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Information technology for spatial greenhouse gas emission inventory ready to use for any part of Poland, and any time period

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

Deliverable 1.3. Information technology for spatial greenhouse gas emission inventory ready to use for any part of Poland, and any time period

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Work package 1. Spatially resolved greenhouse gas inventory for Poland

Deliverable 1.3.Information technology for spatial greenhouse gas emission inventory ready to use for any part of Poland, and any time period

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3. Geoinformation technology for spatial GHG inventory: transport sector

Based on the IPCC classification, the road transport subcategory includes GHG emissions from fuel combustion and evaporation from the motor transport, which consists of passenger cars, light and heavy duty vehicles, buses, tractors, motorcycles, and mopeds. According to the Poland's National Inventory Report to the United Nations Framework on Climate Change, the transport sector is responsible for 14,5% of all the GHG emissions in Poland in 2010 (NIR, 2011).

On a scale of the whole country, the distribution of GHG emission sources in road transport is very irregular — automobile transport is highly dense in large cities, when compared to low emissions in villages and uninhabited areas. In order to adequately grasp this diversity, the territory of Poland is split into cells using the 2 x 2 km grid and the administrative borders of municipalities. The spatial inventory of GHG emissions consists of carrying out bottom-up inventory for each grid cell, and then summing up the inventory results for all the fuel and vehicle types.

The GHG emission from the road transport in a grid cell is in turn a sum of emissions from all the emission sources, which are fully or partially located within its borders (Hamal, 2008). In order to build the spatial cadastre of certain gas emissions, it is necessary to calculate its territorially distributed specific emissions. Such specific emission values are calculated, using the parameters and data, which describe emission process for a selected activity, and which also take into account geographic location of the emission sources. That is, the specific GHG emission is a function of: (i) the activity intensity parameters in a certain territory and a period of time, (ii) the proper emission coefficients, as well as (iii) the geographic coordinates of the territory under investigation.

In the road transport sector, motor vehicles operating on roads are the sources of GHG emissions. For practical implementation of spatially distributed inventory, motorways and highways are interpreted as line GHG emission sources in this sector. Urban road networksare treated as area sources, due to a very high density, and only main urban roads are separately treated as line sources.

In general, the level of GHG emissions in a grid cell depends on the amount of fuel consumed by transport within this cell borders. That is, the amount of fossil fuel used by transport is disaggregated to specific emission sources before the spatial GHG emission inventory from road transport is attempted. The obtained fuel quantity is multiplied by the corresponding emission factors to calculate emissions for a certain GHG. For the road transport, the emission sources are as follows:

- the automobile roads of all types, including main roads that, cross settlements;
- the territories of settlements, which are the area sources of emissions from the fuel combustion in transport on the internal road network of a settlement (on the roads and streets of settlements that ,are within its administrative borders).

Thefollowingsteps are taken to disaggregate the regional fuel combustion data to individual roads and settlements.

1. The fuel used for road transport in an administrative unit is disaggregated by settlements and suburban areas for large cities within the unit. If exact information on fuel consumption on road transport sector is available for some cities, it is directly located to the territory of the city and suburban areas around it. For small cities, disaggregation of transport fuel is proportional to the population density.
2. The fuel used in road transport sector in a certain administrative unit (district – in Polish 'powiat' – or voivodeship) is disaggregated to the automobile roads of the unit according to the developed algorithms (including main roads within settlements). This step takes into account the length and width of each road segment, its capacity, and current state. The amount of fuel used in suburban territories, which were found in p.1, is disaggregated to road segments located within their borders.
3. For each emission source, which is fully or partially located within a grid cell, the total amount of fuel used by a certain road transport category is calculated taking into account either the area of emission source – for area emission sources, or the length of an object – for line sources. In this approach the following assumptions are taken: (a) a part of the fuel that, was bought in a settlement for the road transport purposes is used (burnt) within its borders (for the needs of internal urban transport), (b) a large part of the fuel is used on automobile roads in suburban territories that, are located within a certain distance from the administrative borders of the settlement, and (c) the rest of the fuel is used outside the settlements and located to the road segments according to the road maps.

