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DO WE NEED HEATING SYSTEM SCHEMES FOR EMISSION INVENTORIES OF URBANIZED AREAS ? STUDY CASE FROM UPPER SILESIAN METROPOLITAN AREA

8.1 INTRODUCTION

The paper focuses on the issues related to the carrying out of the air pollutants' emission inventories in the local scale on urbanized areas. The main idea concerns taking into account the data on the population density [10] and validating it indirectly using the map of the urbanized areas [5]. This kind of validation is essential during elaboration of the spatial surrogate (proxy) for the unknown, spatial distribution of greenhouse gases or air pollutants released into the air. Hence, such methodology can be relatively easily used for improving the input data management in air quality modeling. The objective of the study are emissions from households located in the Upper Silesian Metropolitan Area [41], southern part of Poland (shown in the Fig. 8.1).

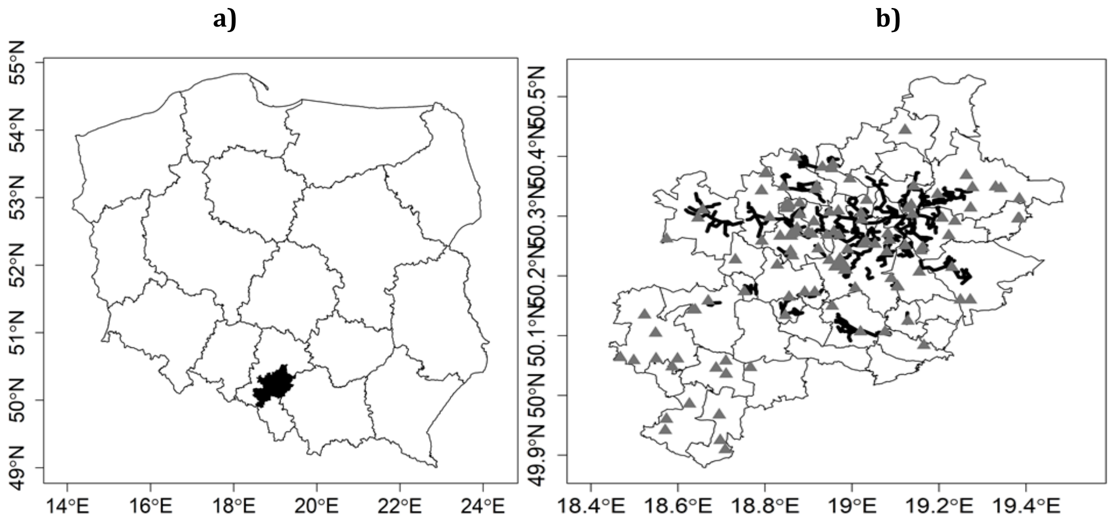

Fig. 8.1 The location of the study area. On the map of Poland (black spot, a), and in detail (b)with added heating plants (points), and main arteries of the Silesian Heating System (lines)

The analysis described here takes into account the households' access to the Silesian Heating System (dark lines, Fig. 8.1b), which is an essential novelty in air pollutants' low emission inventories. However, as it can be easy seen in Fig. 1b, the scheme of the Silesian Heating System is rather rough, as it was prepared from the scarce spatial data presented in [26]. Usually such data are difficult accessible and very often confidential. The access to the district heating system is very important parameter in spatial analysis, because it can distinctly change the values of the surrogate in points (grids) of occurrence. This is presented in details in [38] and [39].

8.2 DESCRIPTION OF THE STUDY AREA

8.2.1 GEOGRAPHICAL LOCATION

The area of the study has the 6,000 km^2 of approximate extent, 100 km (N→S) per 60 km (W→E). It consists of 41 communities (local administrative units, LAUs) aggregated in 21 counties (from 380 in Poland) [4]. The population density in the area varies approximately from 200 to 4,000 people per square kilometer (see Fig. 8.2). Population is mainly focused near the central and northern part of the study area.

