4th International Workshop
on Uncertainty in Atmospheric Emissions

7-9 October 2015, Krakow, Poland

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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 Greenhouse Gas (GHG) inventory and uncertainty analysis: A case study for electricity generation in Poland and Ukraine

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Abstract

Spatial inventory of greenhouse gas (GHG) emissions allows to identify emission changes in space. In this study we have analyzed the specificity of territorial distribution of GHG emission sources for Poland and Ukraine. Mathematical models and geoinformation technology for spatial analysis of GHG emissions from fuel consumption by power and combined heat and power plants have been improved by taking into account uncertainty of input parameters and specific factors for every separate electricity/heat generating companies. We have updated the input digital maps of emission point sources. Based on it, we have developed a spatial GHG emission distribution for 2012. The uncertainties of GHG emissions in CO_2-equivalent for the power plants which we consider in our study are asymmetric and the upper bounds of 95% confidence intervals do not exceed 20,3%.
Keywords: mathematical modeling, GHG emission inventory, electricity/heat production, uncertainty

1. Introduction

In the last decades, rapid technological progress has caused considerable impact on the environment, in particular on the climatic condition of the planet [16]. Therefore, the problem of global warming caused by the increase of greenhouse gas (GHG) concentration in atmosphere is very relevant. Inventory of GHGs is an essential tool for monitoring the practical implementation of commitments to reduce or stabilize emissions. Emission inventories are often provided with spatial distributions. Some examples of such inventories are published in [1, 5].

Electricity generation, is often the most prominent GHG emission category that is closely related to our economic activities. It corresponds to the subsector "1.A.1.a Public Electricity and Heat Production" in the IPCC methodology [15]. According to the IPCC methodology, enterprises producing electricity and heat (rather – their funnels) are emission point sources.

The high-resolution spatial GHG inventory provides localization of point sources not only for electricity generation, but also for many other categories of human activity. In most cases GHG emissions are calculated in a determinative way. GHG emissions from electricity generation are the largest emitters on the analyzed territory [5, 6]. The uncertainties of results of GHG inventories from electricity production have significant impact on the uncertainty of the inventory results not only for this category but also on the summary results of all categories of human activities [4].

The first results of spatial analysis of GHGs emissions caused by fossil fuel fired power and/or heat plants in a few Polish regions were presented in [13]. The study described the mathematical model for spatial analysis of GHGs, and the experiments that were carried out for all Poland. A similar study for Ukraine has been presented in [11]. It should be noted that those studies [11, 13] didn't take into account the uncertainties of the input data (activity data and emission factors). Uncertainty of inventory results must be estimated. The first results of uncertainty analysis of GHG emission inventory have been presented in [12], but the authors did not consider specific parameters for a single company in their estimations (e.g., limits of uncertainty of emission coefficients).

This paper focuses on analysis of uncertainty of GHG emissions in Poland and Ukraine from heat/power plants. We have recalculated facility level CO_2 emissions from national fuel consumption data [8, 10, 14] and carried out the spatial analysis of GHG emissions from electricity generation for Poland and Ukraine for 2012. We have updated the maps of point source emissions for the year 2012 [11, 13]. These maps include geolocation of all enterprises that produce electricity or combined electricity and heat, with maximal power more than 20 MW.

2. Electricity and heat generation in Poland and Ukraine

Electricity generation is one of the strategical categories in Poland and Ukraine, accounting more than 40% of total GHG emissions. Particularly, the percentage of coal in overall fuel consumption is very high. During burning, coal is characterized by the largest emission coefficients (emissions per ton of fuel). Below we specify the differences and similarities of electricity and heat generation in Poland and Ukraine.

2.1 Poland

Electricity or combined electricity and heat producing plants in Poland are categorized into two types: (1) public power/heat plants and (2) autoproducing power/heat plants. Power/heat plants of first type produce electricity for general purposes. Autoproducing power/heat plants, according to the source classification by IPCC [15], are included in another category of energy sector: "1.A.2.Manufacturing Industries and Construction". However, most of these autoproducing plants produce energy/heat not only for their own use but for residential consumers as well. So, it is difficult to identify to which category this plant should be included. Such division of plants is a part of the statistical reports about amount of burned fossil fuel.

