

## Software of geoinformation system for spatial inventory of greenhouse gas emissions

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**Abstract.** In this paper, the advantages and disadvantages of existing software for inventory of greenhouse gas emissions have been analyzed. Necessity of creation the new specialized software for spatial inventory of greenhouse gas emissions has been proved, and the requirements for such software have been specified. A flexible architecture of specialized geographic information system (GIS), the structure and main modules of the software have been presented. The mathematical model of greenhouse gas emissions caused by using various types of fossil fuels in the residential sector has been described. Using developed specialized GIS, a case study for Zhytomyr region in Ukraine has been conducted.

**Key words:** software, geoinformation technology, architecture, GHG inventory, spatial analysis.

### 1. INTRODUCTION

The industrial revolution of the late eighteenth and early nineteenth centuries transformed most of the countries from a primarily agricultural society into one based on the manufacturing of goods and services. Therefore demand for energy resources, especially fossil fuels, is sharply increasing. This has led to emission of anthropogenic additional greenhouse gases, which cause global warming. The main chemicals that cause the greenhouse effect are carbon dioxide (accounts for 50% of the greenhouse effect); chlorofluorocarbons (25%); methane (10%); nitric oxide (8%); surface ozone levels (7%). Therefore searching for way of reducing the GHG emissions is a burning issue. In order to solve the problem of GHG emission reduction the effective inventory tools in all sectors of human activity are needed.

### 2. MATERIALS AND METHODS

Nowadays different software is developed for inventory of greenhouse gas emissions in various sectors that take into account specific of regions [1-6]. Software that is used for inventory of greenhouse gas emissions can be divided into two types: specialized and non-specialized GIS [7-11]. The non-specialized GIS include software MapInfo and ArcGIS; specialized GIS include TEISS, EMIT2, Copert, e3CAT, webEI, etc.

Tribal Emissions Inventory Software Solution (TEISS) [10] is software with a user-friendly interface for greenhouse gas emission inventory. The system contains an integrated GIS platform that includes all necessary tools for inventory of greenhouse gas emissions and visualization of the results. TEISS contains a description of used methodologies for spatial inventory of greenhouse gas emissions as well as models which are combined into a single user interface. Input data and results of the inventory are stored in SQL database. The system is independent of the provider and allows user to store data in such databases: Oracle, MS-SQL Server, MySQL, and Interbase. The system estimates emissions using AP-42, NEI, and EIIP methodologies. It allows conducting numerical experiments for more than 200 emission sources and provides detailed information on every source. The software is flexible to modifications in calculations of any emission process without adverse impact on system.

Software EMIT [11] was designed for conducting greenhouse gas emission inventory. It was developed by

a group of scientists from CERC (Cambridge Environmental Research Consultants) in 1985 using the latest technology in the field of environmental studies. The developers provided the ability to store, process and analyze data about the greenhouse gas emissions taking into information about emission sources. EMIT is particularly useful for testing different scenarios of emission reductions.

Most of GISes are commercial software. They are not fully adapted for spatial inventory of greenhouse gas emissions or cover only certain sectors of the inventory (ADMS-Airport, SELMA). In contrast to these commercial products, the specialized GIS, which is presented in this article, is based entirely on the modules that are freely available.

### 3. RESULTS AND DISCUSSION

#### 3.1. Generalized approach to architecture construction of geoinformation system

Approximately 80-90% of all information may be considered as spatial data. Operations with such data are seen as a central task for geo-information systems. Geoinformation technology is a multifunctional analysis tool that consolidates tabular, text and cartographic data from various areas: demography, statistics, land management and other information. Geographic information systems are becoming more widely used not only in the traditional areas of application, such as natural resource management, agriculture, environment, urban planning, but also in business, e.g. in telecommunication industry and retail trades. GIS supports business or organizational decision-making activities, hence helps to improve customer service, maintain a high level of competitiveness, and increases profitability of commercial organizations. GIS is an effective tool for selecting sites and determining the areas of trade, outdoor advertising and production facilities, scheduling and routing of delivery vehicles, informational real estate activity.

Input data for GIS are digital maps, plans, space multispectral and radar satellite images. The data contained in the digital map is divided into spatial (geographic, geometric, vector) and attribute (tabular). All GIS operate with the following spatial data objects:

- point objects which are showing location of discrete objects (size of the objects is not significant);
- linear objects, which consist of the nodes that are linked with arcs (one dimension linear data that does not have thickness);
- polygon, which consist of a number of arcs that form a close loop without crossing over one another (indicates area occupied by a particular object);
- text labels on the map.

#### 3.2. Specification of requirements for software architecture

The geoinformation systems are the main instrument for creating an effective software tool for spatial inventory of greenhouse gas emissions. Such tool can provide the opportunity not only to assess the amount of greenhouse gas emissions, but also geographically locate all sources [7-11]. As emission sources are located very unevenly, in order to take decisions about greenhouse gas emission reduction the authorities require information not only about the amount of emissions, but also about localization of emission sources. As national inventory is conducted according to IPCC methodology [12], it does not include the spatial analysis of obtained results. Therefore development of effective software tool for spatial inventory of greenhouse gas emissions is the burning issue.

