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Geoinformation Technologies and Spatial Analysis of GHG Emissions in Polish Regions Bordering Ukraine

The specificity of territorial distribution of the GHG emission sources has been analyzed for polish regions bordering Ukraine. Mathematical models and geoinformation technology for spatial analysis of GHG emissions in the Energy sector that consider the territorial distribution of GHG emission sources and the structure of statistical data for Polish regions Lublin and Subcapathian are developed. The results of spatial analysis for the Lublin and Subcapathian voivodeships are presented.

Introduction

Climate change is one of the main global problems that we face nowadays. Scientists assert that the increase in concentration of anthropogenic green house gases (GHGs) in the atmosphere is the main reason of the global warming. That’s why an agreement in the reductions of GHG emissions is the primary issue of international negotiations. It is very important to accurately assess GHG emissions and produce relevant reports in order to verify the fulfilment of international obligations.

To estimate the effectiveness of GHG emission reduction measures one must have information on GHG sources and sinks at the level of individual regions, not only at the national (country) level. Therefore, countries are encouraged to develop their own mathematical models to assess the processes of GHG emission/absorption. Ukrainian scientists such as Bun R., Hamal H., Yaremchyshyn O. have made a large contribution to the creation of mathematical models and carrying out the spatial analysis of greenhouse gas emissions in different sectors of human activity. From abroad Costa M., Winiwarter W., Webber P. H., Gregg J. S., Lindley S. J., Oda T., Olivier J. G. J., Friedrich R., Bachman W., Brandmeyer J should be denoted.

In the border regions of Ukraine the spatial GHG inventory that would fully encompass a certain sector of human activity has not been conducted. For example, in the Polish voivodeships of Lublin and Subcarpathian the spatial GHG inventory has been done only in the category of households of the energy sector [7], [11]. So, there is a need to modify the mathematical models for spatial GHG inventory taking into account regional characteristics and structure of statistical data on economic activities in these border areas.

Administrative division in Poland

The territory of Poland is divided into the following administrative units: voivodeships (in Polish it is województwo), powiats (in Polish it is powiat) and gminas (in Polish it gmina). Voivodeship is the largest territorial and administrative unit in Poland.

Powiat is a unit with local government. Gmina is the smallest administrative unit in Poland, for an example a city, a village or a group of villages and towns. In total Poland has 16 voivodeships, which are divided into 308 powiats, and the last one into 2469 gminas.

The two polish voivodeships Lublin and Subcarpathian (Lubelskie and Podkarpackie) border western part of Ukraine. The spatial inventory of GHGs only in the category of households has already been made for these regions [7], [11].

Voivodeship of Lublin

The voivodeship of Lublin is characterized with the low level of urbanization. Administratively the region is divided into twenty powiats, four cities with powiat status and 213 gminas. Lublin is a center of voivodeship [4], [9].

Good soil and climatic conditions are favourable to the development of agriculture. Therefore, voivodeship of Lublin is one of the main centers of agricultural production. Chemical and machine-building enterprises are developed as well. Geographically the voivodeship is located on the polish border with Ukraine and Belarus. Therefore important international highways: from Brussels, Berlin, Warsaw to Lviv, Kyiv, Minsk, Odessa and Moscow are crossing its territory. Almost half of the border passenger and half of all traffic flow through the eastern border of Poland. One of the most modern cargo terminals in Europe operates in Koroschyn and there is the largest in this part of the continent dump railway in Malaszewicze.

The long-term evaluation of air pollution in the voivodeship of Lublin shows that air pollution (including GHGs) is negligible in comparison with other regions, except urban areas, where GHG emissions and other pollutants are significant.

Subcarpathian voivoideship

Subcarpathian voivodeship is divided administratively into 21 powiats and four cities with powiat status, and 159 gminas [5]. The capital of the vovodeship – Rzeszów. Almost half of the territory is covered with forests, national parks. For example, Bieszczady and Mahurskyy national parks, 70 nature reserves, many mineral springs and health resorts.

