Methods of Estimating Particulates Emission in Agriculture Exemplified by Animal Husbandry

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Abstract. The indicators of emission from fuel combustion processes may be referred to the unit of raw material or energy obtained from combustion. They may concern a particular technology and make it possible to estimate the amount of pollution emitted to air on the basis of raw material balancing. The indicators may concern a particular technology but their basic function is to create tools that make it possible to compare the volume of pollutant emission to air per a unit of product obtained with the use of different production technologies. The article presents an analysis of the volume of pollution with PM2.5 in animal husbandry conducted in the period 2014-2016. Data concerning particular sources of emission come from the information provided by the Central Statistical Office in Warsaw. The estimation of PM2.5 and PM10 emission was conducted on the basis of the structure of sources of emission resulting from agriculture in accordance with the Tier 2 method. The analysis shows that the highest PM2.5 pollution results from pig and poultry farming and its volume accounted for 0.10 Gg in 2016.

Keywords: Particulates, PM2.5 Emission, PM10 Emission, Animal Production, Agriculture, Poland.

1   Introduction

Pollution with particulates is one of the most disadvantageous forms of air pollution. Particulates should be understood as "a group of solid particles that were thrown into the atmosphere and remain in it for a certain period" [11]. At present, there is a classification of particulates based on the size of particles and their impact on human health. The term total suspended particulates (TSP) means the total content of particulates in air. Particulate matter (PM10) means suspended particulates with a diameter below 10 μm. Fine particulate matter PM2.5 means a group of suspended particulates with a colloidal dispersion of particles with a diameter below 2.5 μm [3].

The source of particulates is common and concerns industry as well as agriculture. For the control of the quality of air, the following classification of suspended particulate matter is used: particles with a diameter of 2,5 m (PM 2,5) and 10 m (PM 10) [20]. Fine particles hover in the air. They reach the atmosphere as a result of natural as well as anthropogenic processes [15]. The natural sources of particulates emission include deposition materials, volcano eruptions and forest fires. The artificial sources of air

pollutants include actually all production processes and combustion (especially fossil fuel combustion) [7]. Five main categories of particulates emission sources may be distinguished: power plants, industrial energy generation, industrial technologies, other stationary sources such as boiler-plants and household fireplaces, and mobile sources [11].

In practice, the measurement is made with the use of different specialist devices depending on the size of particles. Systematic measurement of the level of air pollution with particulates in Poland is conducted in accordance with Directive 2008/50/EC and Regulation of the Minister of the Environment [5, 17]. The measurement of the suspended particulate matter (PM10 and PM2.5) is conducted by the Chief Inspectorate of Environmental Protection [8] with the use of the gravimetric method, which is recognised and used as the most precise one, as well as the automatic method [8]).

Particulates practically originate from any activity, including agricultural operations, soil cultivation, mineral fertilisation, hay collection as well as animal husbandry (fodder provision), drying, reloading, blending dry substances, grist milling, grinding, and bedding animal sheds and fodder houses [4]. Pollution with particulates in farm facilities for livestock is presented in Figure 1.
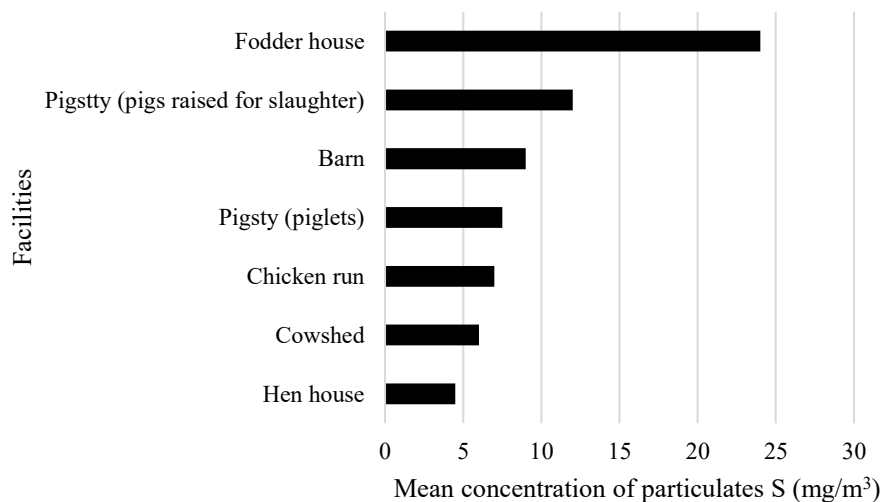

Fig. 1. Pollution with particulates in farm facilities for livestock [12].

