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Review

Odor Emission Factors from Livestock Production

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Abstract

The aim of this study was to review papers about odor emissions from livestock production published between 1997 and 2013. The study concerned three animal species: poultry, swine, and dairy cattle. The results of the research are presented in different units, making it difficult to compare them. For this purpose, the odor emission factors were converted with respect to 1 LU (livestock unit=500 kg). The calculated mean odor emission factor was greatest for poultry, followed by swine and dairy cattle, but the coefficient of variation for all animal species was high. Such a variability could be caused by weather and microclimate conditions, the housing system, and measurement methods. Therefore, it is reasonable to continue the odor emission research in order to precisely determine the values of odor emission factors. It is also necessary to develop the common unified methods for air sample collecting as well as unified unit of odor emission factor to make odor emission factors more comaparable. It may be useful in establishing any legal regulations on this subject.

Keywords: odor, livestock production, livestock building, odor emission factor

Introduction

For many years the odor emissions from human activities have been commonly accepted. But over the past few decades odors have become important elements of air pollution [1, 2].

In the literature there are two terms: odorants and odor, often incorrectly considered synonymous. Odorant is a chemical substance that has a smell or odor. On the other hand, in environmental engineering odorants are defined as air pollution that stimulate the nerve cells of the olfactory epithelium. While odor is a term used in relation to odor nuisance mixtures of substances (odorants), which are an air pollutant, and their amount is determined by total [3, 4]. Odor from livestock facilities is related to the emission of several hundred different substances (odorants) into the air, especially carboxylic acids, phenols, aldehydes, ammonia, and others [1, 5]. The use of odor term results inter alia from the fact that the interaction of odorants can be synergistic, masking or neutralizing fragrance stimuli. In this case, it is not possible to identify substances (odorants) determining the odor [6].

It has been known that odors related to human activities may have a negative impact on people [7]. It depends on the amount and quality of the odor emitted from the source, the distance from the residential area of emission sources, weather conditions, topography and human sensitivity and tolerance [8]. Studies have shown that long-term exposure to odors adversely affects the mood and behavior of people. It was found that they can cause many ailments, such as insomnia, stress, apathy, irritability, depression, headache, cough, runny nose, cramps in the chest, and allergic reactions [9-12].

One of the main odor sources is agriculture, especially livestock production. There are three basic areas of odor emission and their contribution: livestock buildings (30%), manure storage facilities (20%), and applying manure on fields (50%) [13]. Odors are formed in the fermentation process when litter, urine, excrement, and food remains decomposite, and also during respiration, digestion, and evaporation from animal skin [14]. Odor emission depends on many factors, including: animal species, type of produc-

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tion, housing system, type of feed, and feeding system, as well as methods of manure storage and application, and weather conditions [8]. Odor pollution can even affect areas that are far away from the emission sources. This is due to poor odor mixing with the air and distribution in high concentration streams diffused by the wind [15].

Recently, many countries have reported an increase in the number of complaints due to agriculture-related odors [16, 17]. This is caused mainly by the progressive intensification and concentration of livestock production, the increase in residential development near the traditionally agricultural areas, and the increase in sensitivity and demands of the general public for a clean and pleasant environment [18]. About 20% yearly reported complaints in Poland are associated with odor nuisance from rearing and breeding of animals. Approximately 40% of them concerned poultry farms and 35% pig farms [15].

Consequently, the increase of interest in the problems of odor at the international, national, and local levels led to the development of guidelines and regulations regarding the monitoring and mitigation of odor emissions [19, 20].

The aim of our study was to compare and analyze the results presented in the literature concerning odor emissions from animal production. The analysis included three animal species: poultry, swine, and dairy cattle.

Determination of the Odor Emission Factor

Odor nuisance is determined using many methods that can be divided into two groups. The first group is the concentration measurements of select odorants by means of complex physical and chemical analyses, based on the qualitative and quantitative measurement of air samples [21], for example: gas and gas-liquid chromatography, infrared, and mass spectroscopy [22-24]. Another chemical-physical method is measurement with the use of an "electronic nose," an analytical tool that allows quick identification of chemicals through the imitation of the biological mechanism of smell. However, measurement using these devices is not reliable for mixtures of many compounds (odorants) and at very low odor concentrations [6, 25]. The advantages of physico-chemical techniques are the ability to compare occurring odorant concentrations with the standards for air quality and the ability of continuous measurement [23]. However, these methods do not detect interactions between odorants, because in the case of the impact of many substances, there may be a synergistic, masking, or neutralizing fragrance stimuli. Without the participation of human odor perception it is difficult to determine the level of odor nuisance [6]. Important advantages are the small size and weight of the electronic nose, as well as the ability for continuous measurements, which allows its use during *in situ* studies. The results obtained in this way could complement sensorial research [26, 27].