Software for spatial inventory of greenhouse gas emissions must satisfy a number of requirements on the input data and provide necessary tools for operation with spatial data. As input data we use:

- digital maps of the investigated area (administrative regions, forests, land use, road or railways, etc.); these digital maps should contain necessary data for conduction greenhouse gas emission inventories (settlement boundaries, population density, forest types, capacity of roads, etc.),
- georeferenced statistical data about results of economic activities; main focus is on data which leads to greenhouse gas emission or absorption in investigated area; such data are usually available only on regional or district level and include:
  - (a) information about fossil fuel consumption (coal, natural gas, oil, etc.) in different categories of the energy sector [13-15] (electricity and heat production [6], residential sector, industry and construction, mining and processing of fuels, transport [1, 3], etc.),
  - (b) production volumes (cement, lime, meat products, bakery, alcohol, etc.) [2],
  - (c) number of livestock (dairy and non-dairy cattles, pigs, horses, sheep and poultry),
  - (d) amount of chemical fertilizers used in agriculture [16],
  - (e) volume of forest plantations and industrial timber harvesting in forestry,
- emission factors and net calorific values (IPCC methodology [12]) or country-specific values (if available),

- set of geographical elementary objects of spatial cadastre of greenhouse gas emissions, which are obtained using disaggregation grid.

The software of specialized GIS for spatial inventory of greenhouse gas emissions and analysis of obtained results should provide the following functions:

- creation new digital maps of the region/area,
- formation of the set of elementary objects (point-, line-, and area-type objects),
- development of program modules for spatial disaggregation of statistical data about fossil fuels consumption or other activities from regional level to the level of elementary objects,
  - calculation of greenhouse gas emissions and stock from main sectors (Energy, Industry, Agriculture, Waste, Land use, land-use change and forestry) and for all types of economic activities (electricity and heat production, residential sector, transport, etc.),
  - calculation of emissions of carbon dioxide, methane, nitrous oxide, non-methane carbon compounds for every elementary object using mathematical models,
  - visualization of the obtained results of spatial inventory (thematic maps of specific greenhouse gas emissions or absorptions – tons per unit of area),
  - summation of obtained results to the level of administrative units (usually – administrative districts) and summarising in form of diagrams and graphs.

### 3.3. Characteristics of the main modules

Software architecture enables processing geoinformation in various vector and raster formats using library GDAL/OGR [17]. Each map is a set of spatial data which describe certain two-dimensional region with a given coordinate system. A map consists of one or more layers. Each layer contains an attribute table and the associated geographic objects, such as polygons, points, lines, and text (labels). Each graphical object is specified

by its coordinates. In addition, the layer contains information about visual style and scale of the map window.

Architecture of geographic information system involves: (1) organization of interaction of geocoded data from external data sources, (2) work with a variety of specialized modules, (3) and using them in mathematical methods for solving a wide range of modeling tasks. Software modules for working with GIS can be also used to solve many scientific problems related to the processing of geoinformation. Development of specialized software is fully justified and economically feasible as it allows not only to replace the expensive GIS by alternative free software, but also to implement individual requirements of a user.

Any specialized applied software should be designed to fulfill specific needs taking into account functional requirements and the concept of scalability. This enables a developer to build the optimal configuration of GIS to solve a particular problem. The software should be able to interact and share different types of integrated data with other existing GIS.

Main modules in a structure of the cross-functional geographic information system are modules which work with the data of vector and raster formats. We used free library for working with vector and bitmap formats GDAL/OGR for building software architecture. Core modules of geographic information system are presented in Fig. 1. Connections between system modules are weakened by using of architectural decisions such as design patterns, which provide the use of modules in other systems.

