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DISAGGREGATION OF SO_2 AND $PM_{2.5}$ EMISSIONS FROM SMALL DOMESTIC COMBUSTION SOURCES LOCATED IN SOUTHWESTERN POLISH PROVINCES - CASE STUDY

16.1 INTRODUCTION

Fine particulate matter and sulphuric oxides are widely known as pollutants connected with combustion processes [21]. Long-term exposure to air polluted with SO_2 and $PM_{2.5}$ can strongly affect the human health [1]. Small combustion sources, particularly of height up to 40 m [18] can strongly affect air quality in local scale. According to current report by Polish Ministry of the Environment [20], emission from fuel combustion in domestic boilers causes roughly 90% of air quality level exceeding's. Moreover, pollutants from small combustion sources are tend to be deposited locally [18], so struggle with that problem can be very difficult in national level.

This paper presents analysis carried out for three of 16 provinces (voivodeships) located in southwest Poland (Lower Silesia, Opole and Silesia) also their districts. In analysed region are located important centers of Polish industry, such as: public power (mainly located in Silesia), quarrying of copper (Lower Silesia) and chemical industry (Opole). Apart from number of operating industrial emission sources, the inhabitants (almost 21% of Poland's population) are exposed to pollution emitted from their settlements.

Compared to the newest analysis carried out by the Central Statistical Office of Poland [17] the share of emission from small domestic sources in national total emission for three analysed provinces is slightly greater than 20% for both analysed pollutants.

16.2 MATERIALS AND METHODS

16.2.1 Emission estimation

The methodology of emission estimation for small domestic combustion is widely described in national report [14]. The emission (on national level) is presented using following formula:

$$E^X = \sum F \cdot A_F \times {EF_F}^X \tag{16.1}$$

where: E^X - emission of pollutant X [Mg],

A_F - activity rate (amount of particular fuel used) [TJ] or [Mg],
${EF_F}^X$ - emission factor of pollutant X for fuel F [Mg/TJ] or [dimensionless].

16.2.2 Selection of emission surrogates

Considering Formula (16.1), to disaggregate the national total total to scattered sources located quasi-accidentally in particular districts was surrogate methodology adopted [12]. In general, the surrogate method relies on selection auxilliary value suitable for disaggregation. Very often the surrogate is chosen as economical parameter, such as GDP [5] or by the expert judgement [7]. After selection of desired value, the Formula (16.1) is presented as:

$$E^X = \sum \lambda \sum F \, \lambda \times A_F \times {EF_F}^X \tag{16.2}$$

where: λ, - selected surrogate.

16.2.3 Heat demand

To disaggregate emissions from combustion in small domestic sources, we determined the heat demand in particular districts using formula similar to presented by Hławiczka et al. [9]:

$$H_d = A_{IH} \times HDD \times 24 \times 3600 \times 10^{-12} \times \sum Q \, H_d(Q) \times F_Q \tag{16.3}$$

where: H_d - total heat demand in provinces: Lower Silesia, Opole and Silesia [TJ];
A_{IH} - floor space heated individually [m^2] [15];
HDD - heating degree days, separately for provinces, by Dopke [6] [$K \times d$];
$H_d(Q)$ - heat demand assessed considering age of the building, insulation quality and heat losses [9] [$W \times m^{-2} \times K^{-1}$] (low losses: 1.1; medium losses: 1.6; high losses: 2.5);
F_Q - F_Q, floor space of buildings in particular age [m^2].

16.2.4 Age of buildings

According to data derived from the current National Census of Population and Housing [15] and year of built given (8 separated age classes c since 1918 to 2011) the were estimated as: high loss: $F_H = c_{1+2} + 0{,}45 \times c_3$; medium loss: $F_M = 0{,}55 \times c_3 + c_4 + 0{,}75 \times c_5$; low loss: $F_L = 0{,}25 \times c_5 + c_{6+7+8}$, where floor spaces in particular age class was estimated by average floor space per capita in particular district and number of residents [15].

Age classes are defined as follows: c_1, before 1918; c_2, 1918-1944; c_3, 1945-70; c_4, 1971-78; c_5, 1979-88; c_6, 1989-2002; c_7, 2003-2007 and c_8, 2008-2011.

16.2.5 Top-down limitation

Disaggregated heat demand was limited with top-down value (B [TJ]) derived from eurostat, assuming average efficiency (η) of boilers and stoves as 50%, then accepted value had to be smaller than reported internationally:

$$H_d \times \eta^{-1} \leq B \tag{16.4}$$

Top-down methodology is widely discussed in [24]. Limitation given by Formula (16.4) was necessary for purposes of national emission inventory due to maintaining compliance with datasets taken from international statistics.

