UDC 681.51

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Carbon Dioxide Emissions Inventory with GIS

The paper emphasizes the need of spatially distributed carbon dioxide (CO_2) inventory using geoinformation system. It describes the available activity data on fuel combustion in Ukrainian statistics and proposes algorithms for their territorial distribution. The information system for spatial inventory is described and an example of its application for one of Ukrainian administrative regions is presented.

Introduction

Geographical information system (GIS) is a system for capturing, storing, checking, manipulating and displaying data which are spatially referenced to the earth surface. The field of GIS is relatively new and rapidly developing as it can be applied to many types of problem from sophisticated analysis and modeling of spatial data to simple displaying of data allocation [1], [2].

A GIS is useful as essential tool for developing spatially disaggregated emission inventories [3]. Traditional methods of greenhouse gas inventory (also used in countries' National Inventory Reports' preparation under the United Nations Framework Convention on Climate Change) are mainly directed to estimation of emissions and absorptions on a country scale. Such methods are useful as they enable to trace the countries' following international agreements, to analyze historical trends in emission change; to compare with other countries' emission level etc. On the other hand for governmental bodies of every country it is desirable to have a tool, which would enable to analyse the separate constituents of many-sided processes of greenhouse gas emissions and absorptions and thus to find the optimum ways of solving a number of economic or environment protection problems [4]. Therefore, when we talk about emissions from the point of view of single country it is important to have knowledge about spatial distribution of inventory data.

The analysis of spatial distribution of atmospheric emissions has been performed in several studies using different approaches (for example, see [3], [5-9]). Spatial emission data can be useful in:

1) identifying appropriate land use planning strategies;

2) assessing sources which are likely to pose the greatest air quality problems and in providing an identification of suitable emission control targets;

3) providing a useful guide to the potential locations of further air quality monitoring sites [7].

Also knowledge of territorial distribution of emission can be used in uncertainty analysis and help to provide guidelines for the most cost-effective ways of its reduction. Spatial inventory technology allows using all available information on emission factors, even for the certain point plants. Besides, one can easily carry out experiments of total inventory results' and their uncertainty change from, for example, emission control technologies introduced on a certain plant.

The spatial allocation of emissions using GIS can involve top-down and bottom-up approaches. The top-down approach can be roughly divided into two main steps: 1) emissions are calculated for some territory and 2) disaggregated using the assumption that they are highly correlated with some indicators (population, land use, etc.). Developing emission inventories with the bottom-up approach requires dividing an emission area into grid cells or administrative units and creating separate inventories for each sub-unit [3], [10]. Without regard to the approach selected the GIS usage is essential as it provides the following possibilities: the spatially distributed activity data and the main indicators used for emission calculation (bottom-up approach) and emission disaggregation (top-down approach) are allocated and kept in the form of geo-referenced database; map of emission sources can be built so that emissions associated with that source can be spatially disaggregated; GIS provides wide range of possibilities to extract information from emission inventory and display it with tables, charts, graphs and maps or allow the user to export data to other applications [3]; activity data information can be stored in both vector and raster data models (refer to points, polygons, etc.) which is very important in the stage of emissions-related information and indicators' disaggregation; using the GIS spatial emission estimates obtained using the bottom-up and top-down approach can be compared in order to conclude on the relevance of activity data used.

This paper proposes the GIS based information technology for spatial energy related CO_2 emissions inventory using the bottom-up approach. The example of its application is made for the Lviv region, which is in the western part of Ukraine.

Available data and their spatial distribution among emission sources

Carbon dioxide emissions are produced when carbon-based fuels are burned. In contrast to other direct acting greenhouse gases CO_2 is equilibrium carbon product of fossil fuel combustion so the quantities released depend very little on the combustion equipment or technology. But in spite of that the distinction of emissions by sources is very important for environmental policy makers, analysis of emission structure and its change over time. So according to IPCC Inventory guidelines [11] and Ukrainian statistic's specificity the Energy sector is divided into five categories of greenhouse gas sources (subsectors): fuel treatment and electrical energy production (energy industries); residential sector; manufacturing industries and construction; transport; fuel treatment at other sectors.

So the estimates of emission mainly depend on our knowledge of fuel oxidized in a certain economy sector and on the chemistry of that fuel. The data on amount of fuel burnt by sector and by types of fuel are available from the statistical yearbooks for separate administrative regions and administrative cities (see for example [12-14]). Such a rough regionalisation do not allow building high resolution emission cadastres, these data need to be spatially resolved using additional information and indicators.

All CO_2 emission sources are divided into three main types: large point sources, area sources and line sources.

