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Proposals of effective ways for uncertainty reduction in the Polish greenhouse gas inventory system

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Geoinformation technologies, spatio-temporal approaches, and full carbon account for improving accuracy of GHG inventories

Deliverable 1.4. Proposals of effective ways for uncertainty reduction in the Polish greenhouse gas inventory system

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2. Uncertainty analysis using Monte-Carlo method. Practical analysis of uncertainties in modeling of greenhouse gases emission processes.

The analysis with the Monte-Carlo method is particularly useful for a detailed evaluation of uncertainty "from category to category" when the uncertainties are large, and are not normally distributed, when density is described by complex functions, and (or) there is a correlation between some inputs on the activities in the studied category, sector, emission factors, and more.

The essence of the Monte-Carlo method is to generate pseudo-random samples of input data, according to the density of the probability distribution specified for each input variable. The samples are called "pseudo-random" because they are generated by a particular algorithm, called pseudo-random number generator. Therefore, as input data during such assessment we use reproducible numerical series from a pseudo-random number generator (in accordance with input probability distribution) that, have some specified characteristics. If the resulting uncertainty is a function of two or more uncertain input variables, then the random samples are generated for each of the input variables, and the random number obtained for each input parameter is inserted into the mathematical model expression for calculation of the output value. This process is performed many times to produce a set of output estimates in the model. This set of estimates is a sample from the probability density of the output variable. Since the Monte-Carlo simulation is a numerical method, an important element of its application is connected with the accuracy of the results. To improve this accuracy, the number of iterations has to be increased.

Application of the Monte-Carlo method in modeling of the greenhouse gas emission processes requires the knowledge of the distribution of the probability density for each parameter in a complex mathematical model (i.e. for all the data connected with the consumed fuel, calorific values of fuels used, emission factors, etc.). This is the first and very important step in the simulation when using Monte-Carlo method. In the second step, the random values of all the parameters of the mathematical model are generated, according to their probability density functions. In the third step an evaluation of emission on the basis of the random variables, generated in the second step, is carried out. The implementation of the second and the third steps is repeated as many times, as needed to get the values of all investigated output parameters of the mathematical model considered.

Thus, a major problem in the Monte-Carlo method is the modeling of random variables, that correspond to the input parameters of the model. A proper assessment of the magnitude of uncertainties of input parameters, their distributions and correlations are very important, since each parameter has its own peculiarities and specific features. In the IPCC guidelines, the integrated values of uncertainties for most emission factors are indicated. This can be used in absence of regional data, if they are normally distributed. However, the analysis of the emission processes in the production of electricity and heat, as well as in many other categories of human activity, shows that these assumptions cannot be used for all model parameters and for all greenhouse gas emissions. Therefore, the results of in-depth studies of individual model parameters for a particular country, region, or company can give a more detailed assessment of uncertainties and corresponding distributions.

Having analyzed all the causes of the uncertainty of the input parameters in emission process models, a next important step is to collect the data relating to each parameter. Ideally, the required information about the uncertainty of each input parameter should be obtained together with the assessment or measurement of the most input data. However, in practice, it is usually difficult or impossible to obtain them. Therefore, for a quantitative assessment of uncertainties of input parameters the best available estimates should be used. These estimates are often a combination of measurement results, published data, modeling results, and expert assessments.

Software for estimation of uncertainties. The process of analyzing uncertainty in spatial inventory of greenhouse gas emissions from electricity and heat generation, as well as for other categories, requires the use of corresponding software tools, adapted to this particular sector or category of economic activity, with appropriate productivity.

For modeling and spatial analysis of the inventory results of greenhouse gas emissions the appropriate software has been created, which makes it possible to investigate the uncertainty values at any level (enterprise, region, country, etc.), and by major categories of the sector of electricity and heat generation, the residential sector, and others.

The software is implemented using Delphi 7.0. Its main part consists of three tabs:

- "Generation data" (provides possibility to input the number of realizations, to choose a greenhouse gas, for which the modeling will be held, to determine probability distributions for each parameter, and visualization of the generated values in the graph);
- "Generation results" (on the basis of the values generated on the first tab, a generated series of output parameters is prepared and its basic characteristics data are displayed in the appropriate fields, i.e.: the width of interval, the number of partitions, the expected value, the lower and upper bounds of uncertainty range);
- "Histogram" (the histogram is created, using the generated series).

An important component of the program implementation is an Excel input file, obtained on the basis of the georeferenced database created, of point- and area-type emission sources for electricity and heat generation, as well as for other categories of activity. This file contains information about the amount of fuel consumed by corresponding sources of emissions, the emission coefficients for greenhouse gases, net calorific values of the fuels, and the bounds of the 95% confidence interval for each of the parameters used.