16.2.6 LHDI

LHDI (*Local Human Development Index*) is an indicator elaborated by Polish Ministry of Infrastructure and Development [3]. Construction of factor is based on three dimensions of human development: wealth, education and health. As a result the $0 \leq LHDI \leq 100$ is geometric mean of sub factor describing particular dimension, as:

$$LHDI = (F_W \times F_e \times F_H)^{1/3} \tag{16.5}$$

where: F_W - „wealth" sub factor, considers incomes of inhabiting taxpayers and social benefits (social assistance and family policy);

F_E - „education" sub factor, basing on information about percentage of children attending preschool education also results of primary education exam (mathematical part) related to annual average;

F_H - „health" sub factor, similarly considers 2 components: life expectancy of an infant and number of deaths from cancers and (separately) cardiovascular failure (related to 100 thousands of people).

16.2.7 Spatial autocorrelation models

To investigate spatial emission patterns of SO_2 $PM_{2.5}$ also the *LHDI* we used local Moran statistics statistics was used [13]. This statistics is widely use due to its effectiveness and simplicity. Moran lets analyse if particular region is surrounded by similar or distinguishing values in neighboring regions. This statistics can be also used for detections of hot-spots (separated cluster of outlying values) or local clusters Kopczewska. Local Moran is given below:

$$I_i = \left((x_i - x)\sum_{i=1}^{n} w_{ij}(x_j - x)\right)\left(\sum_{i=1}^{n} \frac{(x_i - x)^2}{n}\right) \tag{16.6}$$

Parameters of Moran are: $s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - x^*)$ and $x^* = \frac{1}{n}\sum_{i=1}^{n} x_i$. For purposes of presented analysis matrix assumed as matrix of 6 nearest neighbors as was suggested by Dong and Liang [5].

16.3 RESULTS AND DISCUSSION

For each district, the total floor space of buildings in particular age class was estimated as product of average floor space (per capita) and number of residents (due to building in particular age), data derived from 2011 Census of Population and Housing [15]. That operation let derive general age structure of floor area in each district. According to analysis carried out by Hławiczka et al. [9], the age structure of floor space was adjusted to particular heat demand class. The way of analysis is presented in Fig. 16.1.

d.b. district   **d.b. age class and district**
↑   ↑
average floor space × **number of residents → floor area**
↓
d.b. age class and district

d.b. – disaggregated by

Fig. 16.1 Age structure of buildings: analysis scheme

Source: Own elaboration

Basing on obtained data for 8 age classes (see: 16.2.2), the floor area in each age class was corrected, so heat demand structure was compliant with analysis [9]. Results are presented in Tab. 16.1. Basing on methodology derived from [14], for purposes for this analysis assumed the average efficiency of individual boilers and stoves as 50%. This assumption was necessary due to keeping compliance with international balance.

Tab. 16.1 Structure of heat demand disaggregated by province

Heat demand class	Hławiczka et al. [9]			This paper		
[W×m-2×K-1]	[%]			[%]		
	Lower Silesia	Opole	Silesia	Lower Silesia	Opole	Silesia
1.1	33	45	41	19	16	18
1.6	16	20	19	29	40	50
2.5	51	35	40	52	44	31

Source: Own elaboration

Emissions of SO_2 and $PM_{2.5}$ in each province were calculated using top-down methodology derived from official emission estimation [14] applying factors taken from [17]. Disaggregated emissions basing on methodology introduced above are shown in Fig. 16.2. Comparing presented figures can be notice facts that lower values in case of SO_2 and $PM_{2.5}$ emissions corresponded to the locations with higher values of local human development index. This fact can be explained by occurrences of highly developed areas (cities with usually better socioeconomic conditions). Further analysis of scatterplots did not provided premises on significant correlation between these variables. According to a fact that variables SO_2 vs. *LHDI* and $PM_{2.5}$ vs. *LHDI* are not tend to be correlated (Pearson's correlation coefficients: 0.023 and −0.097, respectively), the hypothesis is that *LHDI* indicator could be used as spatial surrogate for SO_2 and $PM_{2.5}$ emissions [12].