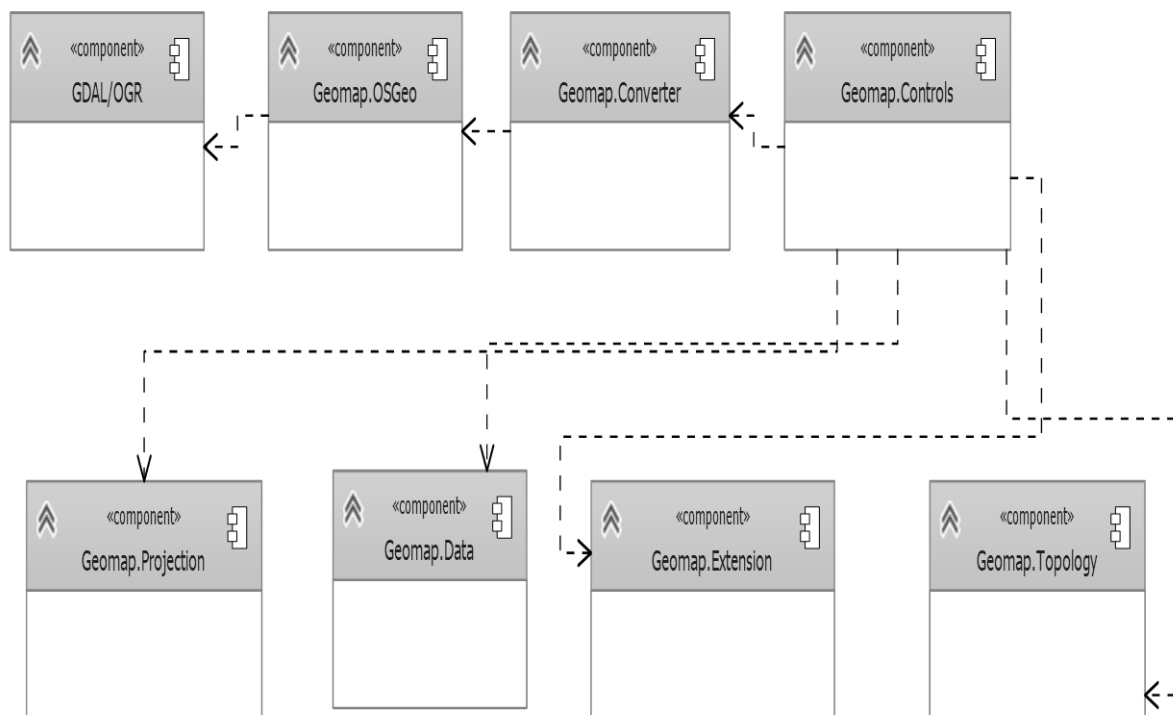


Fig. 1. Components of the specialized software

Spatial data is displayed as digital maps using module `Geomap.Controls`. This module contains the basic functionality to build custom GUI. Class `Map` is essential part of this module and contains all necessary functionality for working with spatial data in various formats. The range of operations includes adding and removing layers of maps, scaling, data visualization, etc. The module design enables visualization to be independent from the libraries, which are responsible for representing graphical objects (GDI + +, DirectX, OpenGL).

The input data of geographic information system are the maps commonly recorded in either a vector or raster format. Vector-formatted data are given in WKB and WKT formats. WKT is a text markup language for representing vector objects on a map. WKB is a binary equivalent, which is used to transfer and store the same information in databases (Microsoft SQL Server, PostGIS and DB2). Module `Geomap.Converters` converts binary and text data to the appropriate geometric shapes. The module reads data from the stream and creates the geometric primitives, which are later displayed on the map. In this module we implemented a set of classes for working with WKB and WKT formats. The exchange of geometric data as binary streams is represented as BLOB, which contains geometric WKB-information.

Functions for data manipulation and setting different styles are implemented in `Geomap.Data` module. Map formats contain a set of graphical primitives (line, point, polygon, etc.) and associated attribute data (types of roads, population, etc.). `DataSet` class provides storage of attribute data of geometric primitives. In class `VectorStyle` a set of basic styles and instruments to display geometric shapes of vector formats is implemented. Class `OGRProvider` works with data in OGR formats, implements reading of attribute and graphic information for further analysis and calculations using SQL queries.

`Geomap.Extension` is a module of additional extensions. It provides classes and libraries which enable user to calculate the area and perimeter of planar objects, the length of linear objects as well as obtain other additional information (location, object type, etc.). In these classes we implemented functional approach, therefore the necessary geoinformation can be retrieved from the database using query 'select'.

`Geomap.Symbology` module is built for working with styles for displaying maps using GDI++. It is designed to draw graphical objects and shade them with gradient. `Geomap.Topology` module contains a set of basic geometric shapes and additional classes. `Geomap.OSGeo` is module from SWIG package that enables to use library GDAL/OGR in high-level programming language C#. `Geomap.Projection` is a

module of map projections. This module is needed to transform point coordinates from one geographic coordinate system to another. The core of this library is a part of the Proj4J library.

### 3.4. Additional modules for spatial inventory

Specialized geoinformation system includes not only modules for mapping, analysis and storage of data, but also a new module for mapping in vector format. Some maps are created in raster format. Any raster map can be converted to vector format using specialized software [7,8].

The digital map can be created using the following algorithm:

- use a physical or any other map of analyzed area,
- digitize map in order to obtain the raster map,
- open raster map, set a percentage of transparency for stroking contours on the map,
- create vector map using boundary points and contours of raster map (using the corresponding module).

The construction of vector map is conducted in the current or a new layer in edit mode. If a map is multi-layered, the objects will be created on the upper active layer (as active we consider visible layer). The size of created file changes automatically depending on the amount of added layers.