The territory of a smaller settlement is treated as one zone (n=1 below), while two level buffer zones are built around administrative borders of each city with population over 20,000 people. The first one (n=2 below) has the width of a half of the radius of the city area, and the second one (n=3 below) the width of one radius:

$$\tilde{Z} = \begin{cases} Z_{1,i}, \text{ the territory of settlement } i; \\ Z_{2,i}, \text{ the zone radius } = \frac{1}{2}\sqrt{S(i)/\pi}; \\ Z_{3,i}, \text{ the zone radius} = \sqrt{S(i)/\pi}, \end{cases} \tag{3.1}$$

where:

$Z_{n,i}$ is the n-th buffer zone around the$i$-th settlement,

$S(i)$ is the settlement's area.

The reason for building the zones, is to identify suburban roads and road segments with a very dense traffic (*Figure 3.1*).

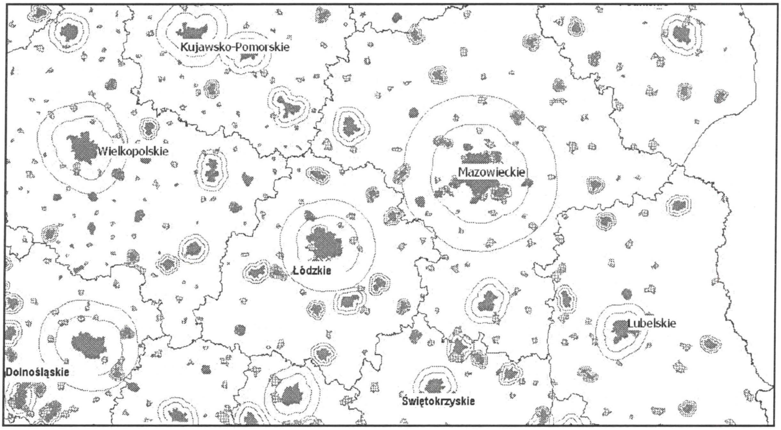

Figure 3.1. Fragment of a digital map of settlements with 2-level buffer zones built for cities with population higher than 20 thousand people.

Emissions for each source type (area and line sources) are calculated, using the bottom-up approach. The quantity of the different type fuel used (diesel, gasoline etc.) is multiplied by the corresponding emission factor. Emission factors differ for various automobile operation modes, as well as for different automobile types and control systems. The total emissions are calculated by summing up emissions from the different phases, namely, the thermally stabilized engine operation (hot) and the warming-up phase (cold start) (EMEP, 2007). Additionally, the age distribution of vehicles is taken into account, as well as the average speed of vehicles on different road segments (using digital maps of road network and their capacity), and within cities.

Following the above specification of variables, the corresponding GHG emissions in a settlement S (or one of its buffer zones $S_{n_s} \in \widetilde{S}^Z$) and a road segment $L_{rd,i} \in \widetilde{L}_{rd}$, are calculated using (3.2) and (3.3), respectively:

$$E_{Tr}^{g}[Z_i(S)] = \frac{Q^{R_2(S)}(f,t,b)}{\sum_w a_b^{R_1(S)}(t,w)} \cdot \frac{P(S)\cdot C_n}{\sum_{s\in\widetilde{S}^{R_2}} P(s)} \times$$

$$\times \sum_{b=1}^{B}\sum_{t=1}^{T}\sum_{f=1}^{F}\sum_{w} EF_{hot}^{g}[f,t,V(H_S),w]\cdot a_b^{R_1}(t,w)\left\{1+K_S(\beta)\left[\frac{EF_{cold}^{g}}{EF_{hot}^{g}}(t_a,w)\Big|_j -1\right]\right\}$$

$$R_2(S)=\{R_2\in\widetilde{R}_2 \wedge S\,\hat{\in}\,R_2\};R_1(S)=\{R_1\in\widetilde{R}_1 \wedge S\,\hat{\in}\,R_1\};\widetilde{S}^{R_2}=\widetilde{S}\,\hat{\cap}\,\widetilde{R}_2, \qquad (2)$$

where:

