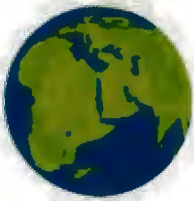

4th International Workshop on Uncertainty in Atmospheric Emissions

7-9 October 2015, Krakow, Poland

PROCEEDINGS

IBS PAN

IIASA

KRAKÓW

krakow.pl

4th International Workshop on Uncertainty in Atmospheric Emissions

7–9 October 2015, Kraków, Poland

PROCEEDINGS

Warszawa 2015

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

Printed from the material submitted by the authors.

ISBN 83-894-7557-X
EAN 9788389475572

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.

Steering Committee

Rostyslav BUN (Lviv Polytechnic National University, UA)
Matthias JONAS (International Institute for Applied Systems Analysis, AT)
Zbigniew NAHORSKI (Polish Academy of Sciences, PL) – Chair

Scientific Committee

Evgueni GORDOV (Siberian Center for Environmental Research & Training, RU)
Piotr HOLNICKI-SZULC (Polish Academy of Sciences, PL)
Joanna HORABIK-PYZEL (Polish Academy of Sciences, PL)
Olgierd HRYNIEWICZ (Polish Academy of Sciences, PL)
Katarzyna JUDA-REZLER (Warsaw University of Technology, PL)
Petro LAKYDA (National University of Life and Environmental Sciences of Ukraine, UA)
Myroslava LESIV (Lviv Polytechnic National University, UA)
Gregg MARLAND (Appalachian State University, USA)
Sten NILSSON (Forest Sector Insights AB, SE)
Tom ODA (Univ. Space Research Association, NASA Goddard Space Flight Center, USA)
Stefan PICKL (Universität der Bundeswehr München, Germany)
Elena ROVENSKAYA (International Institute for Applied Systems Analysis, AT)
Kazimierz RÓŻAŃSKI (AGH University of Science and Technology in Cracow, PL)
Dmitry SCHEPASCHENKO (International Institute for Applied Systems Analysis, AT)
Anatoly SHVIDENKO (International Institute for Applied Systems Analysis, AT)
Jacek SKOŚKIEWICZ (National Centre for Emissions Management, PL)
Philippe THUNIS (EC Joint Research Centre Ispra, EU)
Marialuisa VOLTA (University of Brescia, IT)

Local Organizing Committee

Joanna HORABIK-PYZEL
Jolanta JARNICKA - Chair
Weronika RADZISZEWSKA
Jörg VERSTRAETE

Spatial GHG inventory in the Agriculture sector and uncertainty analysis: A case study for Poland

Nadiia Charkovska[1], Rostyslav Bun[1,2], Olha Danylo[1,3],
Joanna Horabik-Pyzel[4], Matthias Jonas[3]

[1]Lviv Polytechnic National University, St.Bandery, 12, Lviv, 79013, Ukraine,
mail: charkovska.n@gmail.com;
[2]Academy of Business in Dąbrowa Górnicza, Poland
[3]International Institute for Applied Systems Analysis, Laxenburg, Austria;
[4]Systems Research Institute of the Polish Academy of Sciences, Warsaw, Poland

Abstract

Estimation of uncertainties is an important part of complete inventory of greenhouse gas (GHG) emissions. Information on uncertainty is intended not only to question the reliability of inventory estimates, but to assist in the identifying priority measures to improve the quality of future inventories. This article discusses bottom-up inventory from the agricultural sector in Poland. Accordingly to the developed geoinformation approach area-type sources of emission (arable lands, rural localities) were investigated. In implemented mathematical models for the estimation of GHG emissions from agricultural activity the statistical data on animal and crop production, as well as specific emission factors were used. Methods for the spatial inventory of GHG emissions from agricultural sources, taking into account the specifics of animal nutrition, are described. Monte-Carlo method was applied for a detailed estimation of uncertainty "from category to category," because uncertainties of input parameters (CH_4 and N_2O emission factors) are large and non-normally distributed (95% confidence interval). The land use map is used to calculate the territorial distribution of GHG emissions. The structure of total GHG emissions on different categories of animal sector and agricultural soils sector by type of GHG is presented and visualised as digital maps. Analysis of uncertainty of GHG inventory results were carried out for voivodeships. Results are presented as sets of numerical values of the bounds of confidence intervals for the main GHGs and at different levels of spatial disaggregation. The improving of knowledge on territories, where emissions took places, enables us to better inventory process and reduce the overall uncertainty.