The module for construction of vector maps has the following features:

- 1) creation of the following objects of a map:
  - lines, polylines,
  - polygon,
  - point,
  - rectangle,
  - ellipse,
  - text,
- 2) setting:
  - shape fill of planar objects (polygon, ellipse or rectangle),
  - thickness and type of shape outline,
  - colour filling area-type objects and their outlines,
- 3) cancelation or reversing the last operation or more another commands executed during the process of map creation,
- 4) deleting objects,
- 5) selecting objects while drawing and synchronization with corresponding database.

A simplified diagram of classes of the module for mapping in vector format is presented in Fig. 2.

Spatial inventory of greenhouse gas emissions is conducted at the level of elementary objects. Within one sector of human activity emission sources can be presented as point, line or polygon objects. In order to summarize

inventory result, we need universal map of investigated area. For this purpose was created tool "Grid", which splits the investigated area maps with grid (spatial resolution  $n \times m$  km). This tool has the following features:

- this function is applied to layers which contain polygons, lines and points,
- data from attribute table for polygons and lines are copied and attached to each created object in resulting map; points are copied to new map together with related data from attribute table,
- the result is presented as a new layer with all new geographical objects created by splitting input map with a grid.

The algorithm of the module "Grid" is presented in Fig. 3.

Visualization of the results of spatial inventory is an essential component of the emission analysis. A module for spatial visualization uses tool „Grid” that disaggregate tabular and spatial data to the level of elementary object. The algorithm of the module consists of the next steps:

- selected layers of the map are splitted using tool "Grid" into set of elementary objects (developed disaggregation algorithm is implemented),

- new layers, which contain the geoinformation about greenhouse gas emissions, are created,
- the inventory results are visualized.

The algorithm of visualization module is presented in Fig. 4. The results of applying this module to Zhytomyr region is shown in Fig. 5 (specific  $N_2O$  emissions from burning fossil fuels in transport sector in Zhytomyr region of Ukraine).

### 3.5. Spatial inventory of greenhouse gas emissions using specialized software

An integral part of greenhouse gas emission inventory is development of an approach and mathematical models that describe a particular kind of human activity, performing numerical experiments and analysis of the results. As an example of such inventory, we perform greenhouse gas emission inventory in the residential sector of Zhytomyr region in Ukraine. The emissions in this sector are caused by burning fossil fuels and wood by households in order to meet their energy needs for space and water heating, cooking, including cooking and water heating for sanitary needs for livestock.