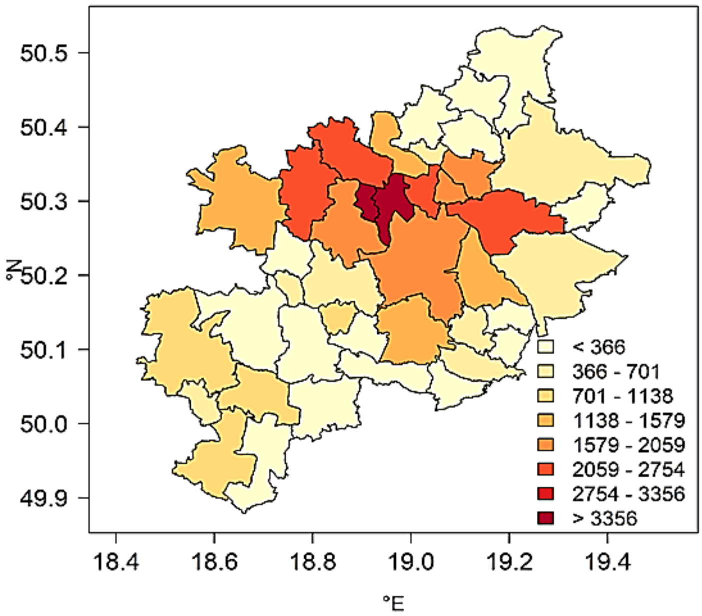

Fig. 8.2 Population density in the communities of the study area

The study area is highly urbanized, dwelled by almost 2.6 million people [29]. The spatial structure of the urbanization is very inconsistent considering applied construction technologies, condition of thermal insulation, and access to the district heating infrastructure. For this reason the dwellers' quality of life strongly varies across the study area [41]. In particular, in the sub-community scale, the areas connected with the district heating are frequently neighboring with the areas without the district heat supply. The same issues can be applied to all matters connected with the heating demand, and then – air emissions associated with the residential sector.

8.2.2 DISTRICT HEATING IN THE STUDY AREA

District heating (DH) in Poland supplies ca. 41% of the residential sector's heat demand [6, 27, 30] which is approximately equal to 50% of dwellers supplied [1]. In case of urbanized areas, the share of dwellers supplied from the DH can be slightly bigger. It is estimated for Upper Silesia that the 50% of dwellers is supplied from the DH [26].

Apart from the analysis of scientific studies, some information about the availability of district heating in particular LAUs can be given in selected documents considering energy strategies, and fuel supply [2, 3, 9, 12, 16, 17, 18, 19, 20, 22, 23, 24, 25, 32, 33, 36, 40]. The information about occurrence of the heating network is mostly given as the total length of pipelines. The map of heating pipelines' length is presented in the Fig. 8.3.

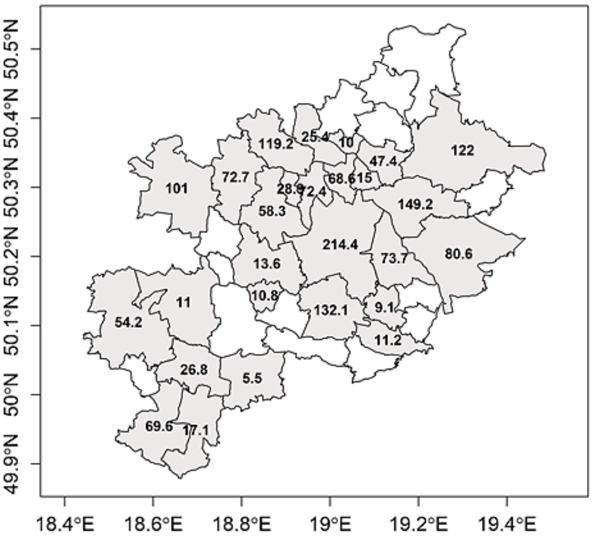

Fig. 8.3 The length of district heating networks in the study area [km]
Source: Own elaboration on the basis of data derived from [2, 3, 9,12, 16, 17, 18, 19, 20, 22, 23, 24, 25, 32, 33, 36, 40].