Large point sources

The digital map is built with stationary emission sources with relatively large amount of annual emissions (power plants, engineering plants, sugar-refineries, etc.) using the land-cover digital map of Ukraine and the information of the biggest emitters in the region and their addresses.

The information on fossil fuel combustion on these plants is assigned to the corresponding point objects directly. It is also important to have the specific emission factors for individual plants and fuel types because then the uncertainty of overall emissions will be much lower comparing to inventory with default emission factors. The point sources are located always within one grid cell, and though the calculated emissions are linked to the exact location of the enterprise they will be anyway transferred to the grid cell within which the enterprise is located.

Line sources

Such emission sources as roads, highways, pipelines, railways belong to the so-called "line emission sources". Activity data distribution along these objects is carried out using the digital maps with their location information (for example, digital map of roads in Ukraine). These maps in addition to the spatial location of objects contain additional parameters which are extremely helpful for activity data disaggregation.

For example, there is the information about the amount of gasoline used by light duty vehicles in a certain region; this region is divided into grid cells. The first order assumption is to distribute the gasoline consumption among the grid cells proportionally to the road length within the cell. More precise way would be to take into account also the road width, type of road surface cover, road type and so on.

The distinction can also be made by regions concerning the average vehicle types used on a certain region to calculate the fuel use per kilometre travelled, car efficiency, emission factors and other parameters.

Area sources

Area sources include residential natural gas and coal combustion, gasoline stations, non-road mobile sources (agricultural equipment, commercial land-use equipment, small plants etc.). Urban traffic is also treated as an area emission source because of high density of roads in urban areas and besides.

For these sources the form of weighted spatial allocation [3] was used to disaggregate activity data, which refer to a certain category of an area sources and are available only on the regional scale. The following general approach was used: these sources were associated with spatially varying indicators which were assumed to be highly correlated with the source's actual activity levels. The indicator's maps are compiled and using these maps activity data were allocated among the grid cells based on the proportion of the cell's indicator value.

An example of such approach is disaggregation of natural gas consumption on the residential sector proportionally to the population density at a certain grid cell or allocation of fuel burnt in small plants proportionally to the amount of industrial production sold at a certain grid cell.

If area or line source come to be located not in one grid cell they are split into parts and activity data (which refer to the total source) are divided proportionally to the square of area in each cell (in case of area source) and proportionally to length of part of road or pipeline (in case of line sources).

Theoretical approach

The bottom-up spatial inventory approach can be divided into three main steps:

1) territory under investigation should be split into cells (the square of cell should be as small as data are available);

2) statistical activity data should be transformed into the corresponding grid cells using the information on the geographical location of emission sources (big point sources can be localized directly while area and line sources demand certain assumptions and additional parameters with geographic information); emission factors and other parameters used in inventory process should be established for each cell (it is desirable that they differ among cells, considering the peculiarities of fuel treatment, which refer to a certain area or point source);

3) using the "bottom-up" approach the emission inventory should be carried out for individual grid cells (multiplying the corresponding activity data with appropriate emission factors).

The principal point of spatial inventory model is that the greenhouse gas inventory is carried out in turn for each plot following the traditional IPCC methodologies [11]. So the input and output data relate to elementary plot and are presented in a form of distributed (geo-referenced) database.

To carry out spatial inventory the grid is selected so that one grid cell contains the territory piece of only one administrative region (if one cell contained the piece of border between regions it was split up into 2 separate cells). It is important if one wants to keep the region's cumulative fuel amount used constant after disaggregation and also to analyze the emission structure by region.

Geo-information technology

The geo-information technology for high-resolution emission inventory is based on the IPCC methodology [11] and includes an integrated GIS platform providing the ability to use digital maps in activity data distribution process and providing users with the tools to visualise the inventory data.

The technology is based on performing the inventory step-by-step for all elementary plots. Although the technology fully based on the IPCC methodologies it is also highly adjusted to the specificity of Ukrainian statistics, division into fuel types and economy sectors and so on. The basic input information is based on the information from ordinary statistical yearbooks and editions for the regions of Ukraine. All the other necessary information for activity data disaggregation and inventory compilation (digital maps on population distribution, road networks, default emission factors and many others) is included as default information. But for needs of advanced inventory compilation there is a possibility to refresh maps if there are more recent versions available, to substitute the default emission factors with more specific ones for some fuel type used on a certain plant or region. Depending on the purpose of inventory and accuracy needed CO_2 inventory can be carried out using the different approaches (Tier 1 approach – without fuel use subdivision into economy sectors or Tier 2 approach for a higher detail level).

The structure of developed geo-information system consists of five main modules (see fig. 1).