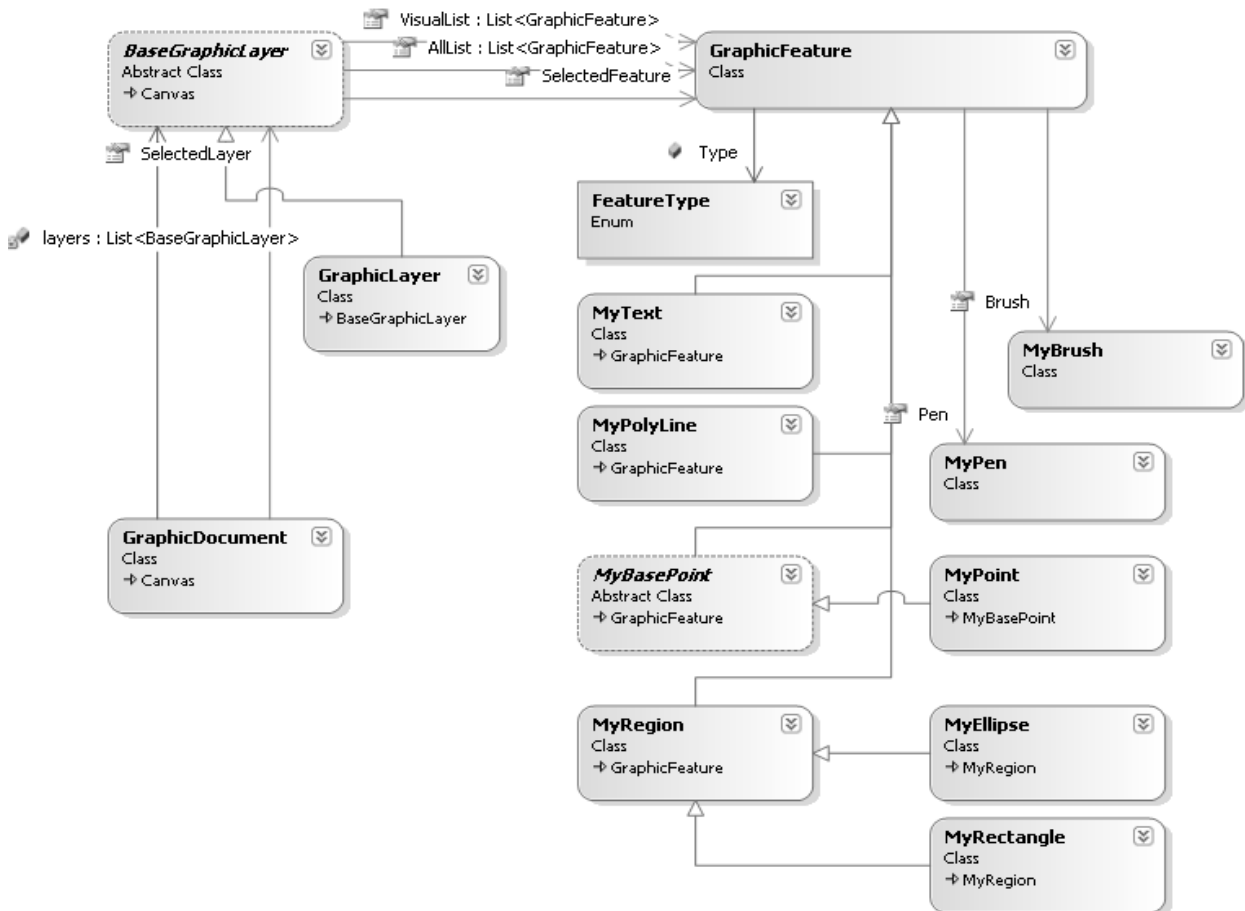


Fig. 2. Simplified diagram of classes of the module for mapping in vector format

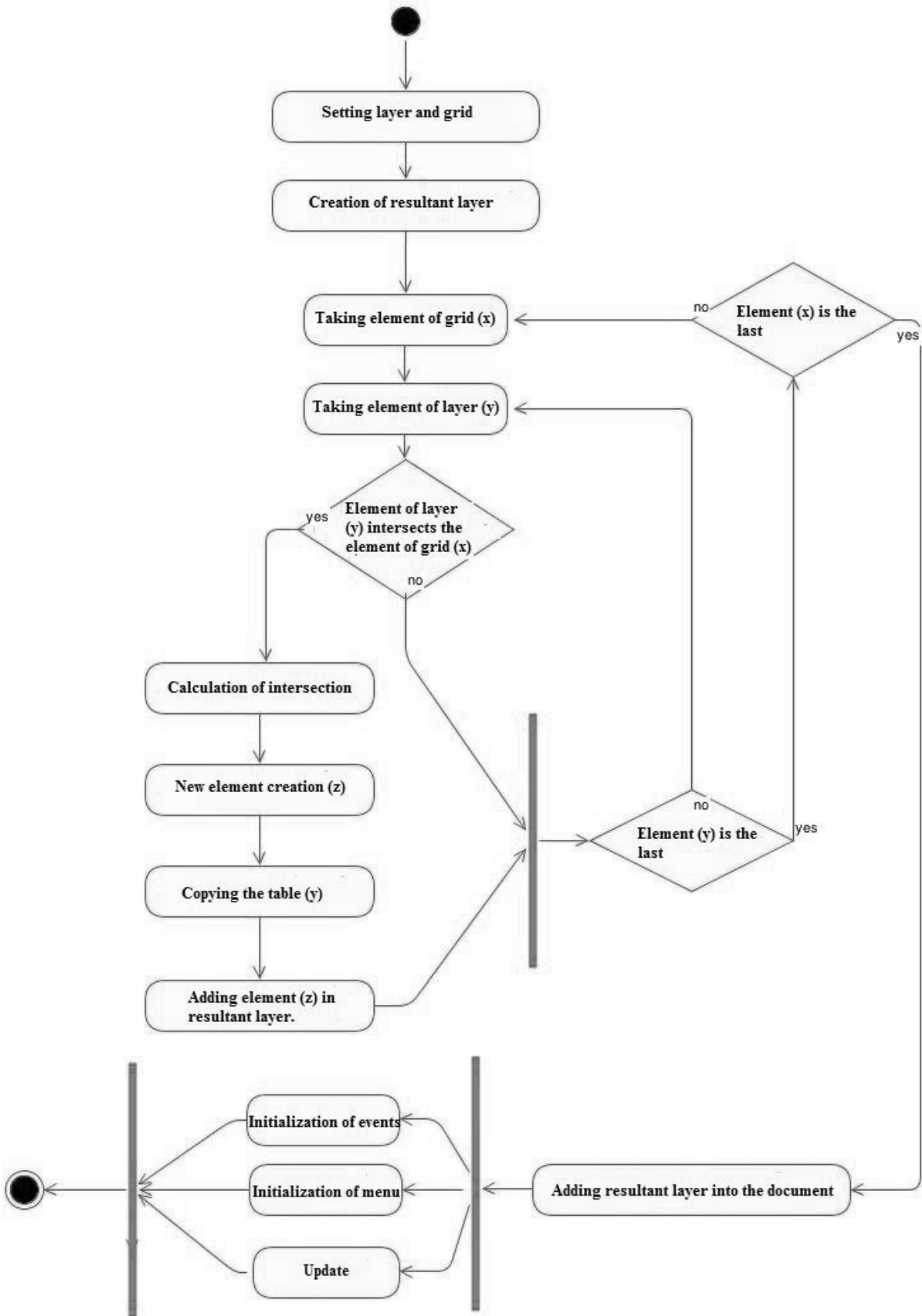


Fig. 3. The algorithm of the module "Grid"

