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ISSN electronic version 2353 - 9119
Central and Eastern European Journal of Management and Economics
Vol. 4, No.4, 321-332, Dec. 2016

CEEJME
Central and Eastern European Journal of Management and Economics

Influence of selected sources of pollutants emissions on the air quality in Cracow

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Abstract: The article is an attempt to estimate the emissions of pollutants such as particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO_2) and carbon dioxide (CO_2) in Cracow in 2015 resulting from the solid-fuel boilers (especially coal fired boilers) and fireplaces and emissions resulting from the operation of road vehicles. Estimated emissions of pollutants were compared with the emissions of plants of significant nuisance to air quality in Cracow. Conclusions have been drawn about the directions of Cracow authority policy in environmental protection.

Keywords: pollutants emission, coal fired boilers, road transport, environmental protection
JEL: Q01, Q53

1. Introduction

Cracow is a city where concentrations of the individual pollutants, particularly in the winter season, frequently exceed the limit values by significant intervals. This results in Cracow being perceived as a polluted city that does not cope with the problem of excessive emissions, which diminishes the tourist attractiveness of this location as well as negatively affects human health and increases the degradation of precious natural habitats in Cracow (Dubel et al. 2016), making them difficult to manage (Dubel et al. 2010).

In order to improve the ambient air quality, the city authorities decided to pursue a policy of emission reduction. This is part of the European Union policy of mitigation and adaptation to climate change (Bayer et al. 2015: 1011-1023).

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Within the framework of this policy, the most restrictive are the actions concerning emissions from solid-fuel boilers, which are used for heating and domestic hot water preparation. On 15th January 2016, resolution no. XVIII/243/16 was adopted concerning introduction of restrictions, within the area of the Municipality of Cracow, in the scope of operation of installations in which fuels are combusted. This resolution establishes a prohibition on the use of solid fuels in all heating appliances. Implementation of this resolution will involve significant financial costs incurred by the municipal budget of the city of Cracow and will lead to considerable interference in the technical facilities in properties belonging to private entities. Other very important sectors causing negative impacts on the environment are road transport and industry.

However, it should be noted, that in the case of road transport, despite increasing transport activity, the negative impact is gradually declining, which is a consequence of implementation of emission standards EURO (Pindór, Trela 2014: 117-129). The negative impact of the industrial sector also has a downward tendency as a result of environmental investments in this sector of the economy (Preisner 2016: 62-65).

The objective of the paper is to perform a comparative analysis of pollution emissions resulting from operation of solid-fuel boilers and fireplaces with pollution emissions from the public road transport and the industrial sector. The analysis of these values will contribute to the establishment of the priorities that should be adopted in order to pursue the struggle for a better air quality in Cracow.

The calculations presented herein concerning pollution emissions from solid-fuel boilers and fireplaces were made according to the methodology shown in the paper. Calculations of pollution emissions from the road transport were made using the COPERT IV method by processing the statistical data concerning Cracow in accordance with the methodology of preparing data to be used in the COPERT IV method (Trela 2016: 226-236; Trela 2016: 281-292). Emissions from particularly noxious industrial facilities were determined based on the available statistical data.

2. The source of data on the number and ways of application of solid-fuel boilers and fireplaces in Cracow

Data concerning the number of heating boilers powered by solid fuels (23,854) were adopted based on the inventory taken in 2013-2015 on behalf of the Municipal Office of Cracow. Data concerning the number of fireplaces (12,000) were adopted on the basis of the results of the research by the CEM Market and Public Opinion Research Institute from September 2013. However, the quality of the data concerning the fireplaces may raise some doubts. The data presented in the resolution no. XVIII/243/16, deriving from the research by the CEM Market and Public Opinion Research Institute from September 2013, are not fully reliable as the shares of the three listed groups of fireplace users (users indicating fireplace as the main source of heat, as a supplementary source of heat in the flat and indicating fireplace as a solely decorative element) add up to 103.3%. From this it follows that some of the users would have to indicate at least two functions of the fireplace at the same time, while each of the three functions excludes the other two. So, the survey was conducted in a rather careless manner or the wrong data were entered in the survey report, or possibly an error was made in the resolution and the wrong figures were referred to.