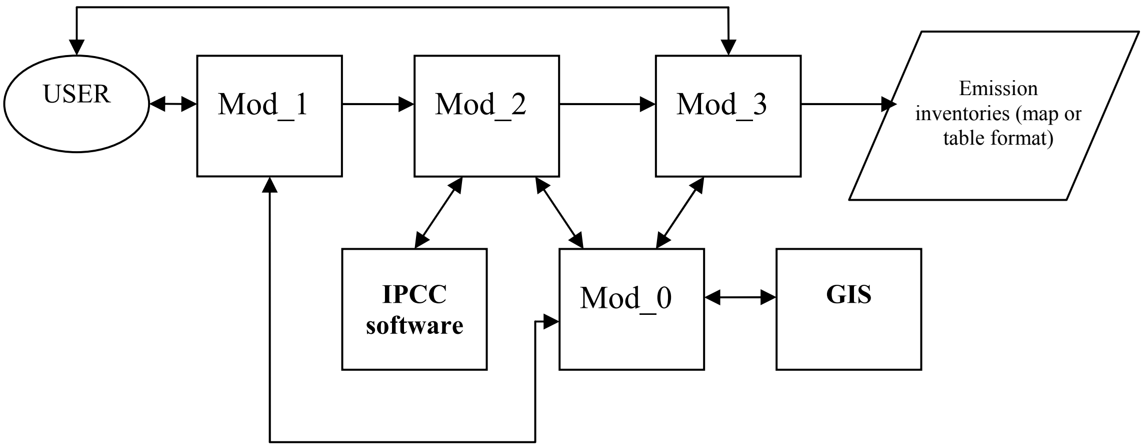

Figure 1 – The structure of geo-information system for emissions inventory

The user selects the territory for which the inventory should be carried out together with the method for inventory (depending whether there is information on fuel consumption by separate economy sectors). Then the appropriate forms with the information of the amount of fossil fuel consumption within separate economy sector or in total should be filled up based on the statistical information published annually. Such forms should be filled for each administrative unit. Module *Mod1_Input* is used to form the geo-referenced database of input data for spatial inventory.

Using the digital map (or spatial database) with the largest point sources in the region the user is asked to fill in information for each of them (if such information is available). The following information should be desirably provided for each Large Point Source: 1) type and amount of fossil fuel used for a certain activity; 2) specific net calorific values of fuel used; 3) specific emission factors for CO_2, which should be based on fuel type; the subcategory of Energy sector, where the fuel was burnt; fuel treatment technology, etc.; 4) uncertainties which refer to the corresponding activity data and emission factors. The module works with GIS using the *Mod0_MapInfoServer*, which serves for program MapInfo starting and management. By means of this module the MapInfo window and other windows (legend, information window etc.) are built in the main inventory program and information interchange between them occur using MapBasic commands.

The information for the large point sources this module locates in the corresponding grid cells directly, using the database with geographical information. The rest amount of fossil fuel used in the certain economy sector of some administrative region (total amount without fuel used by large point sources within the region) is disaggregated among the rest cells according to some assumptions and using additional digital maps. The module contains default and specific regional and national emission factors and their uncertainty values together with the uncertainty of statistical activity data. There is an option for user to improve them and to use more detailed specific values if available.

The process of emission inventory is compiled using the module *Mod2_Inventor.* Under the Kyoto Protocol Ukraine must calculate and submit the emission estimates using the IPCC inventory guidelines. To help the countries in inventory compilation and to make the countries' national inventory reports comparable and similarly structured the IPCC developed the inventory software in the form of Excel-tables [15]. So the basic function of this module is to apply the IPCC software for inventory compilation for each grid cell: input activity data and emission factors are filled into corresponding cells of Excel-tables; inventory of greenhouse gases, which were emitted in corresponding (selected by user) sector/subsector. Geo-information for each elementary plot using OLE-technology and MapBasic queries is entered in corresponding cells, which are later used by Excel program. From the obtained results in greenhouse gas emissions by sector and gas the module forms the database, where each line refers to a certain grid cell. This database is an input for the next module. This module also calculates uncertainty levels for separate subcategories of Energy sector also subdivided by gas types using two approaches, recommended by the IPCC methodologies.

The formed tables with inventory results are an input for module *Mod3_Visualization,* which interacts with the user to built needed geo-information layers with the elementary plot's inventory results and present them on the region digital map. The input data for this module are formed using inventory result tables and topographic information from the region's digital map. For each economical activity a separate layer of the digital map is generated.

