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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High resolution spatial inventory of GHG emissions from stationary and mobile sources in Poland: summarized results and uncertainty analysis

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Abstract

Greenhouse gases (GHG) inventories at national or regional levels include the total emissions and emissions for many categories of economic activity. The aim of our research is to analyze the high resolution spatial distributions of emissions for all categories of economic activity in Poland. GHG emission sources are classified into point-, line- and area-type sources. We created maps of such sources for all categories of economic activities covered by IPCC Guidelines, using official information of companies, administrative maps, Corine Land Cover maps, and other available data. The worst resolution is for area-type sources (100 m). We used statistical data at the lowest level as possible (regions, districts, and municipalities). We created the algorithms for these data disaggregation to the level of elementary objects for GHG spatial inventory. These algorithms depend on category of economic activity and cover all categories under investigation. We analyzed emissions of CO_2, CH_4, N_2O, SO_2, NMVOC, and others, and we calculated the total emissions in CO_2-equivalent. We used a grid to calculate the summarizing emissions from the all categories. The grid size depends on the aim of spatial inventory, but it can't be less than 100 m. For uncertainty analysis we used uncertainty of statistical data, uncertainty of calorific values, and uncertainty of emission factors, with symmetric and asymmetric (lognormal) distributions. On this basis and using Monte-Carlo method the 95% confidence intervals of results' uncertainties were estimated for big point-type emission source, the regions, and the subsectors.

Keywords: GHG emissions, high resolution spatial inventory, uncertainty, Monte Carlo method

1. Introduction

Preventing climate changes requires of the humanity to reduce greenhouse gas (GHG) emissions. To control the performance of obligations to reduce or limit GHG emissions, we need to make inventories of emissions and absorptions of these gases. GHG inventories at national or regional levels include the total emissions and emissions for many categories of economic activity. But for deeper study of emission processes as well as their structure, it is more reasonably to make a spatial inventory of GHG. Such an inventory reflects the emissions linked to the territory where they appear. Scientists are constantly trying to reduce the spatial resolution of the inventory results to better reflect the specifics of territorial emission processes [1, 8, 9, 11]. The aim of our research is to analyze the high resolution spatial distributions of emissions for all categories of economic activity in Poland.

2. Spatial inventory approach

For all sectors and categories of anthropogenic activity covered by IPCC Guidelines [7], we analyzed the sources of emissions or sinks in terms of their spatial representation for inventory procedures. GHG emission sources are classified into point-, line- and area-type sources [3] (see below). Then we built digital maps of sources / sinks for each category. For some categories they are digital maps of point objects, for other categories they are digital maps of linear objects or area-type objects (polygons). We further analyzed the emission / absorption from these diverse elementary objects (points, lines, and areas) without using any regular grid, as it is often made. The line- and area-type (diffused) elementary objects are split by administrative boundaries. It gives us a possibility to keep administrative assignment of each elementary object to the regions (voivodeship in Poland), districts (powiat), and municipalities (gminas).

The next step was to create algorithms for calculating GHG emissions from these elementary objects. Basically, these algorithms reflect the main principles of IPCC Guidelines [7], according to which the emission is a product of activity data and emission factors. However, a common problem is to obtain data about the activities at the level of elementary objects. For this purpose we have developed algorithms for disaggregation of available statistical data for regions (or even for municipalities in some categories) to the level of elementary objects. These algorithms are different for each category. They take into account the available statistics relevant to corresponding administrative level, and use other parameters, that can be considered as indicators for disaggregation of statistical data.

The specific feature of the approach is an ability to use different emission factors for separate elementary objects (or even part of objects), if such data are available, as opposed to using averaged default values. The results of calculating emissions in each category of anthropogenic activity for elementary objects can be visualized in the form of digital maps using different approaches, depending on the source type. Since this approach 'saves' information about administrative assignment of each elementary object (emission source), it is possible to aggregate emissions for whole administrative units (even for small units like municipalities) without loss of accuracy.

3. High resolution maps of emission sources

Examples of the point-type emission sources are electricity or combined electricity and heat production plants, cement plants, production of glass, ammonia, iron and steel, aluminium, pulp and paper, petroleum refining, mining etc. Using the official information on these companies we determined their addresses, and then, using Google Earth (TM) we searched for their production facilities treated as point emission sources (stacks of power plants, for example), and we fixed their geographical coordinates (latitude and longitude). Thus the digital maps of emission sources were built for the categories of human activity, in which the emission sources can be presented as point-type objects. The spatial resolution of these maps is of the order of several meters, that can be considered very accurate for spatial inventory of GHG emissions.