An alternative for using these data are data coming from the inventory taken in 2013-2015 on behalf of the Municipal Office of Cracow. According to the inventory, the number of fireplaces amounts to 4,044 with the reservation however that the number of fireplaces was not determined in the 1st stage of the inventory-taking process, which comprised parts of the districts of Stare Miasto (Old Town), Grzegórzki and Dębniki.

Taking into account the fact that other reliable data are available concerning the number of fireplaces in Cracow, it was assumed that the calculation error resulting from the inaccuracy of the data from the research carried out by the CEM Market and Public Opinion Research Institute would be smaller than the calculating error resulting from underestimating the number of fireplaces in Cracow as a result of the incomplete inventory of this source of heat. In the calculations, it was assumed that the share of fireplaces fulfilling a merely decorative function is smaller than indicated in the survey (29.7% instead of 33%), thus obtaining share values that added up to 100%.

3. Pollution emissions from solid-fuel boilers and from fireplaces

Calculations of pollution emissions from solid-fuel boilers were made with the following assumptions:

1) The indicator of seasonal heat demand amounts to 350 kWh/m^2 * year; (Alsabry et al. 2010: 39-45) - it was assumed that coal fuel boilers are installed mainly in the oldest buildings - until 1966.
2) The average floor area of flats in Cracow amounts to 57.7 m^2 (Housing..., 2016).
3) The indicator of emissions of selected pollutants from combusting hard coal in coal boilers was adopted according to Table 1.
4) The number of coal boilers is 23,854 (Resolution no. XVIII/243/16).
5) The boilers are fuelled with hard coal.
6) One boiler supplies heat to one flat.
7) The energy needed to prepare domestic hot water was adopted at the level of 28.012 GJ per 1 flat - The calculations were based on the methodology for calculating the energy performance of the building using a computer program BuildDesk Energy Certificate Professional assuming that water is prepared in the dual-function, constant temperature boiler.

Table 1. Values of the selected emission factors for hard coal combustion in coal boilers with manual feeding

pollutant	PM	NO_x	SO_2	CO_2
emission factor [g/GJ]	444	110	400	91

Source: *Methodology* ... 2016: 7.

Calculations of pollution emissions from fireplaces were made with the following assumptions:

1) The number of fireplaces is 12,000 - functions of the fireplaces: 4.3% fireplaces are the main source of heating the dwellings; 66% fireplaces serve as a supplementary source of heating; 29.7% fireplaces merely fulfil a decorative function (resolution no. XVIII/243/16).
2) For the fireplace function as the main source of heating, it was assumed that 100% of the heat demand is covered by the fireplace; for the function of a supplementary source of

heating, it was assumed that 50% of the heat demand is covered by the fireplace; for the decorative function, it was assumed that the fireplace does not supply any heat.

3) Emission factors for the selected pollutants for combusting wood in the fireplaces was adopted according to Table 2.
4) It was assumed that the fireplaces are installed in single-family buildings.
5) The average floor area of a single-family building as well as the heat demand indicator were adopted according to Table 3.
6) It was assumed that the number of houses that have a fireplace installed in them is identical in each age category of the buildings.

For all calculations, it was assumed that 100 kWh can be converted into 0.36 GJ.

Table 2. Values of the selected emission factors for combusting wood in fireplaces

pollutant	PM	NO_x	SO_2	CO_2
emission factor [g/GJ]	800	80	11	88

Source: Source: *Methodology* ... 2016: 7.

Table 3. Average floor area of the houses and the heat demand indicators

year	average floor area of the houses [m^2]	heat demand indicators [kWh]
do 1966	99	350
67-85	99	260
86-92	108.1	200
93-97	123.1	160
po 98	138.4	120

Source: Alsabry et al. 2016: 60-68.

The volumes of emissions for the particular pollutants coming from combustion of hard coal in solid-fuel boilers and from combustion of wood in fireplaces in Cracow have been presented in Table 4.