This technology allows carrying out inventory for individual sectors. It provides possibilities for comprehensive analysis of emissions trends over time, their spatial allocation, and structure of emissions by sector or by gas type, etc. It also provides emission maps, which perform the emission density in graduated colors on a map, either for each cell individually or using interpolation methods, which take into account the spatial correlation of neighboring cells. Using such maps one can immediately identify "hot spots", separate low and high emission areas and obtain general picture of emission sources' spatial distribution (which is mostly far from uniform). Such information is extremely useful for policy makers and bodies, responsible for environment protection strategies planning. It gives bases for investigation of the most cost-effective reduction of emission and uncertainty of inventory results.

Results

Lviv region is one of 24 administrative regions in Ukraine. Total area of Lviv region – 21 831 km^2 (3,6 % of cumulative territory of Ukraine) and the population is more than 2,6 million people. Considering that the investigated territory is rather big and also taking into account data availability the territory was decided to be cut into cells 10 km x 10 km for advanced spatially distributed inventory.

On the basis of formed input data on fuel consumption the geoinformation technology of spatial inventory allows building the geodistributed emission cadastres according to certain methodology on the level of elementary plots. As an example, on the fig. 2 the spatial distribution of total emissions in CO_2-equivalent for the Lviv region of Ukraine is presented.

Different kinds of interpolation can be used to visualize better emission data and to take into account the influence of neighboring grid cells. This kind of maps can be used only to derive the general situation in spatial distribution of emission sources. From the map on fig. 2 the conclusion can be done that the location of emission sources is highly no-uniform in Lviv region. More precisely, only one city (Lviv) is responsible almost for one third of all emissions in the region (the territory of the city Lviv occupies only 7 % from the territory of the whole region).

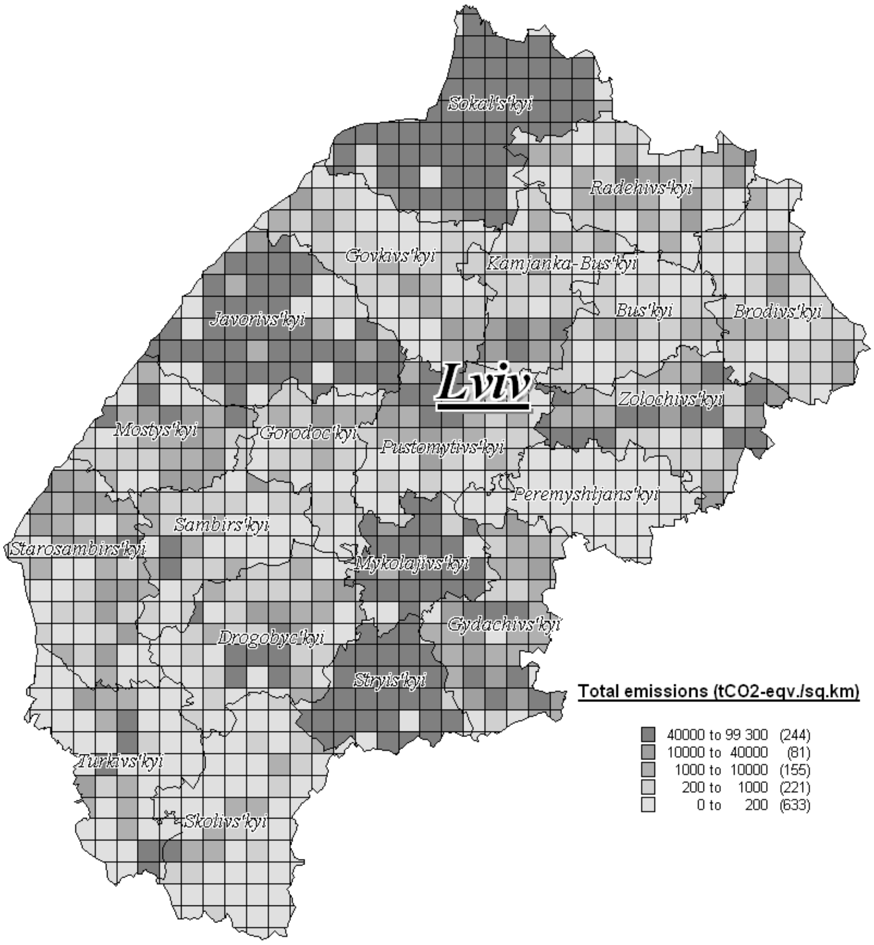

Figure 2 – Spatial distribution of total emissions by grid cells in Energy sector (tCO_2-eqvivalent/km^2)

Geo-information technology of spatial inventory allows investigation of structure of greenhouse gas emissions by economic activities on the level of elementary plots, administrative units or on the level of region in general (fig. 3).