Subcarpathian voivodeship is characterized by the lowest level of industrialization to compared with other voivodeships. The area is in good ecological condition. The main sources of greenhouse gases and pollutants are households, industry and transport. Almost 67% of GHG emissions are caused by surface sources, including households, 21% is industry, 12% is road transport [10].

GHG inventory in Energy sector

Most of the estimates of carbon dioxide emissions in the energy sector are based on the data concerning fossil fuel consumption. Emissions are calculated as the product of amount of fuel burned, the carbon content in fuel consumption efficiency (example, the proportion of fuel that is not oxidized). The fuel fraction which is not oxidized is quite small in modern systems of fuel consumption. The IPCC recommends assume that 100% of carbon in fuel is oxidized. Amount of consumed fuel could be measured, but it is really difficult to measure carbon content. There is a good correlation between the share of carbon in the fuel and the amount of energy released from burning, so the transfer of consumed fuel per unit of mass or volume to energy units enables to take into account the carbon content in it [1], [3]. Required inventory data on fuel consumption is not always available. In some cases emissions of carbon dioxide can be estimated using mathematical models that reflect the basic processes of consumption, such as the amount of released gas by motor vehicle when passing a certain distance. At the national level it is sometimes appropriate to assess the amount of fuel consumed on the basis of available information on the amount of produced fuel, its imports and exports. However, fuel is not always consumed where it has been purchased. For example, purchased fuel for the ships, aircraft and other vehicles may be burned in different countries.

Quantity of consumed biomass is reported according to the UNFCCC, but the corresponding emission of carbon dioxide isn't reported in such a way. In the process of growing biomass absorbs CO_2 from the atmosphere, but when it is burned the gas again is emitted to the atmosphere. Therefore, the resulting emissions are considered to be "zero". However, emissions from consumed fossil fuel during processes of production, harvesting and transporting biomass are reported in the appropriate categories. When biomass is combined with another type of fuel or waste, the emissions caused by the burning part of the other fuels are only reported. When, for example, pure ethanol is combined with gasoline as fuel, the emissions are reported only those that are caused by the gasoline consumption [1], [6].

Carbon dioxide emissions are estimating by the next steps [1]:

– analysis of the energy sources in the region;
– calculation of carbon in conventional units;
– assessment of contained carbon in products that are made from fossil fuels;
– calculation of the share of burning carbon;
– calculation of CO_2 emissions for all fuels.

CO_2 emissions are calculated as the product of quantity of consumed fuel, the calorific value and the rate of oxidation. The general formula for calculating CO_2 emissions [1]:

$$E = D_{stat} \cdot K_{en} \cdot K_C \cdot F_C \qquad (1)$$

where E is emission, Gg; D_{stat} is activity data in physical units, t; K_{en} is amount of energy released during combustion of 1 ton of material, J / t; K_C is emissions of carbon dioxide per unit of obtained energy, Gg / J; F_C is carbon oxidation factor (in numerical experiments realized it was thought that $F_C = 1$).

The IPCC recommends using an amount of fossil fuel, emission factors and carbon oxidation factors. However, for different categories of human activities and properties of different fuel types these parameters have different values. For better estimation of GHG emissions it is recommended to use emissions factors that were estimated for a certain region and category. Table 1 and Table 2 present the examples of these parameters that were estimated for Polish regions.

For other greenhouse gases (CH_4, N_2O) the emission estimates are based on the statistical data for various sectors of human activity. The amount of emissions depends on the fuel type, processes, conditions of production, type of equipment and methods of monitoring.

Table 1 – CO_2 emission factors for coal [8]

Category of human activity	Calorification K_{en} [MJ/kg]	CO_2 emission factor K_C [kg/GJ]
Power plants	21,10	94,42
Industrial power plantsi	21,51	94,86
Boiler houses	21,65	94,82
Manufacturing and construction	23,87	94,31
Agriculture/forestry/ fisheries and others	25,17	94,05
Average values	22,34	94,65

Table 2 – CO_2 emission factors for other fuel types [8]

Fossil fuel	Calorification [MJ/kg]	CO_2 emission[kg/GJ]
Natural gas	48,0	55,82
Wood	15,6	109,76
Liquid gas	47,31	62,44
Gasoline	44,80	68,61
Diesel	43,33	73,33
Masout	40,19	76,59

Emissions N2O, CH4 and other gases are estimated by the next steps:

- estimating an amount of consumed fuel per year for the certain human activity;
- estimating the basic factors for each type of activity;
- calculating emissions.