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

1. Introduction

During the last century the environment has experienced a lot of irreversible changes. Equally serious impact of global climate change felt the economies of many world countries and humanity in general. Most of scientists in the field of climate changes research affirm that climate change is largely, except natural factors, influenced by results of anthropogenic action. According to the latest assessment report of the IPCC the human activity from 95-100% degree of confidence is the main reason of climate changes after 1950. First of all anthropogenic factors include increasing the concentration of greenhouse gases (GHG) in the Earth's atmosphere and its pollution with the tiniest solid particles. For example, in Ukraine and Poland we are watching more frequent droughts and floods, which are the main reason of agriculture productivity reduction. Apart from the energy sector, a significant share in terms of GHG emissions belongs to agricultural activity.

The IPCC has developed a universal traditional methodology of GHG inventory in different categories of anthropogenic activity [9]. Using of these methods makes it possible to form national reports about GHG emissions and provides emissions assessment at the level of the whole country. General methods are ineffective for evaluation of emissions at the regional level, because they don't take into account the specifics of emission processes and irregularity of territorial distribution of the emission sources. At the same time, it's more useful to implement the essentially new spatial inventory of GHG emissions with the possibility of assessment on small areas of territory and building spatial emission inventories in order to plan the strategic development of individual regions. It's also important that GHG inventory loses its significance, without the uncertainty analysis of input and output data (statistical information about the results of anthropogenic activity, the emission factors, the emission estimates) [4].

Below an approach is presented for spatial inventory of GHG emissions in agriculture sector in Poland. For all categories of this sector covered by IPCC Guidelines [9], we analyzed the sources of emissions in terms of their spatial representation. Such emission sources can be analyzed as area-type (diffused) objects. We built the digital maps of the sources using Corine Land Cover vector map [7], and analyzed them as polygons without using any regular grid, as it is often made. Such elementary objects are split by administrative boundaries regions/voivodeships, districts/powiats, and municipalities/gminas. It gives us a possibility to keep administrative assignment of each elementary object. Then we created the algorithms for calculating GHG emissions from these objects using activity data and emission coefficient. For the activity data assessment, we have developed the algorithms for disaggregation of available statistical data (at the lowest level as possible) to the level of elementary objects.

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 GHG emissions caused by enteric fermentation, manure management, agricultural soils etc. (according to the agriculture sector structure in the IPCC Guidelines [9]). Maximum resolution is determined by the resolution of used digital maps of land use and does not exceed 100m. Below, this approach is illustrated on the example of animal sector only.

2. The specificity of greenhouse gases emissions processes

Animal sector, as one of the subsectors of agriculture, plays a very important ecological, economic and social role in various parts of the world. The emissions of GHG from animal sector occur as a result of the animals enteric fermentation (dairy and non-dairy cattle, sheep, goats, horses and pigs), and also the decomposition, collection, storage and use of animal manure in various storage systems (manure reservoir in solid and liquid forms separately). However, the scientific literature has not evaluated the long-term trend of GHG emissions from animal sector separately for developed and developing countries [4].

Except animals, the cultivated lands (arable lands), where agricultural crops grow that are manured by various kinds of fertilizers, and thanks to them the processes of leaching and runoff of nitrogen take place, and it can be considered polygonal (area-type) sources of emissions. The changes in agricultural production and, consequently, changes in GHG emissions since the mid-1990s were mainly caused by adaptation to the demand in the domestic market, priorities of international trade, the prices of agricultural means of production, such as machinery and agricultural prices. Since 2004, when Poland joined the European Union agricultural subsidies started to influence on the development of promising tendencies of agriculture.

