties of the input data (activity data, and emission factors) and the output data (emissions) [5].

2. High resolution spatial GHG inventory

Traditional inventory at country level does not answer the question, where the biggest emitters are located. For this purpose we have developed a geoinformation approach to high resolution spatial inventory of GHG on the example of Poland. In the categories of spatial GHG inventory every large plant for the production of industrial materials is presented as a major point-type source of GHG emissions.

The case study covers all categories of industrial sector: cement, lime, ammonia, nitric acid, iron and sinter production etc. (categories within sectors 1A2, 2A, 2B, 2C according to IPCC Guidelines [1]). This approach basically includes the stages of creation the maps of emission sources, and emission calculation for each source. On the basis of official information on industrial companies localization it is possible to set locations of their production facilities using Google Earth (TM). Also using a digital map of land use (Corine Land Cover [4]) the map of industrial zones as area-type emission sources was created. Thus digital maps of point- and area-type sources of emissions in each category of economic activity were built.

We have developed special models of disaggregation of official statistical data (activity data) from the national level (or where possible from the regional level) to the level of separate plants or industrial areas, that we consider as the elementary objects of study. These models use a set of parameters as disaggregation indicators, including production capacity of companies, data on gross value added in the subregions, available data on the specific of technological processes, fuel used and many others.

Then, using created digital maps and mathematical models we carried out spatial inventory of emissions for each elementary object and got sets of geospatial data on CO_2, CH_4, N_2O emissions, and total emissions in CO_2 equivalent. Below, this approach is illustrated on the example of cement industry only.

The specificity of the main sources of GHG emissions in the industrial sector in Poland is their uneven territorial distributions. The spatial inventory reflects this peculiarity. Also the special feature of our spatial inventory is the high resolution of the obtained results. Maximum resolution is determined by the resolution of used digital maps of land use and does not exceed 100m.

3. Mathematical models and results

Cement industry suffered a significant development before and during the two periods of commitments under the EU ETS. In 2009-2011, the absolute CO_2 emissions from European cement industry decreased by 20-22% compared to the 2000-2005 years. Most emissions from the cement industry are caused by clinker production as an intermediate mineral in the cement production process [2].

Polish cement industry is widely developed in 7 of 16 voivodeships. The cement industry is presented by 11 cement production plants with full production cycle, 1 cement grinding plant, and 1 alumina cement production plant. The full production cycle means all stages of the cement production, in particular the processes of the clinker calcination and cement grinding [6]. The largest cement producers are Górażdże Cement S.A. (concern Heidelberg), Lafarge Cement S.A. (concern Lafarge), and Grupa Ożarów S.A. (concern CRH). The shares of these groups in total cement production are 26%, 21% and 17%, respectively [3].

The main three ways to reduce GHG emissions from the cement industry are the reduction of emissions caused by fuel combustion, the reduction of emissions due technological processes modernisation, and reduction of indirect emissions from electricity consumption by improving the electric energy efficiency during the clinker and cement production. The reduction of emissions due technological processes modernisation is primarily connected with substitution of clinker by other minerals (a); with decreasing of carbon content in cement (b); with capture and storage / capture and disposal of carbon (c). The analysis showed that about 40-60% of the total emission reductions should be the option of carbon capture and storage of CO_2 [2].

We adapted the mathematical description of carbon dioxide emissions from cement production at the level of separate plant, as a single point source of emission [3], for GHG spatial inventory. According to this mathematical model the carbon dioxide emissions from a single point source is calculated as a product of the quantity of clinker produced, CaO content in clinker, and cement kiln dust losses by the formula:

$$E_{\text{Cement}}^{CO_2}(\zeta_n) = F_{\text{stat}_{\text{clinker}}}(\zeta_n) \cdot K_{\text{clinker}}^{CO_2}(\zeta_n) \cdot K_{CKD}, \quad \zeta_n \in \Xi_{\text{cement}}, \quad n = \overline{1, N_{\text{cement}}}, \tag{1}$$

where $E_{\text{Cement}}^{CO_2}$ is the amount of annual carbon oxide emissions from the cement plant; $F_{\text{stat}_{\text{clinker}}}$ is the activity data on clinker production for the cement plant ζ_n; $K_{\text{clinker}}^{CO_2}$ is the emission factor for clinker for the cement plant ζ_n; K_{CKD} is the correction factor for losses of cement kiln dust (it was assumed that $K_{CKD} = 1.02$); Ξ_{cement} is the set of cement production plants; N_{cement} is the number of these plants.