Despite the development of renewable energy sources, almost 90% of electricity in Poland is produced by power/heat plants that are located close to the miners of fuel raw materials in Silesia, in the central regions and in Pomoria. The production of electricity based on coal is about 62% of the total energy production. Another important energy resource is brown coal that covers 30% of the energy production [3, 5, 7, 14]. Plants that use brown coal for electricity production are located close to the miners of that fuel [5, 6].

2.2 Ukraine

The specificity of the location of electricity generation plants in Ukraine is similar to Poland. Most power plants are concentrated in the industrial regions of the country and in the places of fuel mining – it is the eastern part of Ukraine. Some power plants are located in the strategic places, for example, Burshtyn power plant is located at the intersection of the power lines that connect Ukraine with Hungary, Romania and Slovakia. Another power plant Dobrotvir is located not far from Poland and is connected to Polish electrical network.

Outdated equipment (boilers, generators, filters etc.) that is still utilized in many power plants increases the amount of GHG emission. It should be noted that statistical data of fossil fuel used for electricity generation by private companies is not available. Instead, there is available information about amount of generated power, fuel type and fuel consumption per unit of energy produced.

For spatial GHG inventory it is required to have information about amount of fuel consumption or amount of energy output for each individual plant, appropriate emission factors, technical power characteristics, fuel chemical composition, etc. It is difficult to fulfill these requirements due to the lack of available data. For example, in Ukraine the information about the activities of power plants in most cases is not available. In this study, a detailed research of technical parameters of power/heat plants activity (emission factors, technical power characteristics, fuel chemical composition) are done only for a small amount of enterprises.

3. Maps of electricity and heat generating companies

Unlike emissions from diffused sources (e.g. residential and commercial), it is often difficult to model emission spatial distributions for the intense point sources such as electricity and heat plants. Thus, those emissions need to be mapped using the specific location information (geographical coordinates of smoke stacks). We developed a map of point sources for the year 2012 [11,13]. The map for the year 2012 was developed in following steps: (1) collect and compile information about companies that produce electricity (we used all available data about electricity generation branch in Poland and Ukraine), (2) identify geographical coordinates (latitude and longitude) of power/heat companies by using Google Earth high resolution imagery (TM)) and (3) create digital maps using the MapInfo GIS environment. As a result, we developed a database of electricity generating plants that includes the next information: unique identification number; name of electricity generation plant, city, region;geographical coordinates (latitude and longitude);power of plant, MW.

4. Spatial GHG inventory for Poland and Ukraine

Using the point source map we developed, we developed a spatial GHG inventory for the category of electricity and heat production for Poland and Ukraine. We used the models for spatial GHG inventories presented in [11] and [13] for Poland and Ukraine, respectively. These models use specific emission factors for individual power plants and calorific values of fuel, the information about location of plant and its characteristics (if it is available).

The results of GHG emissions estimation are in the form of sets of numerical values of GHG emissions (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O),) for certain year and for every point source. The thematic maps have been then created based on the results of GHG emission estimates by sources. Figures 1 and Figure 2 illustrate these thematic maps for Poland and Ukraine, respectively. The emission leaders are industrialized regions, where the main production facilities of the country take place. For example, in Ukraine it is Donetsk region, Luhansk region, Dnipropetrovsk region and Kharkiv region; and in Poland it is Silesia voivodeship, Lodz voivodeship, Mazovia voivodeship and Wielkopolska voivodeship.

The results of spatial GHG inventory of Ukraine and Poland enable to adequately assess the current situation of the industry in terms of GHG emissions and to accept the relevant decisions for GHG emissions reduction.

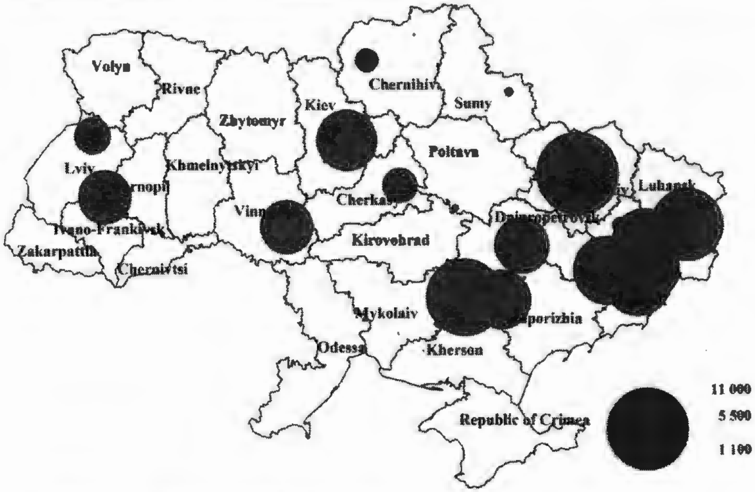

Figure 1. Map of GHG emissions from electricity production in Ukraine, CO_2 equivalent (2012, 10^3 t)