An analysis of statistical information of livestock numbers in Poland in 2010 showed that in one municipality/gmina the number of pigs was over 800 thousands [1,2]. Despite strong criticism of environmentalists in this gmina in 2004 it was opened two large pig farms. This case and many others show that emission territorial distribution in animal subsector is essentially non-uniform. Therefore we need tools for spatial analysis of GHG emissions, which will give an opportunity for experts and authorities to take effective measures to reduce emissions in areas where they are high [6].

3. Mathematical models for spatial inventory

During modeling the emission processes in animal subsector in Poland (in categories "Enteric Fermentation" and "Decomposition, collection, storage and use of animal manure") the several presumptions were used. Especially, because there is no possibility to monitor emissions from individual animals, so we estimate total emissions from all animals of one species within each rural locality in general. In proposed mathematical models was taken into account the fact that the Polish statistical data on livestock and poultry served separately for agricultural enterprises and households (population) in gminas/municipalities. It's assumed that the number of animals in the households are distributed geographically between rural settlements in proportion to gmina rural population.

The ratio of the population in the analyzed elementary object to the population in gmina can be calculated as:

$$V(\delta_n)=\frac{p(\delta_n)\cdot area(R_{3,n_3}\cap\delta_n)}{P(R_{3,n_3})},\quad n=\overline{1,N}, \tag{1}$$

where $V(\delta_n)$ is the desired share of the population in the n-th elementary object δ_n; N is the total number of such objects in Poland; $p(\delta_n)$ is the population density in the n-th elementary object; $P(R_{3,n_3})$ is the number of people in gmina; R_{3,n_3} is the third level of administrative unit, which includes the n-th elementary object, that is $\delta_n \subset R_{3,n_3}$ (geographical object δ_n is within the geographic object R_{3,n_3}), besides that $n_3 \in \left[\overline{1,N_3}\right]$; N_3 is the number of gminas in Poland; *area (x)* is the area of object x, $\cap$ is the operation of intersection of the common area of two geographic objects. Further, this parameter $V(\delta_n)$ is used as an indicator for disaggregation of known statistical data on the number of animal livestock within gmina to the level of elementary objects.

Geographically the farms are located on agricultural lands, that's why statistical data on livestock and poultry within these farms are disaggregated to the level of elementary objects in proportion to the area of agricultural land (arable land, grassland, etc.) using the formula:

$$S(\delta_n)=\frac{\sum\limits_{f_i\in F} area(f_i\cap\delta_n)}{\sum\limits_{f_j\in F} area(f_j\cap R_{3,n_3})},\quad \forall f_i\cap\delta_n\neq 0,\quad f_j\cap R_{3,n_3}\neq 0,\ n=\overline{1,N}, \tag{2}$$

where $S(\delta_n)$ is the ratio of the sum of areas of agricultural lands $f_i \in F$, that are located within elementary area δ_n, to the sum of such areas of lands in the gmina R_{3,n_3}, which contains this elementary object, that is $\delta_n \subset R_{3,n_3}$, F is the set of elements of digital map of land use of the whole country that are agricultural lands.

The methane emissions from enteric fermentation of animals, which are owned by population and by agricultural enterprises, can be calculated using mathematical model:

$$E^{\mathrm{CH}_4}_{EntFerm}(\delta_n) = \sum_{t=1}^{T} \left[A_t^{ind}(R_{3,n_3}) \times V_t(\delta_n) + A_t^{agr}(R_{3,n_3}) \times S_t(\delta_n) \right] \times K_t^{\mathrm{CH}_4}(\delta_n), \quad n = \overline{1,N}, \quad (3)$$

where $E^{\mathrm{CH}_4}_{EntFerm}(\delta_n)$ is the total annual emissions of methane in the n-th elementary object δ_n; $A_t^{ind}(R_{3,n_3})$ and $A_t^{agr}(R_{3,n_3})$ are the statistical data on the number of the t-th animal species (dairy cattle, non-dairy cattle, sheep, goats, horses, pigs, poultry) in individual households (rural population) (*ind*) and agricultural enterprises (*agr*) for the appropriate year in gmina R_{3,n_3}, which contains this elementary object δ_n; $V_t(\delta_n)$ and $S_t(\delta_n)$ are the coefficients calculated using formulas (1) and (2) for disaggregation of statistical data on livestock of the t-th animal species, accordingly, in households and agricultural farms, from R_{3,n_3} gmina level to the level of elementary object δ_n; $K_t^{\mathrm{CH}_4}(\delta_n)$ is the coefficient of methane emission from enteric fermentation for the t-th animal species in the n-th elementary object (in fact, this coefficient depends on the climate zone, in which this object is located); *EntFerm* is the index that means emissions from enteric fermentation.