The structure of statistical information on consumption of fossil fuels by category in the Polish regions is [2]:

- heat and power plants (according to IPCC sector classification - 1.A.1);
- industrial boilers and other heating units (1.A.1);
- non-industrial boiler-houses (1.A.1);
- industry and manufacturing (1.A.2);
- transport (road, rail, etc.) (1.A.3);
- other sectors including: agriculture and forestry, households, and other (1.A.5).

To carry out spatial analysis of GHG emissions geographic information system (GIS) has been used. GIS allows forming a database on GHG emission sources as geographic features that are characterized by spatial coordinates and results of simulation on digital maps.

As input data for spatial inventory we used digital maps with information on administrative division with population and statistical data on consumption of fossil fuels obtained from special yearbook prepared by Department of Statistics in each polish region. Based on these data the spatial distributed database has been formed. The process of spatial distributed analysis is divided into the following steps:

1) collecting statistical data and forming input databases (for example, Excel, Oracle or Access);

2) splitting the digital maps of investigated areas into elementary objects using grids (for example, grid with resolution of 2 km x 2 km) and disaggregating data on population proportionally to the area of newly created objects;

3) running modules that simulate the processes of GHG emissions in different sectors of human activity for each elementary object;

4) forming thematic maps that illustrate the spatial distribution of GHG.

After splitting regional maps into elementary objects the programmed modules that are based on the developed mathematical models calculate emissions from stationary and mobile sources. The final step is a spatial analysis of the achieved thematic maps with information on the GHG emissions at the level of elementary objects.

Mathematical background

In consistence with the structure of national statistics on the consumption of fuels in Poland stationary sources include:

– heat and power plants;
– boiler and heating installation of industrial facilities;
– non-industrial boilers;
– fuel combustion in industry and construction;
– fuel combustion in agriculture, forestry and fisheries;
– households.

Heat and power plants, industrial and non-industrial boiler-houses have specific locations more often in settlements. As the statistical data is only available concerning total amounts of consumed fuels by category in each voivodeship [2], [8], so this amount should be disaggregated by the number of emission sources. The emissions of a elementary object (area) for a particular voivodeship could be calculated by the formulas:

- emissions from consumption of fossil fuels by heat and power plants:

$$E_{TEC,G,R,i} = \sum_{F\in\Gamma} \frac{D_{TEC,F} \cdot K_{TEC,F,en} \cdot K_{TEC,F,G,em} \cdot P_{R,i}}{\sum_{j\in N_R} P_{R,j}} \cdot \frac{N_{TEC,R}}{N_{TEC}}, \qquad (2)$$

where $E_{TEC,G,R,i}$ is emissions of gas G from burning fuels by heat and power plants for elementary object i that is located in gmina R; $D_{TEC,F}$ is an amount of burned fuel F by heat and power plants; $K_{TEC,F,en}, K_{TEC,F,G,em}$ is a calorification and an emission factor of gas G for burned fuel F by heat and power plants; $N_{TEC,R}$ is account of heat and power plants in gmina R (or other parameter that characterised energy and heat production); N_{TEC} is total account of heat and power plants in voivodeship; N_R is a set of the elementary objects in gmina R; $P_{R,i}$ is population in the elementary object i from gmina R; Γ is a set of all types of fossil fuels;

- emissions from consumption of fossil fuels by industrial boiler-houses:

$$E_{KZ,G,R,i} = \sum_{F\in\Gamma} \frac{D_{KZ,F} \cdot K_{KZ,F,en} \cdot K_{KZ,F,G,em} \cdot P_{R,i}}{\sum_{j\in N_R} P_{R,j}} \cdot \frac{N_{KZ,R}}{N_{KZ}}, \qquad (3)$$

where $E_{KZ,G,R,i}$ is emissions of gas G from burning fuels by industrial boiler-houses for elementary object i that is located in gmina R; $D_{KZ,F}$ is amount of burned fuel F by industrial boiler-houses; $K_{KZ,F,en}, K_{F,KZ,G,em}$ is the calorification and emission factor of gas G for burned fuel F by industrial boiler-houses; $N_{KZ,R}$ is the account of industrial boiler-houses in gmina R; N_{KZ} is total account of industrial boiler-houses in the voivodeship;