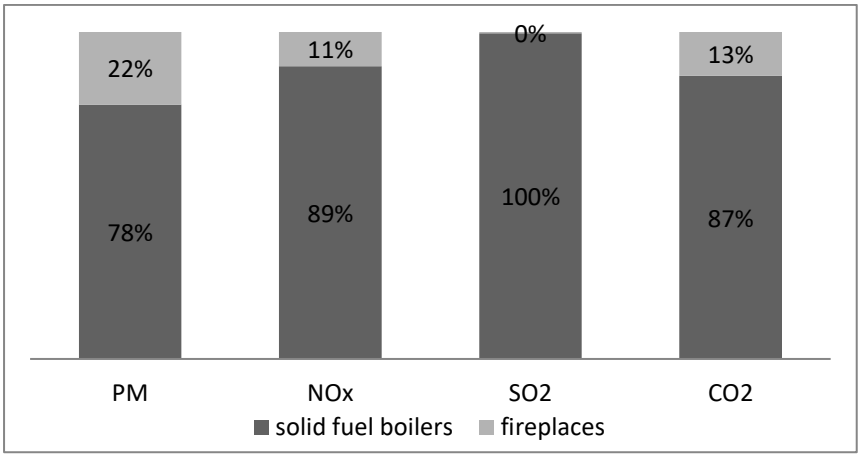
Emissions from the fireplaces are essentially lower than the emissions from coal boilers for each of the compounds analysed. This is particularly apparent in the case of SO_2 where emission of this compound is virtually negligible in relation to the emission from the solid-fuel boilers.

Table 4. Emissions of PM, NO_x, SO_2, CO_2 resulting from generating heat and preparing domestic hot water by means of solid-fuel boilers and fireplaces in Cracow in 2015

source of emission	PM	NO_x	SO_2	CO_2
	[Mg]			
heat generation by means of solid-fuel boilers	770	191	694	158
preparation of domestic hot water by means of solid-fuel boilers	297	73	267	61
heat generation by fireplaces	305	31	4	34
total	**1,372**	**295**	**965**	**253**

Source: author's own research.

Graph 1. The share of pollution emissions from solid fuel boilers and fireplaces in the total pollution emissions from heating appliances fired with solid fuel



Source: author's own research.

However, when analysing the share of emissions from the fireplaces in the total pollution emissions coming from solid-fuel heating appliances (Graph 1), it turns out that in the case of PM it is 22%. This share, even though significantly lower than that for solid-fuel boilers, constitutes a considerable contribution of the fireplaces to the poor quality of ambient air in Cracow, manifesting itself in the form of smog.

4. Pollution emissions from the road transport

Pollution emissions in Cracow resulting from operation of means of road transport were calculated based on data from the Central Statistical Office. For the assessment of the pollution emissions, the COPERT IV methodology was applied. In order to prepare the data so as to enable application of the COPERT IV method, *Cracow in numbers 2015* was used to determine the number of vehicles registered in Cracow. The numbers of the particular types of vehicles (Table 5) were determined with the following assumptions:

1) It was deemed that means of road transport would include: cars, lorries (trucks), buses, tractors, special vehicles, motorcycles and mopeds.
2) The percentage structure of the shares of the individual types of vehicles in the total number of vehicles was assumed to be identical with the structure for the entire Małopolskie province, which was calculated on the basis of: *Transport – activity results in 2015*.
3) It was assumed that agricultural tractors do not move within the city of Cracow.
4) Special vehicles were classified as 50% vehicles with GVW <= 3.5 t 'delivery vehicles' and 50% vehicles with GVW > 3.5 t 'lorries'.
5) In statistical data, the category of lorries (trucks) classifies vehicles starting from payloads not exceeding 999 kg, through the category of 1,000-1,499 kg to the category of over 15,000 kg. It was assumed that emissions form vehicles within the category of payloads up to 999 kg would be calculated in the same manner as for cars (Trela 2016: 226-236) as these are vehicles of the construction of a car but registered as lorries. It was assumed that vehicles with payloads of 1,000-1,499 kg belong to the category of light commercial vehicles with GVW <= 3.5 t – "delivery vehicles".
6) The category of buses includes city buses (530 pcs – the fleet belonging to the public transport operator MPK Cracow) as well as coaches (2,145).