Particulates found in agriculture are organic fine particles (of animal, plant and microorganism origin) or non-organic particles (chemicals or minerals) [18]. Agricultural particulates may contain bacteria (e.g. mites), the Acaridae (arachnids), mould, pollen, and particles of hair, feathers, skin or fur [4]. Although the structure of particulates and their fractions has an enormous impact on their movement, the spatial and climate conditions play an important role. Pollution with particulates differs depending on the place. The highest concentration of particulates is recorded in poorly ventilated closed areas (e.g. fodder houses) and places where intensive operations are

performed, e.g. reloading or harvesting (mowing). The main climatic factors affecting the movement of fine particles in air include a strong wind and low humidity.

2 Methodology

The measurement of the intensity of pollution with particulates is conducted based on the factor determining air pollution. The factor of emission (EFpollutant) of PM10 and PM2.5 may be determined in different ways:

- Direct measurement conducted with the use of initial separators. Sampling consists in the division of an air stream from the source of pollution into different components based on aerodynamic features of the particulate matter. The measurement provides immediate results and makes comparison possible.
- Measurement of the share of PM10 and PM2.5 in the total particulates emission.
- Analysis of the calculation of PM10 and PM2.5 fractions in relation to TSP.

The indicators of pollutant emission are calculated in order to determine the size of emission to the atmosphere as a result of technological processes. Pollutant emission indicators are determined for most of the typical production processes in different industries. They specify typical amounts of pollutants with the greatest impact on the environment. They are emitted as a result of a certain process and expressed in units of a given pollutant mass per a unit of time, product or useful effect, and a unit of combusted fuel or energy used [14]. Emission indicators in relation to the unit of product are compared with emission standards: BAT – Best Available Technique [2].

The description of emission indicators can be found in EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016 published by the European Environmental Agency. The Guidebook is aimed at serving the unification of emission inventory systems worldwide. Emission indicators are broadly developed individually for each source of emission subdivided into the following main categories:

- Combustion processes in the production of electricity and heat,
- Combustion processes in industry,
- Fuel combustion processes in heating plants and boiler-houses (other non-stationary combustion sources),
- Industrial processes (industrial technologies), including other processes except fuel combustion,
- Road transport and other transport (mobile sources), including rail transport, inland navigation, agricultural transport as well as air and sea transport,
- Waste management and treatment,
- Agriculture.

The methodology adopted in the Guidebook envisages estimation of emission at three tiers. The first basic one (Tier 1) encourages applying emission factors that represent 'typical' or 'averaged' process conditions, which are technology independent. At the second, intermediate tier (Tier 2), emission factors refer to particular technologies. On

the other hand, the third tier (Tier 3) requires detailed data concerning facilities being the source of emission.

Below, there is a presentation of pollutants in agriculture for which emission factors are determined and the place in the EMEP/EEA Guidebook [16], where the information concerning the value can be found. It was decided to limit the list to presumed factors (Tier 1) because in most cases, the factors refer to the same substances regardless of technology used. The list of emission factors of the EMEP/EEA Guidebook [16] for agriculture is presented in Table 1.

Table 1. List of factors for agriculture [16]

Process	Pollutants for which emission factors are determined	Source of information according to EMEP/EEA
Manure management	NH3, NO, NMLZO, TSP, PM10, PM2.5	Sub-chapter 3.B Tables from 3-1 to 3-4
Crop production	NMLZO, NH3, PM10, PM2.5, NO	Sub-chapter 3.D
Burning of stubble	NOx, CO, NMLZO, NH3, TSP, PM10, PM2.5, soot, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno (1,2,3-cd) pyrene	Sub-chapter 3.F

The latest indicators of the emission of CO_2, SO_2, NO_X, CO and TSP in the course of electricity production were published in February 2017. In the document, there are calculated pollutant factors based on the data provided in the 2015 report by the National Centre for Emissions Management (KOBIZE). In the course of estimating the value of emission factors, fuels (including renewable ones) used in internal combustion facilities within the SNAP-0101 category (power plants and heat generating plants) and SNAP-0301 (energy industry), were taken into account. It was determined that the value of TSP emission indicator for electricity produced in combustion facilities accounts for 0.063 $kg \cdot MWh^{-1}$, and the value for end users of electricity is 0.062 $kg \cdot MWh^{-1}$ [10].

The National Centre for Emissions Management is an institution reporting the level of pollution emitted to the atmosphere. The level of particulate emission is estimated each year and published in the report entitled "Krajowy Bilans Emisji SO_2, NO_x, CO, NH_3, NMLZO, Pyłów, Metali Ciężkich i TZO w układzie klasyfikacji SNAP i NFR". The air pollution level is calculated based on the structure of emission sources laid down in the "EEA/EMEP Emission Inventory Guidebook" [6] in accordance with the SNAP classification. The share of PM2.5 in successive years accounted for 7.25, 6.22, 1.51 and 9.68% respectively. The PM2.5 emission from selected sources in the period 2012-2015 is presented in Table 2.