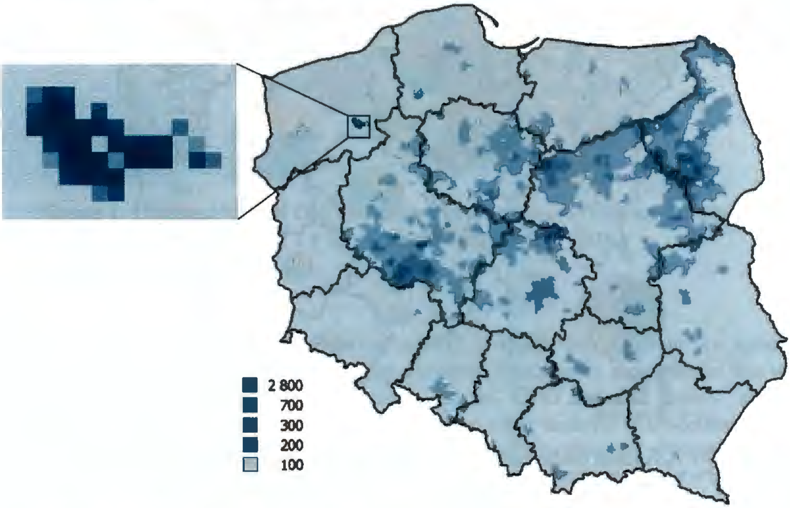

Figure 1. The specific total GHG emissions in animal sector in Poland (elementary areas 2 x 2 km; Mg/km^2, CO_2-equivalent, 2010)

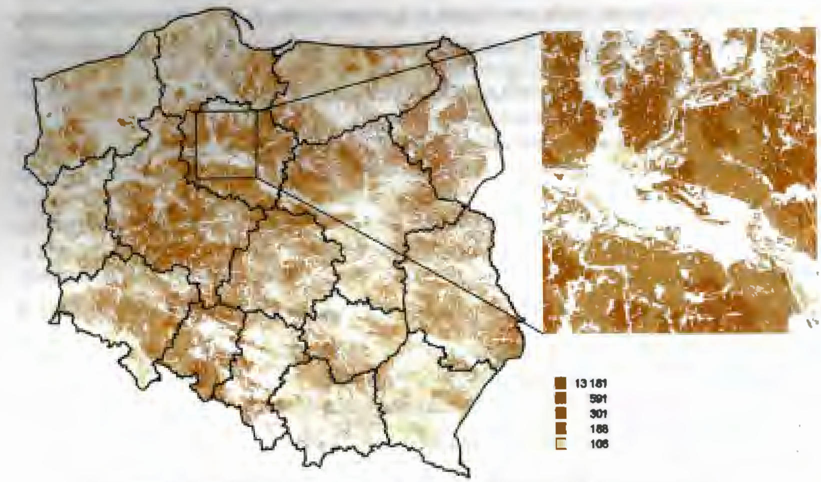

Figure 2. Specific N_2O emissions from fertilization of arable lands in Poland (kg/km^2, 2010)