8.2.3 EMISSION INVENTORY AND INCONSISTENCIES IN SPATIAL DATA SETS

Spatial emission inventories can be split into two groups:

- emission estimated and spatially associated using remote sensing [eg. 28, 31, 37];
- emission estimated using assumptions, and disaggregated using geographic information systems (GIS) tools [eg. 8, 11, 21].

Presented case focuses on the second (ii) type of emission inventories, when the air emission of pollutant p (mass of p released into the air during particular time period) is estimated using formula:

$$E_p = \sum_i A_i \cdot EF_{i,p}, \quad (8.1)$$

where:

E_p– estimated emission;
A_i – activity for emission source i, eg. amount of energy or goods produced;
$EF_{i,p}$ – emission factor of pollutant p: mean emission of pollutant p generated by production of particular good's unit (commodity, energy or heat).
Then, the E_p is spatially disaggregated, using formula:

$$E_p = \sum_i^N E_{p,i}(x_i), \quad (8.2)$$

where:
N – the number of grids (regular spatial units) [see eg. 14, 15] or administrative units (irregular spatial units) [see eg. 13];
$E_{p,i}$ – summary emission of pollutant p for spatial unit i;
x_i – coordinates associated with spatial unit i.
Comparing the Figures 1b, and 3, we can see that the scheme of the Silesian DH system does not cover the southern part of the study area, where the pipelines' lengths are identified. That type inconsistency of spatial data can cause problems with disaggregation of estimated air emissions. For instance, using a proxy spatial surrogate obtained from the digitized scheme (Fig. 1b) results with the significant overestimation in the southern part of analyzed area.
The same situation is associated with emission inventories. Using average parameters such as amount of CO_2 emitted *per capita* (*pc*), and number of dwellers supplied from district heating estimated on the basis of Fig. 1b overestimates the emissions in the southern part of analyzed area.
Similar inconsistencies between various spatial data sets occur frequently. In many cases it leads to very different results of emission estimations, and then – spatial emission inventories.

8.3 INCONSISTENCY EXPRESSED BY NUMBERS

The official statistics show that the nearly 50% of the Polish households use coal, nearly a quarter – natural gas, and ca. 20% – wood [7]. The annual emission of CO_2 released from the residential sources (1A4bi category in the IPCC nomenclature) located in the study area is estimated as 33,571.32 kt. The value bases on the own estimations using officially reported data on activities (fuel mix), and national emission factors [34, 35, 39]. Considering spatial disaggregation of the value i.e. preparing the spatial distribution of the CO_2 emission aggregated in communities or regular grids, it can be noticed from the Fig. 1b, and 3, that the scheme of Silesian DH system skips the six communities (Czerwionka-Leszczyny, Jastrzębie-Zdrój, Pawłowice, Rybnik, Suszec, Żory). This fact can be caused by occurrence of the two independent district heating subsystems, however the available spatial data does not contain such information. This can cause significant overestimation of disaggregated values in enumerated communities.
Basic statistics for the communities are presented in the Table 8.1.
It can be noticed (Table 8.1) that possible overestimation in CO_2 emission can be associated with the 363,432 dwellers.