The roads and railways are examples of the line-type emission sources. To construct the maps of these sources, we used the OpenStreetMap. This digital map is created using GPS navigators. Therefore its spatial resolution is also high for GHG spatial inventory. Information on road category was used as one of the indicators for disaggregation of data on fossil fuel combustion by various categories of vehicles in the transport sector.

Area-type (or diffused) sources or sinks are croplands, settlements, industrial areas, forests and others. We created digital maps of such sources / sinks for all categories of human activities under investigation. Elementary objects for GHG spatial analysis are represented as polygons. To build these maps we used Corine Land Cover vector maps [4]. These maps are obtained on the basis of processing raster maps with a resolution of 100 m. This resolution determines the resolution of all created digital maps of area-type (diffused) sources. It further defines the resolution of the summarized results of GHG spatial inventory.

4. Input data and disaggregation algorithms

As activity data, we used statistical data at the lowest level as possible (levels of voivodeships/regions, powiats/districts, and gminas/municipalities, as some statistical data are available even at the level of gminas) [2]. The amount of fossil fuel used, data on production, the number of animals in agriculture, and any more are examples of such activity data in different emission categories. We created the algorithms for these data disaggregation to the level of elementary objects for GHG spatial inventory (level of point-, line-, and area-type emission sources). These algorithms depend on category of anthropogenic activity and cover all categories under investigation. As input data we also used the values of certain indicators, which are needed for activity data disaggregation to the level of elementary objects. The population density, data on access to energy sources, power of electricity generation plants, gross value production, and many others are examples of such indicators.

In cases where it was possible, the emission coefficients and parameters that reflect the territorial specifics of emission and absorption processes were applied. For example, when calculating accumulated carbon in forests, we used the information of Local Data Bank (BDL) [2] on species composition, age structure, etc. at the level of districts/powiats and communes/gminas.

5. Results of spatial inventory

By using created digital maps of GHG emission sources / sinks in Poland and the algorithms for activity data disaggregation, we formed the geospatial database needed for the spatial inventory. Then we calculated the GHG emissions using appropriate mathematical models. We analyzed emissions of CO_2, CH_4, N_2O, SO_2, NMVOC, and others, and we calculated the total emissions in CO_2-equivalent, using Global Warming Coefficients. These results we obtained at the level of elementary objects (point-, line- and area-type sources of emissions).

We used a grid to calculate the sum of emissions from all categories under investigation. But the cells of this grid are split by administrative map. The grid size depends on the aim of spatial inventory, but it cannot be less than 100 m. This is due to the fact that the worst spatial resolution of the digital maps is for the area-type sources of emissions and it is 100 m. For visualization of results on the maps we calculated also a specific emission, i.e. emissions divided by area, because areas of these objects are not equal.

As an example, the map of total specific GHG emissions in Poland and the Silesian voivodeship, which is the most industrialized region, is presented in Figure 1.

As a rule, the emission from point sources are significant, therefore it causes problems when we visualize the spatial inventory results. Figure 2 presents the results using the square root scale for visualization of spatial inventory results for the Silesian region in Poland. For the purpose of this figure the results of spatial inventory at the level of point-, line-, and area-type elementary sources are aggregated to the regular grid 2 km in size.

Based on the results of GHG spatial inventory at the level of elementary objects or regular grid we can calculate the total emissions in the administrative units like gmina/municipality, powiat/district or voivodeship/region. These results reflect a structure of emissions by sectors or certain categories of activity, by types of fossil fuel used, and the structure of certain emissions of greenhouse gases. In Figure 3 we can see the structure of total GHG emissions from all sectors in Poland at the regional level, and Figure 4 presents the structure of emissions in the Energy sector, which is the most influential one.