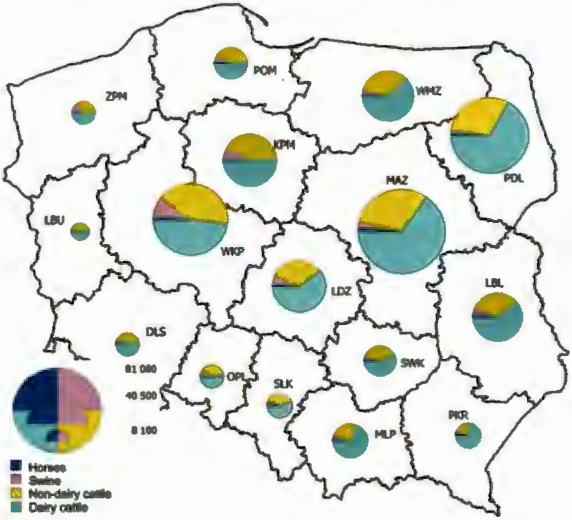

Figure 3. Annual emissions of methane from enteric fermentation of agricultural animals in the voivodeships in Poland (tons, 2010)

4. The results of spatial inventory

Developed mathematical models gave the opportunity to obtain spatial estimates of GHG emissions for each source category in the agricultural sector. The results of computational experiments showed that the largest methane emissions in the agricultural sector occurred as a result of enteric fermentation of farm animals, such as dairy and non-dairy cattle. In such a way, the results of spatial inventory were obtained at the level of elementary areas (see an example in Figure 1), at the level of arable lands or rural settlements (see an example in Figure 2). The spatial inventory results can be aggregated to the larger area-type objects like the voivodeship in Poland (see Figure 3). The total GHG emissions in the agriculture sector are presented in Figure 4.

As we can see in Figure 3, the biggest emissions of methane in the animal subsector are in the Mazovian voivodeship (80,694 tons), Greater Poland (60,956 tons), and Podlaskie (66,266 tons), but the least is in the Lubusz voivodeship (5,190 tons). The total emissions of methane from enteric fermentation of all species in 2010 amounted to 434.7 ths. tons, that is 75% of total emissions of this gases in animal sector and the rest of 25% is caused by decomposition of manure.

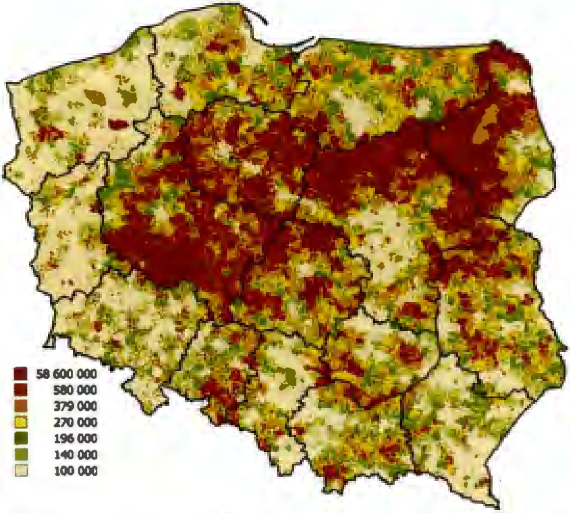

Figure 4. The specific total GHG emissions in the agriculture sector in Poland (elementary areas 2 x 2 km, kg, CO_2-equivalent, 2010)

5. Uncertainty analysis

Input data for developed mathematical models of spatial inventory are not known exactly, and they can be simulated as random variables. For example, the statistical data on livestock population and the specific animal species' GHG emission factors can be attributed to random variables. Currently, one of the main methods of modelling GHG emissions taking into account uncertainty, 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 areas, regions and the country as a whole.

The resulting emissions uncertainties in the agricultural sector were analyzed at the level of voivodeships/regions, particularly from enteric fermentation of farm animals (cows, non-dairy cattle, sheep, goats, horses and pigs). As for the uncertainty of statistical data on these animal livestocks, it should be noted that the accuracy of the data depends greatly on the completeness and reliability of the national census methods. In addition, in the census there are different rules for accounting of agricultural animals that don't live during the year, such as pigs, so this should be considered during analysis of emissions uncertainty. Another source of emissions uncertainty from livestock is the use of various data in the formulas to calculate methane emission factor [5].