Table 8.1 Basic statistics of communities skipped in spatial data set

Name	Population	Population density
[–]	[–]	[people/km^2]
Czerwionka-Leszczyny	42,170	368
Jastrzębie-Zdrój	89,590	1,050
Pawłowice	18,143	240
Rybnik	139,129	938
Suszec	12,157	162
Żory	62,243	963
Total	363,432	645

Source: Own elaboration on the basis of data for 2017 [29]

Assuming that six enumerated communities (for brevity, 6 CM) are supplied with the heat from the DH system in the national average (41% of dwellers), the overestimation in particular communities/grids can achieve:

Total study area (emission *per capita*):

$$33{,}571.32\ \text{kt}\ CO_2/2\ 595{,}249 \approx 12.94\ \text{t}\ CO_2\ pc, \tag{8.3}$$

6 CM_0:

$$363{,}432 \cdot 12.94 \approx 4{,}703\ \text{kt}\ CO_2, \tag{8.4}$$

6 CM_{41}:

$$4{,}703\ \text{kt}\ CO_2 \cdot 0.59 \approx 2{,}775\ \text{kt}\ CO_2. \tag{8.5}$$

6 CM_0 – no dwellers supplied from the DH system;

6 CM_{41} – 41% dwellers supplied from the DH system.

The error for the considered six communities referred to the number of dwellers can be estimated:

$$\Delta = \frac{6CM_0 - 6CM_{41}}{363{,}432} = 5.3\ \text{t}\ CO_2\ pc. \tag{8.6}$$

That means the CO_2 emission can be significantly lower in considered communities. The error related to the mean CO_2 emission *pc* from the *top-down* estimation for all study area is estimated as:

$$E = \frac{5.3}{12.94} \cdot 100\% \approx 41\%. \tag{8.7}$$

8.4 SUMMARY

The officially reported uncertainty of the CO_2 emission inventory from the residential combustion (1.A.4 'Other Sectors') is estimated at 4.3% [34]. However, this value might be substantially underestimated because official methods do not take into account neither uncertainties arising from spatial distribution of emission sources nor complicated spatial relations between them. This effect becomes particularly important on areas with lower population density and with an unevenly used heating network.

Our results suggest that the emission uncertainty related to six analyzed communities taken as a simple case study in our work may even be several times larger than officially reported one. Thus the detailed information on the scheme of the Silesian Heating System is a great importance.

Moreover, it should be emphasized that the uncertainties for the administrative units or spatial grids would tend to increase along with the number of spatial data transformations as well as with an increasing spatial resolution used in such analyzes. To avoid presented inconsistencies it is need to use various, and possibly the newest sources of spatial data to effectively validate each other. Although, the available technologies could basically let for automations of emission inventories taking into account main spatial aspects, presented results show that in practice full automation is still not an easy task and related spatial analyses should be intensively developed together with development of experimental and measuring techniques.

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DO WE NEED HEATING SYSTEM SCHEMES FOR EMISSION INVENTORIES OF URBANIZED AREAS ? STUDY CASE FROM UPPER SILESIAN METROPOLITAN AREA

Abstract: The paper presents the quick look on the possible consequences associated with the spatial data manipulations in air emission inventories. The study area is the Upper Silesian Metropolitan Area, located in the southern part of Poland, where the substantial part of dwellers is supplied with the heat from the district heating system. Is shown that skipping some spatial information, or use of incomplete/obsolete data sets can make the uncertainties of the CO_2 emission inventory from the residential sector almost ten times bigger in particular areas. Uncertainties tend to increase along with the number of spatial transformations.

Key words: emission inventory, CO_2, uncertainties, spatial analysis

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Streszczenie: Przedmiotem artykułu jest krótkie przeanalizowanie konsekwencji błędów wynikających z przekształceń niekompletnych (nieaktualnych) danych przestrzennych. Obszarem badawczym jest część Konurbacji Górnośląskiej, której znaczny odsetek mieszkańców jest zaopatrywany w ciepło sieciowe. Wykazano, że pominięcie części informacji przestrzennej albo wykorzystanie niekompletnych danych przestrzennych może prawie dziesięciokrotnie zwiększyć niepewność oszacowania emisji CO_2 w wybranych częściach obszaru badawczego.

Słowa kluczowe: inwentaryzacja emisji, CO_2, niepewności, analizy przestrzenne

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