$E_{Tr}^{g}[Z_i(S)]$ – the emissions of the g-th GHG in the settlement S ($i = 1$) or one of the buffer zones around it (i=2,3);

$Q^{R_2(S)}(f,t,b)$ – the vehicle mileage in the administrative unit $R_2(S)$ (f – fuel type, t – type of vehicle, b – ownership);

$R_2(S)$ – the district, where the settlement S is located,

$R_1(S)$ – the voivodeship,where the settlement S is located,

$P(S)$ – the population density in the settlement S;

$a_b^{R_1(S)}(t,w)$ – the number of the automobiles of the type t and the ownership b in the administrative unit $R_1(S)$,within the age group w;

EF_{hot}^{g} – the emissions of the g-th GHG during operation of the vehicle of a certain type, construction, and age, in the condition of thermallystabilizedengineoperation;

V – the average annual speed of vehicles within the borders of a settlement of the type H_S (city, village, small town etc.);

$K_S(\beta)$ – the ratioof the mileageduring the warming-upphasefor the settlement S (depending on the settlement type and the ratio of overall mileage during the warming-up phase β);

$\dfrac{EF_{cold}^{g}}{EF_{hot}^{g}}$ – the ratioof the emissionsof$g$ GHGduringthewarming-upphase (coldstart) andthermallystabilizedengineoperationfor 1 km;

t_a – the average annual temperature;

C_n – the coefficient of buffer zone around settlement.

For some transport categories and fuel types, the vehicle mileage parameter $Q^{R_2(S)}(f,t,b)$ in (3.2) is not available from statistical yearbooks. Then, it is recalculated, based on the information about fuel consumption by corresponding vehicle types

$$E_{Tr}^{g}\left[L_{rd,n_l}\right]=\frac{Q^{R_2(L_{rd,n_l})}(f,t,b)}{\sum_w a_b^{R_1(L_{rd,n_l})}(t,w)}\cdot\frac{C_{total}(L_{rd,n_l})}{\sum_{l\in\widetilde{L}_{rd}^{R_2}}C_{total}(l)}\times$$

$$\times\sum_{b=1}^{B}\sum_{t=1}^{T}\sum_{f=1}^{F}\sum_{w}EF_{hot}^{g}\left(f,t,V\left[k\left(L_{rd,n_l}\right)\right],w\right)\cdot a_b^{R_1(S)}(t,w)\cdot\left\{1+K_{L_{rd,n_l}}(\beta)\left[\frac{EF_{cold}^{g}}{EF_{hot}^{g}}(t_a,w)\bigg|_j-1\right]\right\}+$$

$$+\sum_{z\in\widetilde{Z}_{L_{rd,n_l}}}\frac{E^{g}(z)\cdot C_{total}\left(L_{rd,n_l}\right)}{\sum_{i\hat{\in}z}C_{total}(i)},$$

$$R_1\left(L_{rd,n_l}\right)=\left\{R_1\in\widetilde{R}_1\wedge L_{rd,n_l}\hat{\in}R_1\right\};R_2\left(L_{rd,n_l}\right)=\left\{R_2\in\widetilde{R}_2\wedge L_{rd,n_l}\hat{\in}R_2\right\};$$

$$\widetilde{L}_{rd}^{R_2}=\widetilde{L}_{rd}\,\hat{\cap}\,\widetilde{R}_2, \tag{3.3}$$

where:

$E_{Tr}^{g}\left[L_{rd,n_l}\right]$ – the emissions of the g-th GHG in the road segment L_{rd,n_l};

$C_{total}(L_{rd,n_l})$ – the road segment's L_{rd,n_l} parameter defining its capacity;

$k(L_{rd,n_l})$ – the road segment's L_{rd,n_l} category or its location (a highway, a rural road, etc.)that helps to define the average speed;

V – the vehicle's average annual speed, which depends on the road category or location;

$K_{L_{rd,n_l}}(\beta)$ – the ratio of the mileage during the warming-up phase for road segment L_{rd,n_l} ;

R_1 and R_2 – the administrative units: voivodeship and district, respectively.