In the implemented mathematical models of GHG emissions evaluation the agriculture statistical data are used, which uncertainty range for animals is 5% (symmetrical distribution). For modeling GHG emissions in the category "Enteric Fermentation" by Monte-Carlo method the methane emissions factor for agricultural animals (IPCC Guidelines [9]) and appropriate uncertainty ranges (50%, symmetrical [8]) were used. On the basis of implemented geospatial database and developed approach to analysis of uncertainties of GHG emissions were realized computational experiments with the using Monte Carlo method on the investigation of GHG emissions uncertainty from enteric fermentation of agricultural livestock. The results were obtained at the level of voivodeships in Poland (according to statistical data of 2010). Results are presented in Table 1.

Table 1. Input data for the uncertainty analysis of methane emissions from enteric fermentation in region of Poland (2010)

	CH_4 emissions, tons The limits of uncertainty range, %					
Voivodeship	Dairy cattle	Non-dairy cattle	Pigs	Horses	Sheep	Goats
Lower Silesian	4674,4 ±50,3	3186,1 ±50,1	419,7 ±50,2	203,1 ±50,2	102,6 ±50,2	32,3 ±50,3
Kuyavian-Pomeranian	17143,3 ±50,3	14177,9 ±50,2	2684,2 ±50,2	172,1 ±50,3	111,4 ±50,2	15,0 ±50,2
Lublin	18223,2 ±50,4	14156,3 ±50,2	1510,1 ±50,3	546,6 ±50,3	133,5 ±50,3	62,5 ±50,3
Lubusz	2879,5 ±50,3	2114,8 ±50,4	300,6 ±50,2	107,2 ±50,3	33,6 ±50,2	9,6 ±50,2
Łódż	21064,7 ±50,3	11696,9 ±50,4	1959,4 ±50,1	271,5 ±50,3	120,7 ±50,2	25,6 ±50,2
Lesser Poland	10986,5 ±50,3	4371,4 ±50,3	541,2 ±50,2	385,1 ±50,2	575,4 ±50,3	89,5 ±50,2
Masovian	52734,1 ±50,4	25303,7 ±50,2	2115,5 ±50,1	856,4 ±50,2	72,9 ±50,3	31,6 ±50,2
Opole	4698,3 ±50,3	3674,8 ±50,2	901,3 ±50,2	72,9 ±50,3	23,6 ±50,2	14,1 ±50,3
Subcarpathian	7266,6 ±50,3	2081,6 ±50,3	448,7 ±50,2	318,1 ±50,3	152,8 ±50,3	76,2 ±50,3
Podlaskie	44430,2 ±50,3	20639,0 ±50,3	827,5 ±50,3	363,2 ±50,2	173,0 ±50,2	15,8 ±50,2
Pomeranian	7428,6 ±50,3	5941,1 ±50,2	1262,6 ±50,1	257,4 ±50,3	133,6 ±50,3	14,8 ±50,2
Silesian	5230,6 ±50,2	3670,7 ±50,1	524,8 ±50,2	155,4 ±50,3	110,9 ±50,2	42,6 ±50,2
Świętokrzyskie	7761,7 ±50,4	5056,4 ±50,2	603,4 ±50,2	213,6 ±50,3	33,1 ±50,2	26,3 ±50,3
Warmian-Masurian	20538,9 ±50,4	11384,5 ±50,3	1025,1 ±50,1	300,3 ±50,2	84,5 ±50,2	19,6 ±50,2
Greater Poland	29543,7 ±50,3	26487,1 ±50,2	5879,3 ±50,2	376,8 ±50,2	196,0 ±50,2	92,0 ±50,2
West Pomeranian	4225,2 ±50,4	3042,0 ±50,1	1815,9 ±50,1	159,5 ±50,2	103,8 ±50,2	15,8 ±50,2

The Monte Carlo method was also used for estimation of emissions uncertainty from applying mineral ammonia fertilizers to soils in Poland (on data of 2010). Based on the results of modelling in main categories of animal sector and agricultural soils sector, the uncertainty ranges of emissions amounted to ±12,7% for CH_4 emissions from enteric fermentation and -51,2% : + 64,1% for N_2O emissions from synthetic fertilizers applied to soils (symmetric normal distribution and asymmetric log-normal distribution are used). The verification of the correctness of realized mathematical and software tools was carried out using Polish national annual reports [10] on GHG emission at the country level as a whole. The obtained results show a high uncertainty of inventory results in the agricultural sector in 2010.