- emissions from consumption of fossil fuels by non-industrial boiler-houses:

$$E_{KnZ,G,R,i} = \sum_{F\in\Gamma} \frac{D_{KnZ,F} \cdot K_{KnZ,F,G,en} \cdot K_{KnZ,F,G,em} \cdot P_{R,i}}{\sum_{j\in N_R} P_{R,j}} \cdot \frac{N_{KnZ,R}}{N_{KZ}}, \quad (4)$$

where $E_{KnZ,G,R,i}$ is emissions of gas G from burning fuels by non-industrial boiler-houses for elementary object i that is located in gmina R; $D_{KnZ,F}$ is amount of burned fuel F by non-industrial boiler-houses; $K_{KnZ,F,en}, K_{F,KnZ,G,em}$ is the calorification and emission factor of gas G for burned fuel F by non-industrial boiler-houses; $N_{KnZ,R}$ is the account of non-industrial boiler-houses in gmina R; N_{KnZ} is total account of non-industrial boiler-houses in voivodeship.

Emissions from combustion of fossil fuels in the category of manufacturing and construction should be disaggregated by a gross value of real assets (in million PLN). Gross value of assets - is the cost of acquisition or production of real assets involved in production (excluding depreciation). The emissions of an elementary object (area) for a particular voivodeship could be calculated by the formula:

$$E_{Ind,G,R,i} = \sum_{F\in\Gamma} \frac{D_{Ind,F} \cdot K_{Ind,F,G,en} \cdot K_{Ind,F,G,em} \cdot P_{R,i}}{\sum_{j\in N_R} P_{R,j}} \cdot \frac{V_{Ind,R}}{V_{Ind}}, \quad (5)$$

where $E_{Ind,G,R,i}$ is emissions of gas G from the consumed fuels in manufacturing industries and construction for elementary object i that is located in gmina R; $D_{Ind,F}$ is amount of burned fuel F in manufacturing and construction; $K_{Ind,F,G,en}, K_{Ind,F,G,em}$ is the calorification and emission factor of gas G for burned fuel F in manufacturing industries and construction; $V_{ind,R}$ is a gross value of real assets for gmina R; V_{Ind} is total gross value of real assets for the voivodeship.

The emissions sources of consumed fuels in agriculture, fisheries, and forestry are mainly located in the countryside. So, the GHG emissions in this category could be estimated by the formula:

$$E_{Agr,G,Rs,i} = \sum_{F\in\Gamma} \frac{D_{Agr,F} \cdot K_{Agr,F,G,en} \cdot K_{Agr,F,G,em} \cdot P_{Rs,i}}{\sum_{j\in N_{R_s}} P_{Rs,j}}, \quad (6)$$

where $E_{Agr,G,Rs,i}$ is emissions of gas G from consumed fuels in agriculture, fisheries, and forestry for elementary object i that is located in gmina R; $D_{Agr,F}$ is amount of burned fuel F in agriculture, fisheries, and forestry; $K_{Agr,F,G,en}, K_{Agr,F,G,em}$ is the calorification and emission factor of gas G for burned fuel F in agriculture, fisheries, and forestry; $P_{Rs,i}$ is population of elementary object i for the village-gmina Rs; N_{Rs} is a set of elementary objects that are located in the gmina Rs.