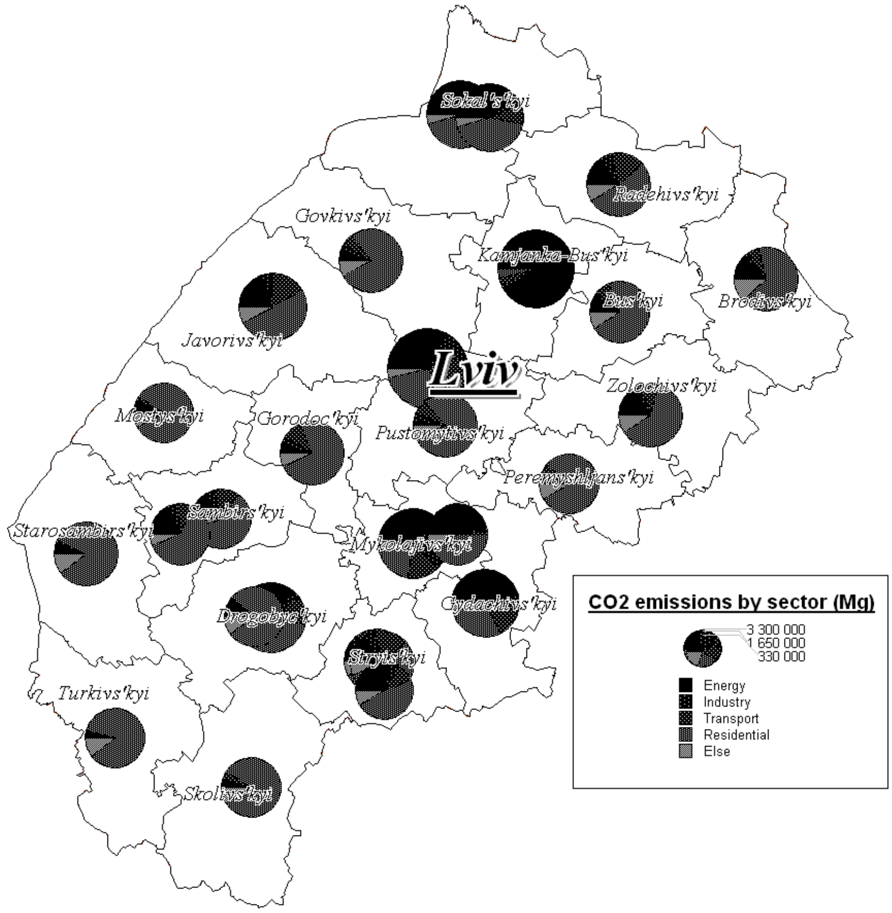

Figure 3 – The structure of emissions by subcategories, analyzed for administrative units (administrative regions and administrative cities) in Mg. Because of high irregularity of emissions distribution the values were taken in logarithmic form

Conclusions

The results of spatial inventory using GIS for the Lviv region showed high irregularity in territorial distribution of CO_2 emission sources together with the emission quantities distribution by economy sectors.

The main carbon dioxide emissions take place in energy industries. That is why it is necessary to make decisions in order to reduce emissions mainly in this sector. The leaders in greenhouse gas emissions are: Lviv agglomeration (31,7 % of all emissions), Kamjanka-Bus'kiy district (16,5 %), and Boryslav-Drogobych agglomeration (12,0 %). Just in the Energy sector of these administrative regions it is necessary to make investments in order to reduce emissions, and to decrease the statistical data uncertainty. Emissions in the rest administrative units don't exceed 500 Gg of CO_2-equivalent per year.

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К. Гамаль
Инвентаризация эмиссий углекислого газа с использованием ГИС
В статье обоснован подход к пространственной инвентаризации эмиссий углекислого газа с использованием геоинформационной системы. Описаны имеющиеся в украинской статистической отчетности данные о сжигании ископаемого топлива и предложены алгоритмы для их территориального распределения. Представлена созданная информационная система для пространственной инвентаризации эмиссий и приведен пример ее использования для одного административного региона Украины.

Х. Гамаль
Інвентаризація емісій вуглекислого газу з використанням ГІС
У статті обґрунтовано підхід до просторової інвентаризації емісій вуглекислого газу з використанням геоінформаційної системи. Описано наявні в українській статистичній звітності дані про спалювання викопного палива та запропоновано алгоритми для їх територіального розподілу. Представлено створену інформаційну систему для просторової інвентаризації емісій і наведено приклад її використання для одного адміністративного регіону України.

Статья поступила в редакцию 23.07.2008.