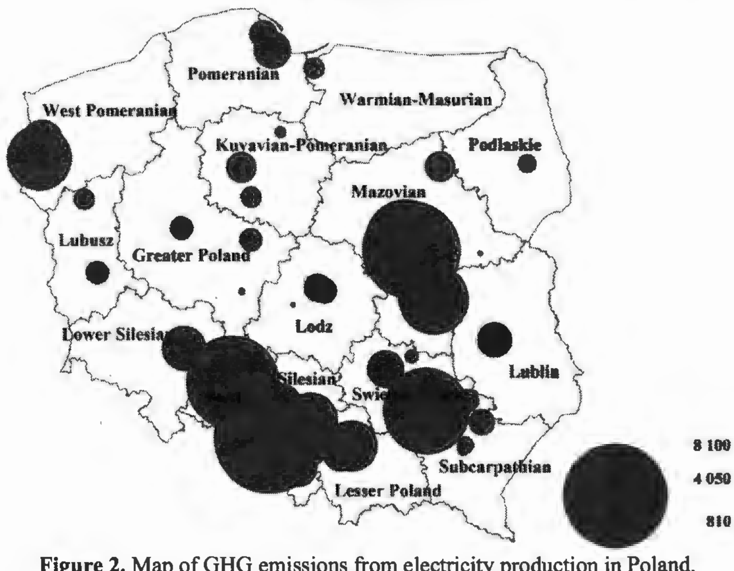

Figure 2. Map of GHG emissions from electricity production in Poland, CO_2 equivalent (2012, 10^3 t)

6. Uncertainty analysis of the results of GHG emission inventories

The mathematical models of spatial inventory of GHG emissions include a number of parameters, which are characterized by uncertainty that has to be considered during the estimation of GHG emissions, e.g. uncertainty of emission factors and uncertainty of statistical data on consumption of fossil fuel. Uncertainties of the spatial inventory results depend on uncertainty of activity data, calorific values, emission factors etc. We are estimated such uncertainties by applying the Monte-Carlo method that is suitable for detailed evaluation of uncertainty "from category to category", particularly, if there are parameters with large uncertainties with distribution different from the normal. The density distribution is described by the complex functions and there are correlations between some input data, emission factors, etc.

The uncertainty of emission factors of major greenhouse gases for 1.A.1.a “Public electricity and heat production” category are characterized by normal (CO_2) distribution and log-normal (CH_4, N_2O) distribution [2]. In Poland’s National Inventory Report [8] it is published that emission factors of the major GHGs are characterized by the normal distribution. Uncertainty of emission factors in Poland’s energy sector for carbon dioxide (CO_2) is 3,4%, methane (CH_4) – 15,5%, nitrous oxide (N_2O) – 11,3% (upper and lower limits of 95% confidence interval, which is approximately equal to two-sigma).

Table 1. Results of uncertainty estimation for ten the most powerful electricity plants in Poland (2012)