The emission sources of consumed fuels in the households or other small activities are difficult to detect, so it is assumed that burned fuels in these category are disaggregated by population in each elementary area in the voivodeship:

$$E_{Other,G,i} = \sum_{F\in\Gamma} \frac{D_{Other,F} \cdot K_{Other,F,G,en} \cdot K_{Other,F,G,em} \cdot P_i}{\sum_{j\in\mathrm{N}} P_j}, \qquad (7)$$

where $E_{Other,F,G,i}$ is emissions of gas G from consumed fuels in households or other small activities for elementary object i that is located in gmina R; $D_{Other,F}$ is amount of burned fuel F in households or other small activities; $K_{Other,F,en}$ and $K_{Other,F,G,em}$ are the calorification and emission factor of gas G for burned fuel F in households or other small activities; P_i is population of the elementary object i; N is a set of elementary objects, $\mathrm{N} = \bigcup_{R\in\Phi} \mathrm{N}_R$, where Φ is a set of all gminas in the voivodeship.

Total emissions from the stationary sources are calculated by the formula:

$$E^{stac}_{F,G} = \sum_{R\in\Phi}\sum_{i\in\mathrm{N}_R}\left(E_{TEC,F,G,R,i} + E_{KZ,F,G,R,i} + E_{KnZ,F,G,R,i} + E_{Ind,F,G,R,i}\right) + \\ + \sum_{Rs\in\Phi_s}\sum_{i\in\mathrm{N}_{Rs}} E_{Agr,F,G,Rs,i} + \sum_{i\in\mathrm{N}} E_{Other,F,G,i}, \qquad (8)$$

where $E^{stac}_{F,G}$ is emissions of gas G from consumed fuel F-th by the stationary sources; Φ_s is a set of the village-gminas.

Emissions from mobile sources (line type), for an example a road transport, are calculated by the formula:

$$E_{road,G,i} = \sum_{F\in\Gamma} \frac{D_{road,F} \cdot K_{em,G,F} \cdot K_{road,i}}{\sum_{j\in\Omega} K_{road,j}}, \qquad (9)$$

where $E_{road,G,i}$ is emissions of gas G from consumed fossil fuels in elementary object i; $D_{road,F}$ is amount of consumed fuel F; $K_{em,F,G}$ is gas G emission factor for fuel F; $K_{road,i}$ is a traffic factor on the elementary part of the road i; Ω is a set of the elementary objects of the roads in the voivodeship.

Emissions from other mobile sources, i.e. railways, are calculated by the formula:

$$E_{rail,G,i} = \frac{D_{rail} \cdot K_{em,G} \cdot K_{rail,i}}{\sum_{j\in\Xi} K_{rail,j}}, \qquad (10)$$

where $E_{rail,G,i}$ is emissions of gas G from the consumed diesel in the elementary object i; D_{rail} is amount of diesel ; $K_{em,F,G}$ is gas G emission factor for diesel; Ξ is a set of elementary objects of railways in the voivodeship; $K_{rail,i}$ is a traffic factor on the elementary part of railway i.

Numerical modeling

Geoinformation technology based on the developed mathematical models has been created using tools of MapInfo and MapBasic. With its help the spatial analysis of CO_2, N_2O, CH_4 emissions in the energy sector for Lublin and Subcarpathian voivodeships has been done. The results are presented in the form of digital maps. For an example, figure 1 shows the total GHG emission in the energy.

Total GHG emissions in the voivodeship of Lublin are higher than in the Subcarpathian voivodeship. This is due to the fact that the voivodeship of Lublin is characterized by a higher level of urbanization and industrialization. The significant emission sources are located mainly in Pulawy, Lublin, Holm. In contrast the Subcarpathian voivodeship is an important agricultural center, the emission sources are located more or less evenly, depending on population density.