Table 2. Emission of PM2.5 in the period 2012-2015 [9, 10].

Emission source	PM2.5 emission [Mg]			
	2012	2013	2014	2015
Total	144,771	144,510	125,520	124,562.5
Combustion in electricity and heat production sector	14,901	14,932	13,404	13,411
Non-industrial combustion processes	71,679	73,498	67,102	66,030
Agriculture	512	339	486	549
	0.35%	0.02%	0.39%	0.44%

The level of the PM2.5 emission in the period 2012-2015 from agriculture was presented in the table above. According to the stated hypothesis the calculation of Tier 2 method that uses the factors for particular categories of animals should compare to the National Centre for Emissions Management [10] PM2.5 emission values. The idea of confirming the hypothesis is to compare the obtained results from both sources.

3   Research Findings

The highest PM2.5 emission accounts for 0.129 Gg and originates from burning agricultural residue, including grass burning, and the lowest emission accounts for 0.002 Gg and originates from horse breeding. The level of PM2.5 emission from animal farming in 2014 according to KOBIZE is presented in Table 3.

Table 3. PM2.5 emission to air from agriculture and fuel combustion in agriculture, forestry and fishing in 2014 [13].

Husbandry/farming		PM 2.5	
Industry	Type	Gg	%
Agriculture	Dairy cattle	0.022	0.005
	Non-dairy cattle	0.031	0.006
	Swine	0.074	0.015
	Horses	0.002	0,000
	Laying hens	0.035	0.007
	Broilers	0.073	0.015
	Other poultry	0.094	0.019
	Field burning of agricultural residues (and grass burning)	0.129	0.027
Fuels	Stationary combustion	8.541	1.757
	Vehicles and machinery (off road)	8.283	1.704
	Fishing (off road)	0.408	0.084

In case of animal production, emission of particulates takes place mainly during cleaning and ventilation of farming facilities, and the removal of manure and other post-production residues. The selection of a proper method of estimating the emission of particulates from animal production, like in case of agricultural production and agricultural soil, should be done in accordance with recommendations laid down in the EMEP/EEA Guidebook [6].

In order to determine particulate emission with the use of the Tier 1 method, it is necessary to determine the right category of farm animals, including the category of cattle and swine and select a proper factor of the level of pollution. Emission of pollutants ($E_{pollutant\_animal}$) for the selected category of farm animals takes into account the average annual animal population (AAP_{animal}) and the rightly selected EF factor ($EF_{pollutant\_animal}$). It is calculated following equation (1).

$$E_{pollutant\_animal} = AAP_{animal} \times EF_{pollutant\_animal} \qquad (1)$$

where:

$E_{pollutant\_animal}$ – pollutant emission for the category of farm animals, kg/year,

AAP_{animal} – average annual animal population, head/year,

$EF_{pollutant\_animal}$ – pollutant factor EF.

The presumed values of the EF factor for particular categories of animals (NFR classification) are presented in Table 4.

Table 4. Presumed EF values in animal classification [1, 21].

NFR	Animal classification	EF for TSP (kg AAP^{-1} $year^{-1}$)	EF for PM10 (kg AAP^{-1} $year^{-1}$)	EF for PM2.5 (kg AAP^{-1} $year^{-1}$)
3B1a	Dairy cattle	138	0.63	0.41
3B1 b	Cattle (young cattle, beef cattle, and sucking cows)	0.59	0.27	0.18
3B1 b	Cattle (calves)	0.34	0.16	0.10
3B2	Sheep	0.14	0.06	0.02
3B3	Swine (fattening pigs)	1.05	0.14	0.006
3B3	Swine	0.27	0.05	0.002
3B3	Swine (sows)	0.62	0.17	0.01
3B4a	Buffalo	1.45	0.67	0.44
3B4d	Goats	0.14	0.06	0.02
3B4e	Horses	0.48	0.22	0.14
3B4f	Mules and asses	0.34	0.16	0.10
3B4gi	Laying hens	0.19	0.04	0.003
3B4gii	Broilers	0.04	0.02	0.002
3B4giii	Turkeys	0.11	0.11	0.02
3B4giv	Poultry (ducks)	0.14	0.14	0.02
3B4giv	Poultry (geese)	0.24	0.24	0.03
3B4h	Other animals (fur animals)	0.018	0.008	0.004

The values (AAP$_{animal}$) should be averaged and refer to an annual scale. Livestock can be determined based on the statistical data of the Central Statistical Office in Warsaw. The emission of particulates in horse breeding and cattle farming is presented in Table 5.