a) SO_2 **b) $PM_{2.5}$** **c) LHDI**

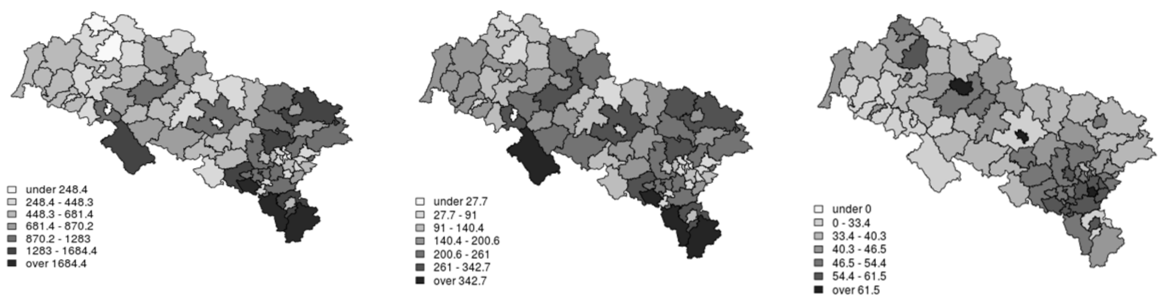

Fig. 16.2 Spatial distributions of SO_2 , $PM_{2.5}$ emissions [t] and *LHDI* [dimensionless]

Source: Own elaboration

For analysis of local Moran statistics I_i, the 6 nearest neigbours distance binary matrix was chosen. The 6 nearest neighbours distance matrix (between districts) is shown in Fig. 16.3.

Fig. 16.3 K nearest neighbours for k=6 (districts located in analysed provinces)

Source: Own elaboration

For purposes of further analysis prepared Moran scatterplots (see Fig. 16.4, pseudo significance level 0.05). Preliminary analysis suggested insignificance of Moran statistics in majority of cases. The disaggregated emissions of SO_2 and $PM_{2.5}$ were tend to be located randomly, which is commonly known as the checkerboard effect occurrence [23]. However the emissions were not spatially correlated, the majority of SO_2 scatter-plot points are focused in „Low-low" sector. This fact suggested occurrence of Low values surrounded by low values with significantly strong influence of outliers. In contrast, in the scatterplots of $PM_{2.5}$ emission and *LHDI* were not visible such as clear pattern. That suggested bigger effect of randomness.

a) SO_2 b) $PM_{2.5}$ c) LHDI

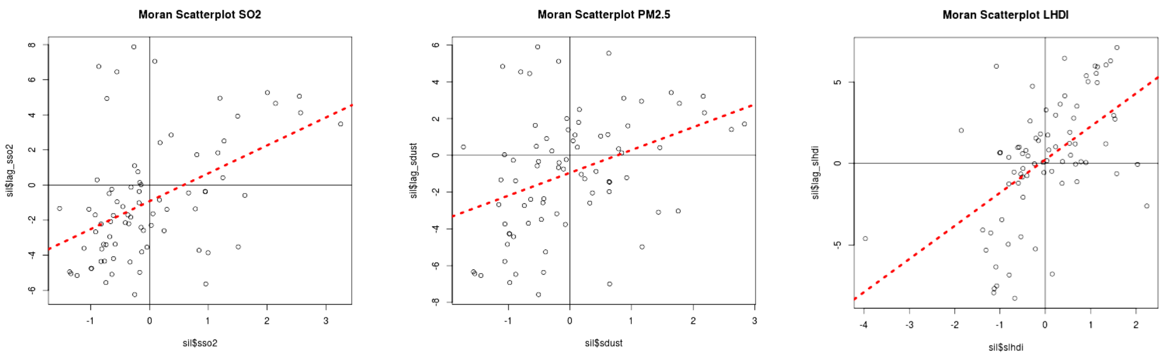

Fig. 16.4 Moran plots of SO_2, $PM_{2.5}$ emissions [t] and *LHDI*

Source: Own elaboration

Maps presenting Moran statistics are shown below. Analysis of local Moran statistic maps confirmed big extent of Moran insignificancy ($I_i \approx 0$, pseudo significance level 0.05). Possible clusters are presented in Fig. 16.5.