The developed software tool is based on the algorithm of modeling uncertainties of the spatial inventory results of greenhouse gas emissions. It consists of the following main steps:

1) for each subcategory 1.A.1.a (in the IPCC Guidelines), and for all input parameters of each emission source (point-type for power generation, and area-type for heat production, as an example) determine the average values and individual distribution density functions;

2) for each source of emission, type of fossil fuel, and greenhouse gas, generate a random value for each parameter, such as activity data, emission factors, and net calorific value of fuel, within the sets of the distribution functions of random variables generated in the first step;

3) use the random values of input parameters, generated for each emission source, for estimation of annual emissions, based on a mathematical model of the emission process, i.e. a single value for each emission source in category under investigation is calculated;

4) calculate the total emissions for all sources included in the input Excel file;

5) calculate the expectation μ_i and the uncertainty U_i, using the results of all the previous iterations of computing, where *i* is the number of iteration of resulting value (total emission) in the current iteration;

6) repeat the steps 2-5, if $|\mu_i - \mu_{i-1}| > \Delta\mu$ or $|U_i - U_{i-1}| > \Delta U$, where $\Delta\mu$ and ΔU are acceptable accuracies of the results. Otherwise stop.

The developed software tool is versatile for the analysis of inventory uncertainty of greenhouse gas emissions. It is only required from the user to form an input file on the basis of georeferenced database, and to specify the distribution law for each parameter of the mathematical model.

Analysis of the required number of realizations. An important element of uncertainty modeling of greenhouse gas inventories using Monte-Carlo method is to determine the required number of realizations. The Monte-Carlo method enables the use of the well-known statistical methods for evaluating the accuracy of the results.

As demonstrated in (Bun, 2009), the number of realizations must meet the condition

$$N > \left(\frac{2c\sigma}{\omega}\right)^2, \tag{2.1}$$

where c is the bound of α=0,95 confidence interval for normally distributed values $\Phi \approx N(0,1)$, i.e. $P(-c < \Phi < c) = \alpha$, σ is the standard deviation, ω is the width of the interval, in which the estimate of mathematical expectation falls with probability α. However, in inventories of greenhouse gases from electricity and heat production, as well as in some other categories, the variables are characterized by the distributions different than the normal one. Therefore, the expression (2.1) is in general inapplicable to determine the number of realizations in Monte-Carlo method.

For mathematical models, which include the values undergoing non-normal distributions, the required number of realizations in the Monte-Carlo method can be determined experimentally. To do this, first the experiments have to be conducted with a small number of realizations to obtain the values for the lower and upper limits of the 95% confidence interval. Next, the number of realizations should be increased, untill the value of the upper and lower boundaries of the interval of uncertainty satisfy the required accuracy.

References

BDL, 2014. Bank Danych Lokalnych, Warszawa, Główny Urząd Statystyczny. Available online at: http://www.stat.gov.pl/bdl/

Bun A., 2009. Methods and tools for analysis of greenhouse gas emission processes in consideration of input data uncertainty. Dissertation, Lviv Polytechnic National University

EMEP, 2007. EMEP/CORINAIR Emission Inventory Guidebook – 2007. Technical Report No. 16, Copenhagen, Denmark: European Environment Agency. Available online at: http://reports.eea.europa.eu/EMEPCORINAIR5/en/page002.html

Galelo F.J., 2010. A population density grid of the European Union. Popul Environ, 31:460-473, DOI 10.1007/s11111-010-0108-y

GHG, 2007. Greenhouse gas emissions estimation and inventories. Addressing uncertainty and accuracy, IPIECA, London, pp. 24.

Gospodarka, 2010. Gospodarka paliwowo-energetyczna w latach 2008, 2009: Informacje i opracowania statystyczne, Warszawa, Główny Urząd Statystyczny, 2010, 369.

GUS (2012) Local database, Central Statistical Office, Poland, http://www.stat.gov.pl/bdl/app/strona.html?p_name=indeks

Hamal Kh., 2008. Carbon dioxide emissions inventory with GIS, Artificial Intelligence (Isskusstvienniy Intellect), Donieck, Ukraine, No. 3, 55-62.

Marland, 2009. Marland G., Hamal Kh., Jonas M. How uncertain are estimates of CO2 emissions?, Journal of Industrial Ecology, Yale University, USA, vol. 13, No. 1, pp. 4-7.

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Eggleston H.S., Buendia L., Miwa K., Ngara T., Tanabe K. (eds), IPCC, IGES, Japan, 2006.

NIR, 2011. Poland's National Inventory report 2011: Greenhouse Gas Inventory for 1988-2009. National Centre for Emission Management at the Institute of Environmental Protection – National Research Institute, Warszawa, May 2011. Available online at: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5888.php.

NIS, 2012. National Inventory Submissions: 2003-2012, UNFCCC, http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php

Rocznik, 2010. Rocznik statystyczny województw, Warszawa: Główny Urząd Statystyczny, 814.

Transport, 2011. Transport – wyniki działalności w 2010 r.: Informacje i opracowania statystyczne, Warszawa, Główny Urząd Statystyczny, 268.

Zużycie, 2010. Zużycie paliw i nośników energii w 2009 r, Warszawa, Główny Urząd Statystyczny, 15.