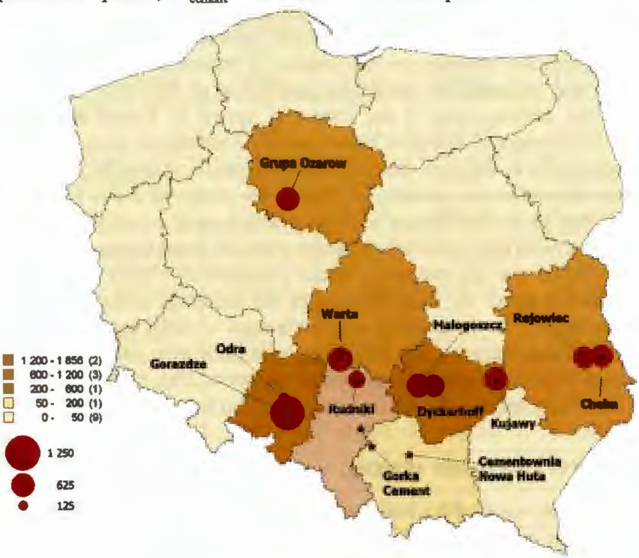

Figure 1. Results of the analysis: main sources of carbon dioxide emissions from cement production in Poland at production plants level, and region level (10^3 tons; in 2010)

Data on industrial production were disaggregated from the country level (administrative regions level if possible) to the level of production companies by using specific indicators of disaggregation, for instance, the capacities of large plants as point-type sources of emissions. The above-described mathematical model of emission processes from cement production (1) is implemented with the usage of geographic information systems (GIS) and developed software in MapBasic.

We formed a set of input geospatial data, and executed computations on GHG spatial inventory in cement production category in Poland (the results are presented in Figure 1). The similar spatial inventories are performed for other categories of economic activity of the Industrial sector, which are characterized by a significant level of emissions.

4. Input data for uncertainty analysis

Input data, which are used in our mathematical models for GHG spatial inventory, are associated with some uncertainties. These uncertainties reflect the lack of our knowledge about emission processes in each category of the industrial sector. Therefore, the statistical data on the output of major industrial goods, which are produced by corresponding plants, and the specific plant's GHG emission factors can be presented as random variables. One of the main methods for modelling GHG emissions taking into account the uncertainty of input data, is Monte Carlo method. Its advantage is the ability of using the information based on uncertainty of input parameters of mathematical models to estimate the level of uncertainty in GHG emissions for different companies, regions and the country as a whole. Today, there are good well-founded price incentives and financial requirements for the accurate accounting of the economic activity (production volumes) [7].

In this regard, the statistics on the results of economic activity tend to reduce uncertainties and decrease the correlation coefficient of data over time. Uncertainty analysis of the activity data in the industrial sector in Poland is carried within preparation of the national inventory reports on GHG emissions. According to estimates of the Polish experts in statistics, the uncertainty of statistical data for various categories of emission sources at the country level is in the range of 2-5% [8]. The national inventory reports show that the most accurate evaluations of emission factors for carbon dioxide together with their uncertainty ranges were obtained for the category "Cement production" (15%) and the category "Metal production" (10%). The uncertainty of methane emission factor for most sources in the industrial processes sector is 20% (normal distribution). In the analysis of uncertainties of GHG emissions from cement production at Polish factories, the following input data were used (see. Table 1): the uncertainty of volumes of clinker produced (symmetric, 2%), the uncertainty range for emission factors for carbon dioxide (symmetric, 15%) for all sources.

5. Results of uncertainty analysis

According to the study of the traditional inventory (not-spatial) the total uncertainty of GHG emission estimates in the industrial sector in Poland in general is 5.2% for carbon dioxide, 13.5% for methane, and 29.7% for nitrous oxide.

On the basis of the created set of geospatial data and the developed approach to the uncertainty analysis of GHG emissions the computing experiments were performed using Monte Carlo method for production of cement, lime, nitric acid, ammonia, iron and agglomerates in Poland (using activity data for 2010). The algorithm of realization of Monte Carlo method consists of 4 steps: setting probability distribution functions of each parameter of mathematical model separately for each cement production plant (1); generating pseudo-random data samples of statistical data and emission factor accordingly to the density of the probability distribution (2); calculation with mathematical model (1) of the emission estimate using modeled at previous step the random values (one random values of emission is calculated for each emission source) (3); calculation of the total GHG emissions from all sources (4).