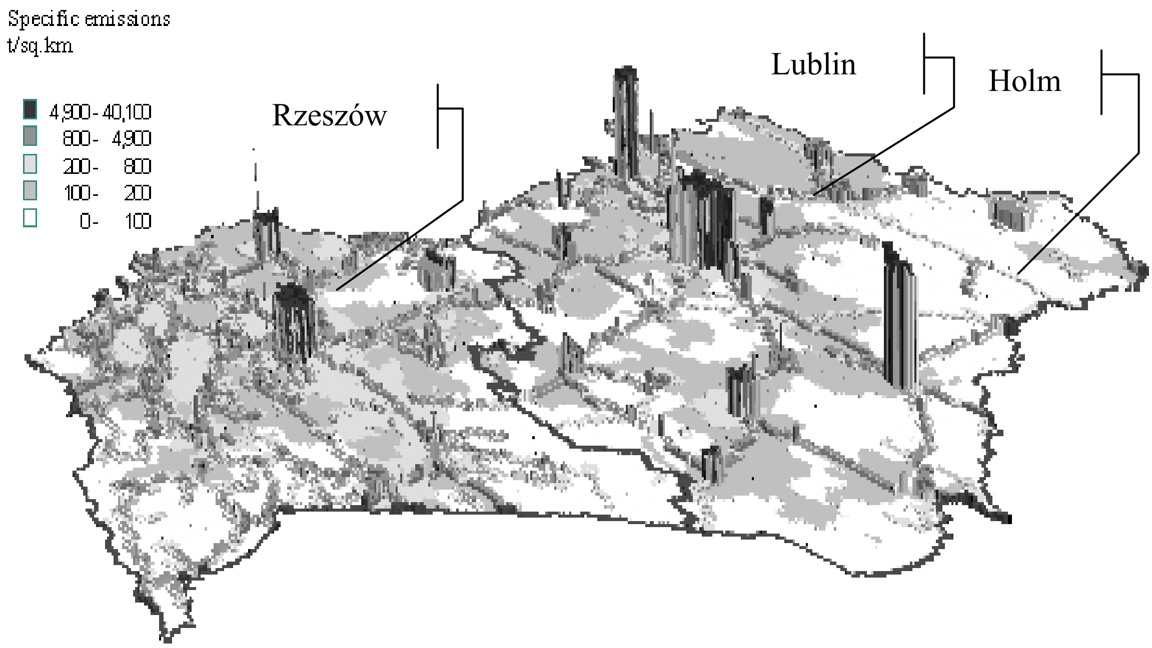

Figure 1. Spatial distribution of CO_2, CH_4, N_2O emissions in the energy sector for Lublin and Subcarpathian voivodeships (in CO_2 equivalent, grid 2 km x 2 km, 2008)

Conclusions

The distribution of GHG emission sources in Lublin and Subcarpathian voivodeships is analyzed. The largest emissions sources are located in Lublin voivodeship. For exapmle, powerful nitrate enterprises in Pulawy, two powerful power plants in Lublin, the cement factory in Holm. The subcarpathian voivodeship is characterized by lots of farmland and forested areas, national parks. For the Subcarpathian voivodeship the GHG emissions are mainly disaggregated by population density. The mathematical model for the spatial GHG inventory and corresponding geoinformatonal technology have been developed concerning the structure of statistical information and specificity of sources. The developed models reflect processes of GHG emissions from stationary and mobile sources and for various categories. Based on the presented mathematical models of emission processes modules were programmed in the MapBasic language using the tools of GIS MapInfo. The spatial analysis of CO2, N2O, CH4 emissions in the energy sector has been carried for Lublin and Subcarpathian voivodeships. Results are presented in the form of digital maps.

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Геоинформационные технологии и пространственный анализ эмиссии парниковых газов в польских регионах, граничащих с Украиной

Проанализирована специфика территориального размещения источников эмиссии парниковых газов в польских регионах, граничащих с Украиной. Разработаны математические модели эмиссии парниковых газов в энергетическом секторе с учетом структуры статистической информации и соответствующие геоинформационные технологии для осуществления пространственной инвентаризации в польских воеводствах: Люблинском и Подкарпатском. Представлены результаты пространственного анализа для этих двух воеводств.

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Геоінформаційні технології та просторовий аналіз емісії парникових газів в польських регіонах, що межують з Україною

Проаналізовано специфіку територіального розміщення джерел емісії парникових газів в польських регіонах, що межують з Україною. Розроблено математичні моделі емісії парникових газів в енергетичному секторі з врахуванням структури статистичної інформації та відповідні геоінформаційні технології для здійснення просторової інвентаризації в польських воєводствах: Люблінському та Підкарпатському. Представлено результати просторового аналізу для цих двох воєводств.

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