For an elementary cell δ, the sources of emissions in the transport sector are parts of the settlements and the road segments located within the cell borders. The sets of the area and the line objects are denoted as $L_{rd}{}^{\delta} = \{L_{rd} \widehat{\cap} \delta, L_{rd} \in \tilde{L}_{rd}\}$ and $S^{\delta} = \{S \widehat{\cap} \delta, S \in \tilde{S}\}$, respectively. When a source is only partially located in a cell, the overall emissions are calculated proportionally to the size of the object's part located within the cell. That is, emissions in the cell δ are calculated as follows:

$$E^{g}(\delta) = \sum_{s \in \tilde{S}} \frac{E^{g}(s) \cdot area(s \widehat{\cap} \delta)}{area(s)} + \sum_{l \in \tilde{L}_{rd}} \frac{E^{g}(l) \cdot len(l \widehat{\cap} \delta)}{len(l)}. \quad (3.4)$$

Statistical information concerning the use of the fossil fuels in the road transport in Poland and the general activity parameters are available for administrative units (voivodeships, districts, or municipalities – in Polish "gmina") in the yearbooks of transport statistics (Transport, 2011), and the online statistical database (BDL, 2014). Other parameters used in the considered model are available from statistical reports containing transport statistics and summarizing yearbooks (Gospodarka, 2010), (Rocznik, 2010), (Zużycie, 2010).

For practical implementation of the spatially distributed GHG inventory, the following road transport activity data are used:

- the fuel consumption in the road transport sector by fuel and vehicle types;
- the road motor vehicles by age groups;
- the road motor vehicles in total;
- the vehicle mileage;
- the roads' capacity and their current state;
- the operation mode for each road segment;
- the population density.

The digital maps of the road network, the population density map and the administrative map of Poland are used. The average speed of vehicles for a certain road segment is established according to the road type (urban street, rural, highway) by overlapping map of road network with settlements' map in the following way:

- an urban road network – streets and roads located within the borders of cities $\widetilde{L}_{rd}^{Urb} = \widetilde{L}_{rd} \hat{\cap} \widetilde{S}^{Urb} = \left\{ \widetilde{L}_{rd,1}^{Urb}, \widetilde{L}_{rd,2}^{Urb}, ... \right\}$;
- roads for high, constant-speed vehicle operation – highways, motorways $\widetilde{L}_{rd}^{Hway} = \left\{ \widetilde{L}_{rd,1}^{Hway}, \widetilde{L}_{rd,2}^{Hway}, ... \right\}$;
- rural roads – roads located within territories of villages and small towns, as well as dirt roads outside the settlements

$$\widetilde{L}_{rd}^{Rur} = \widetilde{L}_{rd} - \left(\widetilde{L}_{rd}^{Urb} \cup \widetilde{L}_{rd}^{Hway} \right) = \left\{ \widetilde{L}_{rd,1}^{Rur}, \widetilde{L}_{rd,2}^{Rur}, ... \right\}.$$

Both the default IPCC emission factors and the emission factors proposed in the Poland's National Inventory Report (NIR, 2011) were assumed in the emission calculations.

A geoinformation system has been developed for practical implementation of the algorithms for the geospatial inventory of GHG emissions, automatically building the corresponding digital maps, and lettingvisual analysis of the resultsobtained.

All the statistical data and any additional parameters, such as emission factors, are collected in Excel spreadsheets. Using the input information tables and maps (digital maps of settlements, roadways etc.), and following the developed algorithms, the georeferenced databases of the GHG inventory are finally constructed. Each record in the databases corresponds to a grid cell (of size 2 kmx2 km) and contains information about emission source types in the cell, as well as the structure of emissions, with regard to the gas, fuel type, and vehicle category.

The results can be visualised as digital maps with various thematic layers. This form helps to roughly and quickly assess emission levels, localise territories with the highest emission rates, investigate emission structure, and make effective decisions on emission reduction. Deliverable 1.2 presents some thematic maps with the inventory results for the regular grid or municipalities. To improve visualization of differences in emission levels among municipalities, results are presented in the form of prism-maps.

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