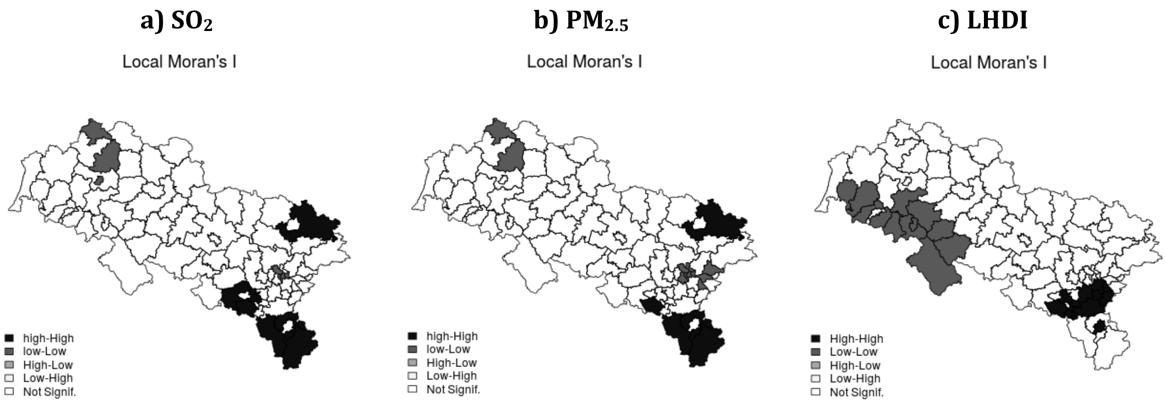

Fig. 16.5 Moran maps of SO_2, $PM_{2.5}$ emissions and *LHDI*

Source: Own elaboration

CONCLUSIONS

Our analysis presented in this paper applied new approach to spatial disaggregation of emission values derived from top-down analysis. Analysis using approach elaborated by Hławiczka et al. [9] generated spatially random of values. Significance was checked using local Moran statistics with pseudo significance level 0.05. Statistics was tested using Monte-Carlo simulation Kopczewska.

The result of analysis could be interpreted as lack of clear spatial dependencies between sub regions (checkerboard effect), which means nearly random location of designated emissions (designation to each sub region its own unique disaggregation factor). We found that *LHDI* could be good disaggregation factor for emissions from small domestic combustion sources.

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Abstract: *The aim of this study is to present disaggregation for SO_2 and $PM_{2.5}$ emissions from small domestic sources. As suggested by Dong and Liang [5], the problem is to analyse air emission from scattered sources (households). Data submitted for Poland [14] indicate that small domestic boilers are one of main sources of air pollutant emission. Their shares in 2013 national total were about 34% for SO_2 and 51% for $PM_{2.5}$ respectively. Results from [21] underline the significance of that source. Moreover, the current analysis found connection between small domestic combustion and air quality worsening in local scale. Despite the fact, solid fuels will remain the main energy resource in the near future [22]. To carry out presented analysis, we used emission data submitted for international purposes [14] and selected statistics published by the Central Statistical Office of Poland [15, 16]. Selected data were derived also from study carried out by Hławiczka et al. [9] for Polish-Czech Republic border region.*

Key words: *emission, SO_2, $PM_{2.5}$, spatial statistics, small domestic combustion*

DEZAGREGACJA EMISJI SO_2 ORAZ $PM_{2.5}$ Z GOSPODARSTW DOMOWYCH POŁOŻONYCH W POŁUDNIOWO-ZACHODNIEJ POLSCE: STUDIUM PRZYPADKU

Streszczenie: *Celem niniejszej pracy jest prezentacja dezagregacji emisji SO_2 and $PM_{2.5}$ do powietrza z gospodarstw domowych. Wyniki pracy [5] wskazują, że występuje problem z małymi źródłami emisji rozmieszczonymi przypadkowo. Dane o emisji krajowej [14] wskazują, że spalanie paliw w gospodarstwach domowych jest jednym z głównych źródeł emisji SO_2 $PM_{2.5}$ do powietrza (udziały w roku 2013 to odpowiednio: 34% SO_2 oraz 51% $PM_{2.5}$). Wyniki [21] podkreślają rolę tego źródła emisji. Ponadto obecnie prowadzone analizy potwierdzają zależność pomiędzy emisją z gospodarstw domowych a jakością powietrza w skali lokalnej. Pomimo tego, węgiel pozostanie w najbliższej przyszłości głównym źródłem energii [22]. W celu przeprowadzenia analizy wykorzystano dane o emisji krajowej [14] oraz wybrane statystyki krajowe [15, 16]. Część danych zaczerpnięto z wyników badań Hławiczki i in. [9] dla regionu przygranicznego Polska-Czechy.*

Słowa kluczowe: *emisja, SO_2, $PM_{2.5}$, statystyka przestrzenna, gospodarstwa domowe*

Mgr inż. Damian ZASINA
EP-NRI, National Centre
for Emissions Management
ul. Chmielna 132/134, 00-805 Warszawa
e-mail: Damian.Zasina@kobize.pl

Dr hab. inż. Jarosław ZAWADZKI, prof. PW
Warsaw University of Technology
Faculty of Environmental Engineering
ul. Nowowiejska 20, 00-653 Warszawa
e-mail: J.J.Zawadzki@gmail.com

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