In order to determine emissions resulting from operation of means of road transport using the COPERT IV method, it is necessary to determine the numbers of the individual types of vehicles conforming to the particular Euro emission standards; and it is also necessary to determine the basic operational parameters of the vehicles, such as average operating speed and the annual mileage for the particular types of vehicles.

Table 5. The numbers of the individual types of vehicles registered in the city of Cracow

cars	**394,107**
lorries	
vehicles of the construction of a car	**37,404**
GVW <= 3.5 t – "delivery vehicles"	**17,609**
GVW > 3.5 t – „trucks"	**13,461**
buses	
city buses	**530**
coaches	**2,145**
motorcycles	**22,642**
mopeds	**22,558**

Source: author's own research.

These values were determined on the basis of the methodology of preparing statistical data that enables application of these data to calculate emissions from road transport by means of the COPERT IV method (similar shares were adopted with respect to the individual types of vehicles depending on the Euro standard in the total number of vehicles of the type concerned; also, similar annual mileages were adopted as well as operating speeds) (Trela 2016: 226-236; Trela 2016: 281-292). Results of the calculations made using this method have been shown in Table 6.

Table 6. Emissions of PM, NO_x, SO_2, CO_2 resulting from operating means of road transport in Cracow in 2015

type of vehicle	PM	NO_x	SO_2	CO_2
	[Mg]			
cars	75.50	1,297.64	3.96	488,253.03
GVW <= 3.5 t – "delivery vehicles"	49.01	334.76	0.39	60,867.17
GVW > 3.5 t – „trucks"	10.22	542.13	0.44	69,567.78
buses	10.09	540.89	0.39	975.86
mopeds	1.05	5.19	0.01	2,140.61
motorcycles	0.36	2.76	0.01	1,586.54

Source: author's own research.

5. Comparison of pollution emissions from sources of heat fired with solid fuels, operation of means of road transport and plants of significant nuisance to air quality

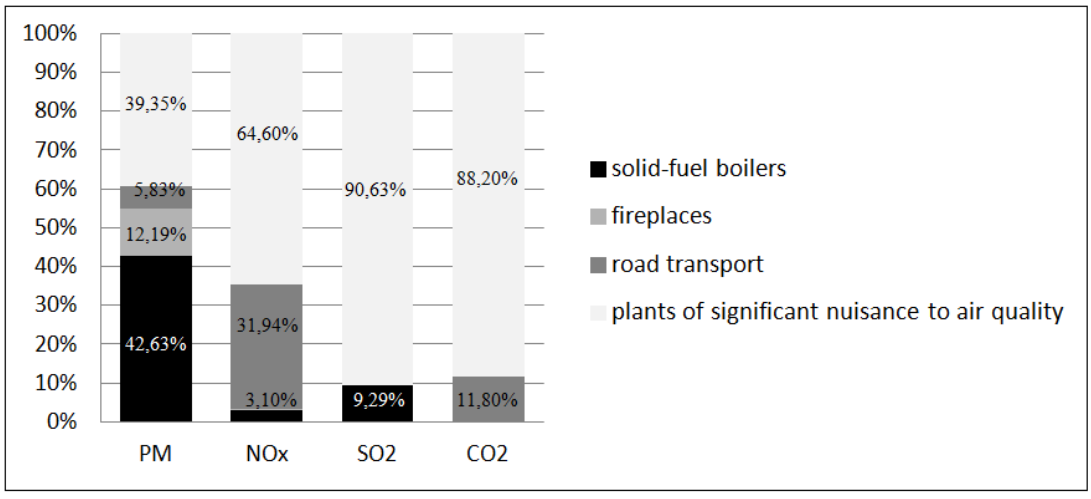
The calculated values of emissions resulting from use of solid fuel boilers and fireplaces as well as the volumes of emissions resulting from operation of means of road transport were compared with statistical data concerning emissions from plants of significant nuisance to air quality (Table 7).