Table 5. Measured PM2.5 emission [1].

NFR	Livestock	State of matter	Emission	
			mg	mg/h
3B1a	Cattle	liquid	172.5	28.5
		solid	89.3	28.0
3B1a	Cattle (including young cattle)	liquid	113.0	13.7
	and dairy cattle	solid	85.5	16.0
3B1a	Cattle (calves)	liquid	127.5	19.5
		solid	132.0	27.3
3B4e	Horses	solid	448.5	47.5
		solid ([a])	55.0	-

([a]) Takai et al. 1998, Seedorf and Hartung 2001 [21, 19]

The EF measurement factors in the Tier 2 method used to determine the level of particulates in animal husbandry venues are developed individually in relation to the level of particulate emission in the given area. The research into the level of particulate emission was conducted in the period 2014-2016 and it confirmed the differences in particulate emission depending on the place of measurement. Data taken into account during the analysis are presented in Table 6.

Table 6. Data ta ken into account during the analysis.

NFR	Livestock	Livestock population [mln]			EF PM2.5 kg/year	AAP$_{animal}$, head/year		
		2014	2015	2016		2014	2015	2016
3B1a	Dairy cattle	2,25	2,13	2,13	0.41	2,247,800	2,134,091	2,129,855
3B1b	Calves	2,89	3,15	3,36	0.1	2,894,868	3,148,445	3,355,103
3B2	Sheep	0,02	0,22	0,24	0.02	201,270	221,187	244,171
3B4d	Goats	0,08	0,08	0,04	0.02	81,727	81,727	44,204
3B4e	Horses	0,21	0,21	0,19	0.14	207,065	207,065	185,494
3B3	Swine	11,72	11,64	1110,75	0.002	5,781,699	5,740,274	5,477,671
3B4gi	Hens	41,77	45,63	47,07	0.003	6,866,134	7,500,726	7,737,938
3B4gii	Chickens	88,09	100,49	121,96	0.002	14,480,822	16,519,454	20,048,292
3B4giv	Other poultry	16,91	17,30	18,74	0.02	2,779,666	2,844,292	3,080,841

The results of the analyses of PM 2.5 levels in animal production conducted in the period 2014-2016 in comparison with the available KOBIZE analyses are presented in Table 7.

Table 7. Results of the analyses of PM2.5 levels in animal production conducted in the period 2014-2016.

NFR	Livestock	$E_{polutant\_animal}$, Gg			$E_{polutant\_animal}^{(a)}$, Gg	
		2014	2015	2016	2014	2015
3B1a	Dairy cattle	0.01	0.02	0.02	0.02	0.02
3B1b	Calves	0.01	0.03	0.03	0.03	0.03
3B2	Sheep	0.00	0.00	0.00		
3B4d	Goats	0.00	0.00	0.00		
3B4e	Horses	0.00	0.00	0.00	0.00	0.00
3B3	Swine	0.02	0.10	0.10	0.10	0.10
3B4gi	Hens	0.02	0.03	0.04	0.03	0.04
3B4gii	Chickens	0.04	0.07	0.08	0.07	0.08
3B4giv	Other poultry	0.01	0.09	0.10	0.09	0.10

[a]KOBIZE 2015, KOBIZE 2017 [9, 10]

4 Conclusions

The biggest amounts of particulates reach air from industry: energy sector, chemical industry, mining, metallurgy and construction. Removing particulates from gas is a necessity in many processes in heavy industry (e.g. ferrous and nonferrous metal making, metalworking, woodworking, plastic working), municipalities (fossil fuel combustion, and ventilation and air conditioning systems) [14] and agriculture (e.g. animal production and straw burning).

The main contribution in article is the comparison of own calculated PM2.5 levels that uses the factors for particular categories of animals to National Centre for Emissions Management PM2.5 emission analysis. The results of the analyses of the PM2.5 level in animal production conducted in the period 2014-2016 in comparison with the available analyses of the National Centre for Emissions Management [10] do not show significant differences. This statement fully confirms stated hypothesis about comparison of obtained results from both sources. The results of the analyses of PM2.5 levels in animal production were additionally calculated for the year 2016. According to estimates, the level of PM2.5 pollution in the year 2016 compared to previous years slightly increased. The increase was specially notice for hens, chickens and other poultry, by value 0.1 Gg per year.

It was not possible to compare the level of PM2.5 for sheep and goats during the analyses. The highest pollution level was typical of swine and poultry farming for which the pollution values accounted for 0.10 Gg according to many authors as well as the 2016 KOBIZE data [10].

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