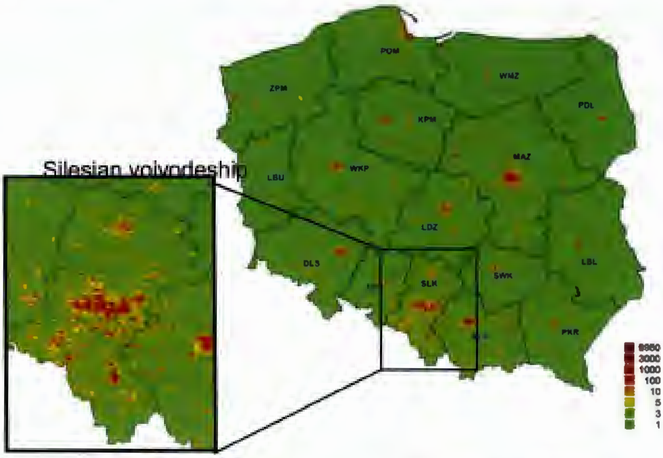

Figure 1. The total specific GHG emissions in Poland and the Silesian region (the all categories without LULUCF, 2010, Gg/cell, CO_2-equivalent, 2 km grid size)

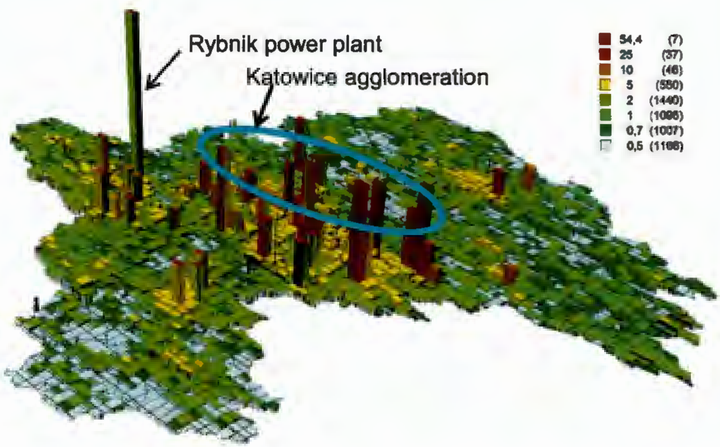

Figure 2. Prism-map of specific GHG emissions from all anthropogenic sectors without LULUCF in the Silesia region at the level of elementary objects (CO_2-equivalent, Gg/km^2, square root scale, 2 x 2 km, 2010)

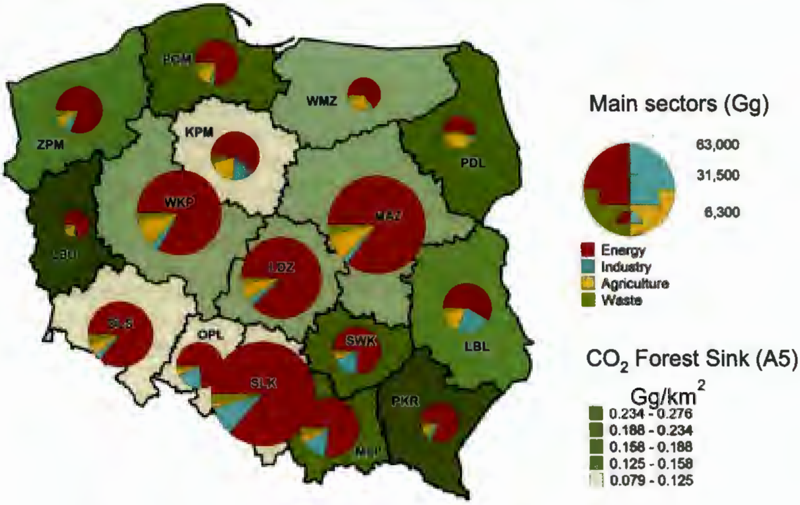

Figure 3. The total GHG emissions structure by sector (Poland, CO_2-equivalent, 2010)

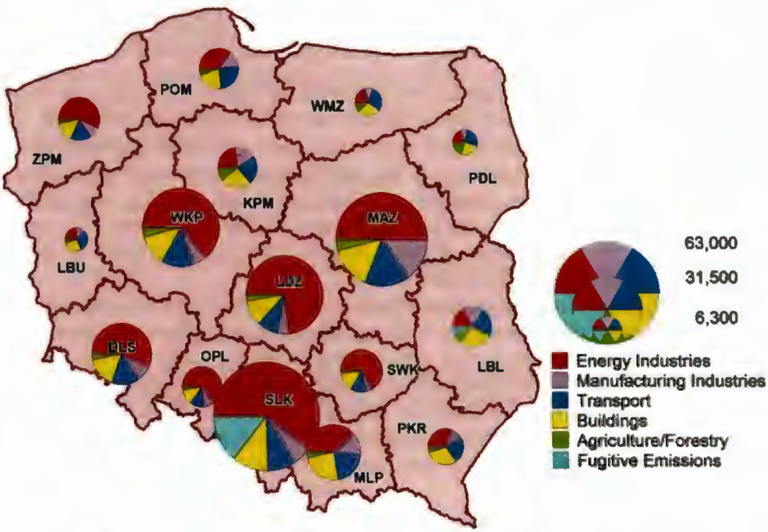

Figure 4. The total GHG emissions in the Energy Sector by sub-sectors (Poland, Gg, CO_2-equivalent, 2010)