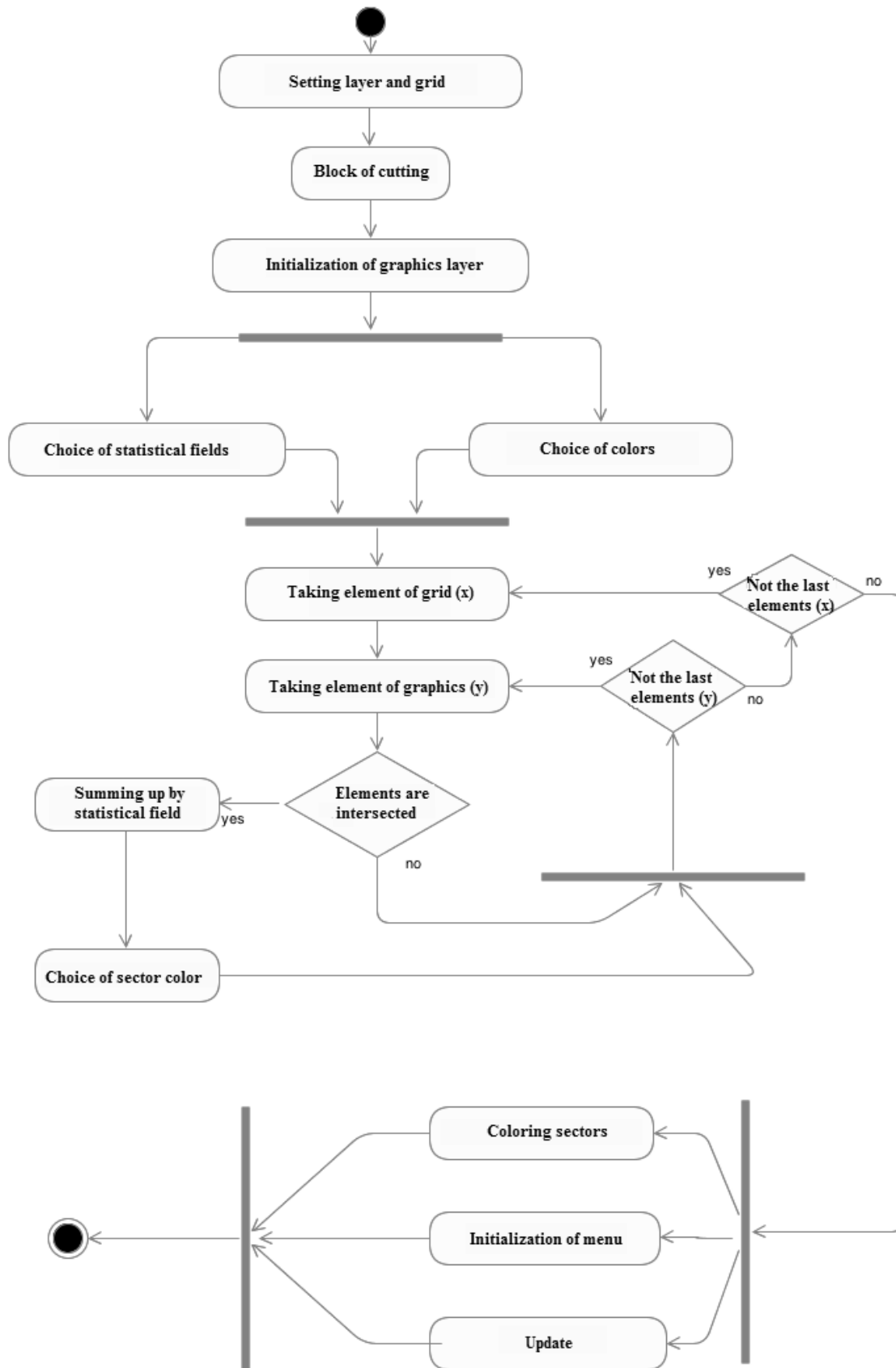


Fig. 4. The algorithm of visualization module

The main energy sources for space heating and cooking in rural areas are natural and liquefied gas, coal and wood. As input data we used official statistical data about amount of fossil fuels that was burned in this region. However, such information is available only on regional level, in some case on district level. Therefore we need to disaggregate statistical data to the level of elementary objects (e.g. settlements). The amount of carbon dioxide emissions from stationary fuel combustion in the residential sector can be estimated by a model:

$$E = \sum_{g \in G} \sum_{\delta \in \Delta} \sum_{i \in I} M_{i,\delta} * A_{i,\delta}^g, \quad (1)$$

where:  $I = \{i_1, i_2, \dots\}$  – set of fuels (coal, natural gas, liquefied petroleum gas, firewood) used in the residential sector;  $\Delta = \{\delta_1, \dots, \delta_n\}$  – set of elementary objects (settlements);  $G = \{g_1, \dots, g_n\}$  – set of greenhouse gases (carbon dioxide, methane, nitrous oxide);  $M_{i,\delta}$  – amount of the  $i$ -th type fuel consumed in the elementary object  $\delta$ ;  $A_{i,\delta}^g$  – emission factor for the  $g$ -th greenhouse gas from burning the  $i$ -th type fossil fuel.