Based on the results of modelling in main categories, the uncertainty ranges mentioned above amounted to 7,4% for CO_2 emissions, 16,8% for CH_4 emissions, 35.5% for N_2O emissions (symmetric normal distribution is used). The verification of the correctness of realized mathematical and software tools was carried out using Polish national annual reports on greenhouse gases emission at the country level as a whole. The obtained results show a small overall uncertainty of inventory results of greenhouse gases in the production of basic metals, minerals and chemicals in 2010.

This should positively affect the total uncertainty regional or national total emissions for the all sectors, and give the authorities the opportunity to take into account this factor in the verification of the fulfilment of arrangements on reduction of GHG emissions.

Table 1. Input data for the uncertainty analysis for GHG emissions from cement production (Poland, 2010)

№	Name of plant	Volumes of clinker produced, 10^3 tons/ year	CO_2 emission factor, t_{CO2}/t	CO_2 emission, 10^3 tons	Uncertainty range (lower), %	Uncertainty range (upper), %
1	Cementownia Górażdże	2400	0,512	1228,82	-15,569	15,979
2	Cementownia Małogoszcz	1215	0,52	631,78	-15,655	15,981
3	Cementownia Kujawy	1215	0,52	631,82	-15,646	15,985
4	Grupa Ozarów	1144,4	0,529	605,38	-15,663	15,993
5	Cementownia Rejowiec	1065,6	0,529	563,72	-15,655	15,986
6	Cementownia Chełm	1137,5	0,529	601,73	-15,650	15,981
7	Cementownia Rudniki	682,5	0,529	361,02	-15,643	15,982
8	Dyckerhoff Polska	1050	0,529	555,43	-15,643	15,975
9	Cementownia Warta	1320	0,529	698,25	-15,659	15,989
10	Cementownia Odra	350	0,529	185,15	-15,653	15,982
11	Górka Cement	50	0,529	26,43	-15,654	15,986
12	Cementownia Nowa Huta	80	0,529	42,36	-15,652	15,978

The authorities should be interested in the reduction of uncertainty of inventory results, and thus in the reduction of uncertainty of its individual components. However, the reduction of uncertainty of emission estimates from certain human activities is an extremely complicated, lengthy and expensive process, it requires the significant investment in the research, measurement and refinement administrative measures. Of course, with gradually increasing of our knowledge about the nature of emissions the respective uncertainties of individual components of the inventory process are reduced, but to solve this problem in global scale by a short time and with limited funds it is impossible.

Thus the problem of determining of the categories of economic activities, which are the most important in terms of sensitivity analysis, is quite interesting. It means that overall uncertainty of inventory results is the most sensitive to the changes in uncertainty of some input parameters. As an example, Figure 2 illustrates graphically a sensitivity of uncertainty of CO_2 emission estimates from cement production. The results show that the relative uncertainty for carbon dioxide emissions is the most dependent on the uncertainty of CO_2 emission factor. The uncertainty of total emissions little depends on improving knowledge about the activity data in cement industry. For example, the reduction of uncertainty ranges of CO_2 emission factor into 50% causes the decreasing of CO_2 emission uncertainty from 15,6% to 7,8%.

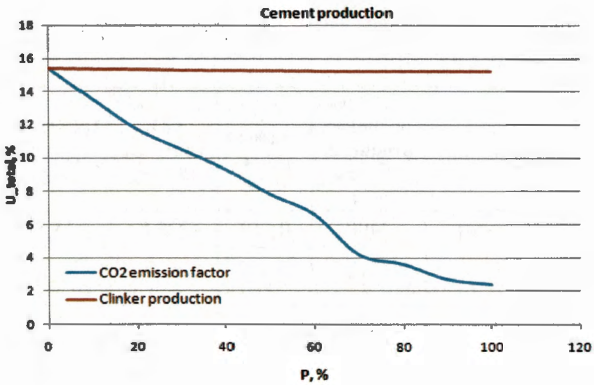

Figure 2. Dependence of total uncertainty of GHG inventory in cement production in Poland from decreasing uncertainty of input data into ***P*** percents

6. Conclusions

The obtained results of the mathematical modeling and the spatial analysis of GHG emissions in categories of the industry sector demonstrated the basically low uncertainties of emissions, especially emissions caused by production of cement by respective companies. It has a positive impact on the uncertainty of total regional or national emissions from all categories of economic activity. Thus it gives a possibility to authorities to take into account this factor in the verification of the performance of agreements on the reduction of GHG emissions. The relative uncertainty of carbon dioxide emissions highly depend on the uncertainty of CO_2 emission factor.

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