6. Uncertainty analysis

The variables and parameters, used in the GHG inventory, are characterized by some uncertainties. These uncertainties are associated with lack of our knowledge on emission processes, inaccurate measuring instruments, etc. Uncertainties of the spatial inventory results, using the above described approach, include three components: (1) the uncertainty of spatial localization of emission sources and sinks; (2) the uncertainty of the used input statistical data, calorific values of fuels, and emission factors; and (3) the uncertainty of spatial disaggregation of activity data to the level of elementary objects. The uncertainty is characterized by the lower and upper limits of 95% confidence intervals of analyzed variables.

The first of these uncertainty components is not taken into account in this study. This is because of the above-described approach to building digital maps of emission sources and sinks, where the uncertainty of localization of point- and line-type elementary objects is kept to the minimum. The uncertainty of localization of area-type (diffused) emission sources / sinks is defined by the uncertainty of the Corine Land Cover maps.

As to the second component, the uncertainty of input statistical data, the uncertainty of calorific values, and the uncertainty of emission factors, we used the appropriate data from [5, 10], and other estimations (e.g., [6] and others). For these variables we used the symmetric and asymmetric (lognormal) distributions.

As described above, the algorithms for disaggregation of activity data are based on certain indicators, that are mostly statistical data. Therefore, for the analysis of the total uncertainty, it was assumed that these uncertainties are described as for statistical data. For some categories of human activities, such as the residential sector, the uncertainty of disaggregated data was evaluated by comparison with similar data from other known sources [2].

Based on these input uncertainties we estimated the distributions using the Monte-Carlo method. The uncertainties of results, as 95% confidence intervals, were calculated, i.e. the expectation, as well as the lower and upper limits. For the point-type sources we estimated the uncertainty of the results separately for each source, and for the total emissions in the category to which they belong. We also analyzed the sensitivity of the total uncertainty to changes of the uncertainties of separate components, as the uncertainties of input statistical data, the uncertainty of calorific values, and the uncertainty of emission factors.

As the number of elementary objects for line- and area-type sources of emissions are large (typically tens of thousands, as in the residential sector or the agriculture sector), we also evaluated the uncertainty of results using the Monte-Carlo method, but at the regional level. We also investigated the sensitivity of the total uncertainty to changes of uncertainties of separate components, including the uncertainties of input activity data, the uncertainty of calorific values, and the uncertainty of emission factors.

7. Conclusions

The presented approach provides the high resolution of GHG spatial inventory in Poland with the use of point-, line-, and area-type emission sources / sinks. The spatial analysis is carried out at the level of these sources without using any additional grid. Consequently, the information on administrative assignment of corresponding emission sources (plants, settlements, etc.) is retained, and this, in turn, makes it possible to aggregate the final results even to the level of sub-municipalities without decreasing accuracy of results.

In principle, according to this approach an inventory is carried out by 'bottom-up' method, but also an element of 'top-down' assessment exists, since we disaggregate available statistical data to the level of elementary objects as point-, line-, or area sources. However, this approach makes it possible to fully use the available even partial information about the specific territorial emission or absorption processes.

The results of spatial inventory of GHG emissions / absorption demonstrate an unevenness of these processes in Poland. Such an unevenness is specific to each category of anthropogenic activity. The positive aspect is that the spatial inventory enables to display a real contribution of each even very small territory to the overall emission processes. What is more, the results presented in such a form show the emissions values, as well as their structural features. It is of interest to authorities to support well-grounded decision making.

Since the spatial analysis takes into account the territorial specificity of many parameters that affect emissions or removals of greenhouse gases (e.g. the differentiated characteristics of the fossil fuel used in the energy sector, the climatic conditions and the energy sources availability in the residential sector, the species and age composition of forests and many others), the total inventory results for the region/country as a whole is more precise comparing with the national inventories without spatial components and regional specifics.

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