Power/heat plant	**CO_2**, th. t (uncertainty, %)	**CH_4**, th. t (uncertainty, %)	**N_2O**, th. t (uncertainty, %)	**Total emissions**, th. t (uncertainty, %)
BOT Elektrownia Bełchatów SA	17535,9 (-13,8: +15,3)	0,16 (-18,1: +20,8)	0,24 (-17,1: +19,5)	17611,5 (-13,8: +15,3)
Elektrownia Patnów II	28624,0 (-13,8: +15,3)	0,26 (-18,0: +20,8)	0,39 (-17,1: +19,5)	28747,4 (-13,8: +15,3)
Elektrownia Rybnik SA	7862,2 (-17,6: +20,2)	0,08 (-21,0: +24,8)	0,12 (-20,1: +23,7)	7901,8 (-17,6: +20,2)
BOT Elektrownia Turów SA	8317,4 (-13,8: +15,3)	0,07 (-18,0: +20,8)	0,11 (-17,1: +19,5)	8353,3 (-13,8: +15,3)
BOT Elektrownia Opole SA	6012,1 (-17,6: +20,2)	0,06 (-21,0: +24,8)	0,10 (-20,1: +23,7)	6042,4 (-17,6: +20,2)
Elektrownia Polaniec	5271,9 (-17,6: +20,2)	0,06 (-21,0: +24,8)	0,08 (-20,1: +23,7)	5298,5 (-17,6: +20,2)
Elektrownia Kozienice SA	3501,3 (-17,6: +20,3)	0,04 (-21,0: +24,9)	0,06 (-20,1: +23,7)	3519,0 (-17,6: +20,3)
Elektrociepłownia Siekierki SA	6511,1 (-17,6: +20,3)	0,07 (-21,0: +24,9)	0,10 (-20,1: +23,7)	6543,9 (-17,6: +20,3)
Elektrownia Dolna Odra SA	3117,5 (-17,6: +20,3)	0,03 (-21,0: +24,9)	0,05 (-20,2: +23,7)	3133,2 (-17,6: +20,3)
Elektrociepłownia Żerań SA	4746,0 (-17,6: +20,3)	0,05 (-21,0: +24,8)	0,08 (-20,2: +23,7)	4769,9 (-17,6: +20,3)

As an example, the results of uncertainty estimations for the 10 most powerful plants of Poland are shown in Table 1. The uncertainty range (calculated using the

Monte Carlo method) of emissions of Elektrownia Patnów II that uses brown coal for electricity production is from -13,8 to 15,3. These numbers are lower that the uncertainty range of GHG emission of Elektrownia Rybnik SA that consumes coal.

National Inventory Reports of GHG are published in Ukraine and in Poland. They include the information about results of GHG inventory of different sectors of human activity in accordance with IPCC methodology. Also, there are reports that present the detailed information about protection of environment for particular regions, e.g. the report on the state of the environment in the Lower Silesia. These reports potentially can be used for validation of the results presented in this study. We will carry out the comparison of the presented GHG emissions and the independent GHG emissions estimates in the nearest future.

Elektrownia Patnów II is the biggest plant in Poland, therefore we analyze sensitivity of the uncertainty of GHG emissions for this power plant to the uncertainty of input parameters (Figure 3). These results were calculated using the Monte Carlo method, and relative uncertainties of activity data, net calorific value, and CO_2 emission factor as input data. The results show that decreasing of the uncertainty of the net calorific value by 50% can decrease the total uncertainty for this plant from -13,8%:+15,3% to around 9%. As uncertainties of other parameters are rather low, the relative change of uncertainty of these parameters will not change overall uncertainty for this power plant significantly.

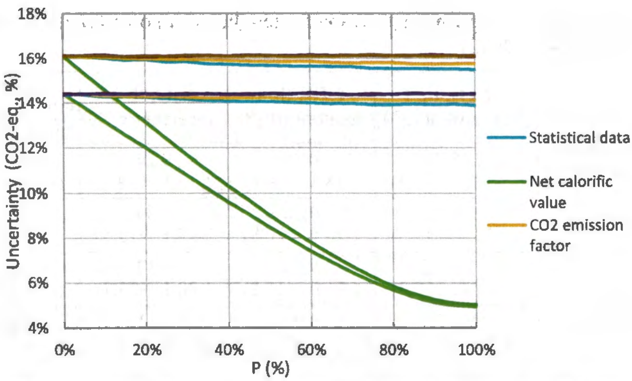

Figure 3. Dependence of total uncertainty of emission estimates for Elektrownia Patnów II to changes of uncertainty (on P %) of input parameters of inventory (the upper and lower limits of 95% confidence interval)

7. Conclusions

In this paper, we presented the results of spatial inventory of GHG emissions and their uncertainty analysis. The study of GHG emissions is based on the official statistics about fossil fuel consumption in Poland and Ukraine

The results of spatial inventory allow to identificate power plants that produce the biggest quantity of GHG emissions and investigation of uncertainty of emission inventory results gives policymakers an effective tool for supporting decisions on strategic baselines of economic development and environmental policy. In Poland the leader in GHG emissions is Silesia voivodeship. It is the biggest industrial region of country. The electricity and heat generating plants from the eastern part of Ukraine emit the most of GHGs in the country.

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