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

Thus the problem of determining of the categories of economic activities, which are important in terms of sensitive analysis, is very interesting. It means that overall uncertainty of inventory results is the most sensitive to the changes in uncertainty of input parameters [2]. Figure 5 illustrates graphically a sensitivity of uncertainty of CO_2-equivalent emissions from the agricultural activity. The results show that the relative uncertainty for methane emissions is the more dependent on the uncertainty of statistical data on livestock numbers than on the uncertainty of CH_4 emission factor. The uncertainty of total CH_4 emissions in animal sector depends on improving the knowledge about census results. For example, the reduction of uncertainty ranges of animal population into 40% causes the decreasing of CH_4 emissions uncertainty in a half.

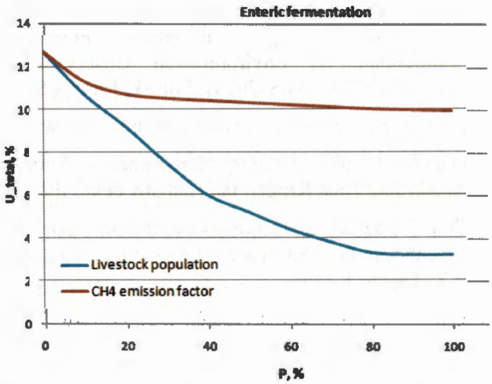

Figure 5. Dependence of uncertainty of CH_4 emissions in enteric fermentation of livestock during decreasing uncertainty of input data into ***P*** percent (total as for Table 1; Monte Carlo method)

6. Conclusions

The main GHG emission sources in the animal sector in Poland, in particular enteric fermentation, are analyzed in this paper. Mathematical models of emission processes from these sources at the level of elementary objects of fixed size are useful for spatial inventory of GHG emissions. Using geoinformation system tools, the geospatial database of statistical information on the number of livestock in Polish regions is formed. As a result of numerical experiments, the estimates of methane emissions by type of animals at the level of elementary areas 2 x 2 km and at the level of voivodeships are obtained.

The obtained results of the spatial analysis of GHG emissions have been showed not so high uncertainties for emissions from enteric fermentation by respective animal species. It has a positive impact on the uncertainty of total regional or national emissions from all categories of anthropogenic activity.

References

[1] Agricultural census 2010 by holdings headquater; Livestock (cattle, pigs, horses, poultry), Available online at: http://www.stat.gov.pl

[2] Bank Danych Lokalnych (Local Data Bank), GUS, Warsaw, Poland, Available at: http://stat.gov.pl/bdl

[3] Boychuk Kh., Bun R. (2014) Regional spatial cadastres of GHG emissions in Energy sector: Accounting for uncertainty, Climatic Change, 124(3), 561-574.

[4] Bun R., Hamal Kh., Gusti M., Bun A. (2010) A spatial GHG inventory on regional level: Accounting for uncertainty, Climatic Change. Springer Netherlands, 103(1), 227-244.

[5] Caro D., Davis S.J., Bastianoni S., Caldeira K. (2014) Global and regional trends in greenhouse gas emissions from livestock, Climatic Change, 126, 203-216.

[6] Charkovska N.V., Bun R.A. (2014) Mathematical modeling and spatial analysis of GHG emissions processes from Agriculture sector of Poland, Proceedings of the International Conference on Environmental Observations, Modeling and Information Systems (ENVIROMIS-2014), Tomsk, Russia, SCERT, 76-77.

[7] Corine Land Cover 2006 raster data, Available at: http://www.eea.europa.eu/

[8] Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Penman Jim, Dina Kruger, Ian Galbally et al.; IPCC, 2001.

[9] IPCC (2006) IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds)

[10] Poland's National Inventory Report 2012, KOBIZE, Warsaw, 2012, 358 p., Available online at: http://unfccc.int/national_reports