Table 7. Emissions of selected pollutants from solid-fuel boilers, fireplaces, road transport and plants of significant nuisance to air quality in Cracow in 2015

	PM	**NO_x**	**SO_2**	**CO_2**
source of emission	[Mg]			
solid-fuel boilers	**1067**	**264**	**961**	**219**
fireplaces	**305**	**31**	**4**	**34**
road transport	**146**	**2723**	**5**	**623391**
plants of significant nuisance to air quality	**985**	**5508**	**9378**	**4660156**

Source: author's own elaboration based on local data bank (http://www.stat.gov.pl).

Graph 2. Shares of pollution emissions from the particular sources in the total emissions from solid-fuel heating sources, road transport and plants of significant nuisance to air quality in Cracow in 2015



Source: author's own research.

It is worth noting the fact that emissions from road transport in the case of PM is considerably lower than from each of the other sources that were analysed – it accounts for less than 6% of the aggregate calculated emissions, which is depicted in Graph 2. Emissions of SO_2 in the case of fireplaces and road transport is on a virtually negligible level with a share below 0.05%. In the case of fireplaces, emissions of both NO_x and CO_2 have insignificant shares in the aggregate calculated emissions. Emissions from plants of significant nuisance to air quality are only for PM slightly lower than the highest calculated value; and in each other case (NO_x, SO_2, CO_2) substantially exceed the aggregate emissions from solid-fuel sources of heat and road transport.

6. Conclusion

The volume of emissions from solid-fuel boilers and fireplaces is not evenly distributed over the whole year, and this is above all due to the autumn and winter season when emissions increase concurrently with the decreasing temperatures. It can be thus assumed that the volumes of emissions from sources of heat fired with solid fuels contribute to a larger extent to the formation of pollution (including smog) in this period than it would follow from the proportion between these values and the values of emissions from road transport and plants of significant nuisance to air quality. This leads to the conclusion that introduction of a prohibition on the use of sources of heat fired with solid fuels in Cracow will lead to significant reduction of pollution emissions in the autumn-winter season, which should be noticeable in a reduction of smog and should improve the condition of the ambient air.

Doubts may arise as to whether this prohibition should also apply to fireplaces, which emit substantially lower volumes of pollution than solid-fuel boilers and some of Cracow's inhabitants only use them for aesthetic purposes.

However, it should be noted that in the case of PM, the share of emissions from fireplaces is currently already as high as 22%. Should a prohibition on the use of solid fuels for heating purposes be introduced, excluding at the same time fireplaces, then there is a high probability that the operation of fireplaces as sources of heat would significantly increase thus nullifying the positive effect brought about by withdrawing solid-fuel boilers from operation. Taking this into account, it appears appropriate that the prohibition should also include fireplaces.

Road transport contributes to polluting ambient air, which includes formation of smog, in a smaller degree, however, than it is suggested by media coverage. PM emissions from road transport account for less than 6% of the aggregate emissions from solid-fuel sources of heat, road transport and plants of significant nuisance to air quality. Emissions of CO_2 in this case reach significant values, which is due to the process of combusting fuels.

The greatest detrimental impact on the condition of ambient air is due to emissions from plants of significant nuisance to air quality, which has been ignored in media coverage in the recent time. Emissions of all of the pollutants from this source that were analysed have a significant share in the aggregate calculated emissions, reaching even up to 90% in the case of SO_2 and CO_2.

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Wpływ wybranych źródeł emisji zanieczyszczeń na stan powietrza atmosferycznego w Krakowie

Streszczenie

Artykuł jest próbą oszacowania emisji zanieczyszczeń takich jak: cząstki stałe (PM), tlenki azotu (NOx), dwutlenek siarki (SO2) i dwutlenek węgla (CO2) w Krakowie w 2015 roku i była związana z wykorzystywaniem kotłów na paliwa stałe i kominków oraz z eksploatacją środków transportu drogowego. Oszacowane wielkości emisji zanieczyszczeń zostały porównane z wielkościami emisji ze szczególnie uciążliwych zakładów w Krakowie. Wyciągnięto wnioski co do kierunków prowadzonej przez władze miasta polityki w zakresie ochrony środowiska.

Słowa kluczowe: emisja zanieczyszczeń, kotły węglowe, transport drogowy, ochrona środowiska

JEL: Q01, Q53