The amount of coal and wood that was burned in elementary object  $\delta$  is calculated using the next formula:

$$M_{i,\delta} = (M_i * F_{i,\delta}^R + M_i * F_{i,\delta}^U) * \frac{P_\delta}{P_w}, \quad (2)$$

where:  $i$  – index that indicates type of fuel (coal or wood);  $M_i$  – statistical data about amount of consumed

fuel of the  $i$ -th type on regional level;  $P_\delta$  – population in a settlement (elementary object  $\delta$ );  $P_w$  – population in administrative unit (district);  $F_{i,\delta}^R, F_{i,\delta}^U$  – indicators that allocate share of the  $i$ -th type fuel from total volume used in urban and rural areas respectively.

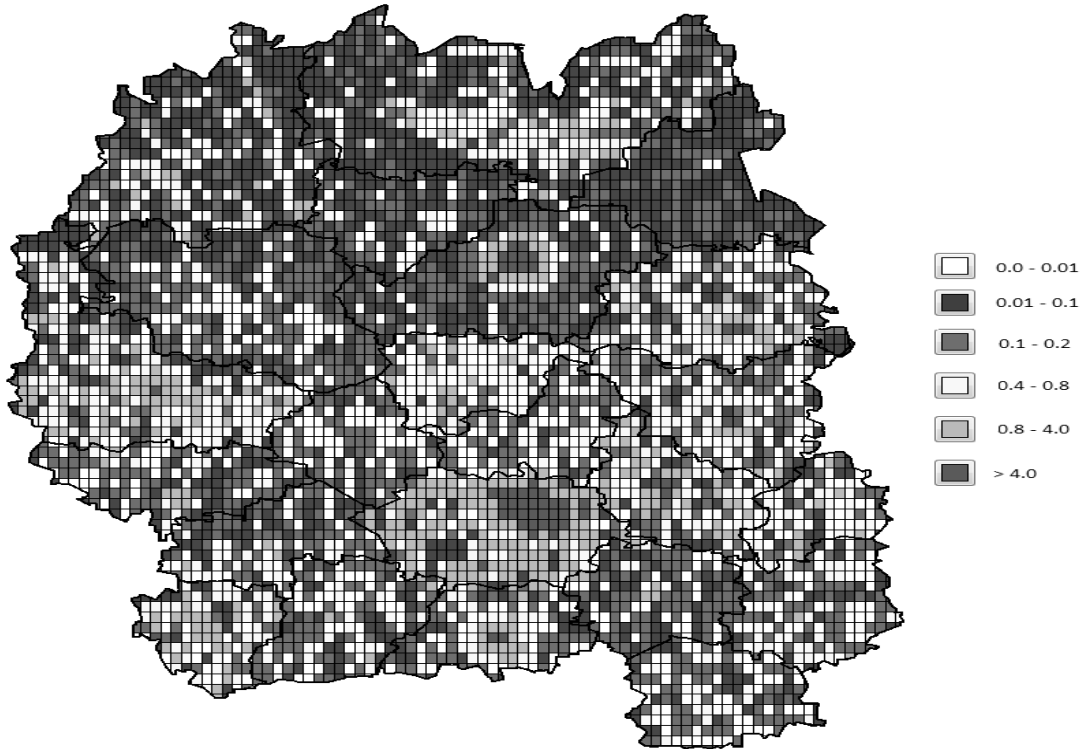
The amount of natural and liquid gas that was burned in elementary object  $\delta$  is calculated using the formula:

$$M_{i,\delta} = (Q_{i,\delta}^R * F_{i,\delta}^R + Q_{i,\delta}^U * F_{i,\delta}^U) * \frac{P_\delta}{P_w}, \quad (3)$$

where:  $i$  – index that indicates type of fuel (natural or liquid gas);  $Q_{i,\delta}^R, Q_{i,\delta}^U$  – numbers of households with access to centralized gas supply in urban and rural areas respectively within an elementary object  $\delta$ ;  $F_{i,\delta}^R, F_{i,\delta}^U$  – indicators that allocate share of the  $i$ -th type fuel from total volume used in urban and rural areas respectively, and are calculated according to the next formulas:

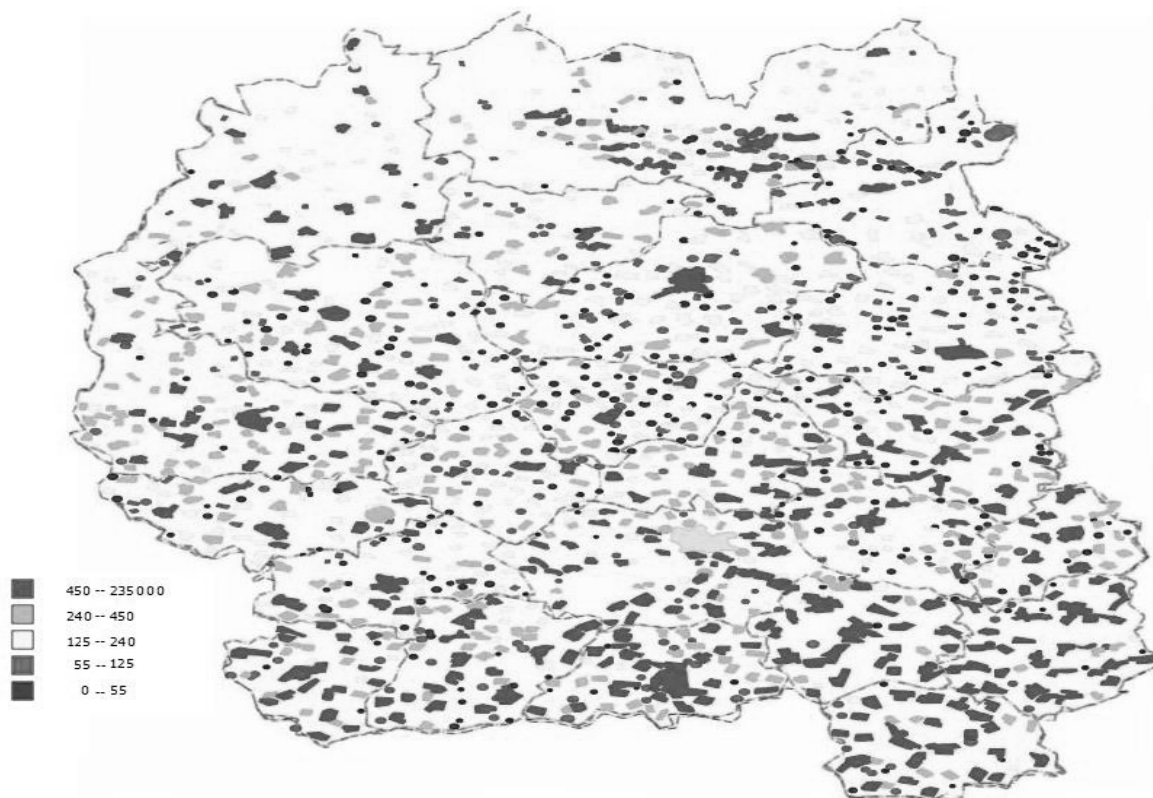
$$F_{i,\delta}^U = M_{i,Region}^U / Q_{urb}^{region}, F_{i,\delta}^R = M_{i,Region}^R / Q_{Rur}^{region}, \quad (4)$$

where:  $Q_{urb}^{region}, Q_{Rur}^{region}$  – numbers of households with access to centralized gas supply in the administrative region (district) in urban or rural area respectively;  $M_{i,Region}^i$  – amount of consumed fossil fuel of the  $i$ -th type (natural or liquid gas) in the region.



**Fig. 5.** Specific  $N_2O$  emissions from burning fossil fuels in transport sector in Zhytomyr region of Ukraine ( $kg/km^2$ ,  $2\ km \times 2\ km$  grid, 2011)





**Fig. 6.** Total specific greenhouse gas emissions from burning fuels in the residential sector in Zhytomyr region ( $CO_2$  -equivalent, tons/km<sup>2</sup>, 2011)

#### 4. CONCLUSIONS

As an example, we conduct numerical experiments for the residential sector in Zhytomyr region in Ukraine in order to obtain the geo-referenced database with the results of greenhouse gas emission inventory. As input information we used statistical data about fossil fuels consumption in the households for districts and cities of regional subordination for 2011. As the base for the creation of geo-referenced database we used digital map of Zhytomyr region.

We made the review of existing software for greenhouse gas emissions inventory and justified the importance of development of specialized geographic information system that fully takes into account specific procedures for constructing spatial cadastres of emissions. According to specified requirements we construct the architecture of the specialized software for greenhouse gas emissions inventory, using the library GDAL/OGR. We implemented modules which enable to work with vector and raster data formats: to present maps in different projections; to work with different layers; to add new object to the map; to create new layers; to operate with attribute map and image data with the possibility of further analysis. We also developed additional modules for disaggregation of statistical data and visualization of results. Spatial inventory of greenhouse gas emissions is conducted for the residential sector of Zhytomyr region in Ukraine for 2011 using developed specialized GIS software.

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