The second group of measurements is sensorial methods, where odor nuisance is determined by human olfactory sensations. The most common is dynamic olfactometry. In general, European Standard EN 13725:2003 (air quality determination of odor concentrations by dynamic olfactometry) is the method used for monitoring odor emissions [4, 28]. Evaluation of odor concentration is carried out in a laboratory by a panel of experts based on samples of air. The study involves making a series (at least three) of measurements, by at least four members of the panel experts at various sample dilutions. This leads to the congregation of at least 12 ZITEs (individual threshold estimates, expressed as a dilution factor), calculated as the geometric mean of the smallest value of the dilution at which the odor was not noticeable, and the largest at which it was already perceptible [6]. The largest advantage of sensorial techniques is direct contact between the air sample and human perception. The disadvantages are the effort it requires and the discrete measurement. Furthermore, the material (Tedlar) of the air sample bags prevents using them at high temperatures [23]. The method of air sampling has not been standardized. The unit used in olfactometry is the European odor unit ($ou_E \cdot m^{-3}$). This is defined as the amount of odorous compounds that, when evaporated into 1 cubic meter of neutral gas at standardized conditions, elicits a response (detection threshold) from a panel equivalent to that elicited by one European Reference Odor Mass (EROM) under the same conditions. The n-butanol is used as a reference substance. One EROM of n-butanol is 123 μg [23, 29].

Momentary air exchange rate can be determined in several ways. In buildings equipped with mechanical ventilation, it shall be determined in accordance with the Polish Standard [30]. On the other hand, in buildings with natural ventilation indirect methods are used, using a tracer gas or carbon dioxide and moisture balance [31].

Odor emission is calculated as a product of the odor concentration and the momentary air exchange rate. The odor emission factor is the quotient of the momentary odor emission and total animal body mass. The odor emission factor is usually expressed in terms of animal, animal body mass, area, or production place [8].

Odor Dispersion

Odor pollution can affect even areas that are far away from the sources of emission and therefore an important issue is to model odor dispersion in the environment. Dispersion models are created based on the odor concentrations and weather conditions. It allows us to simulate the spread of odors and to estimate the value of their concentration at any distance from the source [32, 33]. Today, most of the legislation on odor emissions is created on this basis. However, the specified minimum distances between the source of emissions and residential area cause serious discussions for both the producers and residents. Determination of odor emissions from livestock production is a complex process due to the large number of emission sources and quantitative and qualitative diversity of odorants [34]. For this reason it is necessary to continue work to develop odor dispersion models based on empirical studies [8].

Table 1. Odor emission factors for broilers and laying hens.

Animal group	Odor emission factor			Housing system	Source
	($ou_E \cdot s^{-1} \cdot bird^{-1}$)	($ou_E \cdot s^{-1} \cdot kg^{-1}$)	($ou_E \cdot s^{-1} \cdot m^{-2}$)		
Broilers	-	-	3.16-9.62	no data	[43]
	-	-	0.21-0.43	no data	[44]
	-	-	(0.45)	litter-straw	[8]
	(0.49)	-	-	no data	[45]
	0.32-0.56 (0.44)	-	-	no data	[46]
	0.05-1.22 (0.46)	0.18-0.73 (0.57)	-	litter-wood shavings	[47]
	-	0.27-0.83 (0.59)	-	litter-straw	[48]
	0.11-0.41* (0.24) *	-	-	litter-straw	[29]
Laying hens	-	-	1-3	battery cages deep liquid manure pit	[8]
	-	(0.69)	-	battery cages deep liquid manure pit	[49]
	-	(0.05)	-	battery cages manure belt **	[50]
	-	0.33-0.79 (0.56)	-	no data	[46]
	0.04-0.32 (0.18)	-	0.6-2.5	litter-straw floor	[51]
	0.26-0.62 (0.47)	0.13-0.45 (0.26)	-	battery cages manure belt	[47]
	1.06-1.47 (1.35)	0.53-0.74 (0.67)		litter-slatted floor	[47]
	-	0.12-0.46 (0.23)	-	litter-slatted floor	[48]
	-	0.01-0.08 (0.04)	-	battery cages manure belt	[48]
	-	0.04-0.89 (0.24)	-	litter-straw floor	[48]
	-	0.20-0.40 (0.28)	-	battery cages deep liquid manure pit	[52]
	-	0.09-0.24 (0.16)	-	battery cages manure belt	[52]
	-	0.10-0.25 (0.18)	-	battery cages manure belt*	[52]
	0.10-0.37*	-	-	enriched cages	[29]
	0.14-0.61*	-	-	non-cage systems	[29]

() – mean value, * – per animal place, ** – forced air drying

Guidance and Legal Regulations

The odor emission problem and the associated odor nuisance to humans are a complex issue, dependent on many different factors. Therefore, it is necessary to develop legal regulations concerning the limitation and the possibility of objective determination of odor emissions. For this purpose it is necessary to make a unified method for determination of odor nuisance.

So far, the European Union has no legal regulations regarding air quality standards in respect to the odor. There are guides, guidelines, and draft bills in some countries. Spain and the Netherlands use the parameter $C_{98.1\ hour}$ to determine the odor air quality in residential areas. It means that for 98% of the hours in a year, the maximum concentration of odor at ground level, expressed as an hourly average, may not exceed a specified value. In the first version of the Spanish draft bill value was 5 ou_E/m^3 [35]. In the Netherlands, according to the Regulation of Annoyance from Odours and Livestock, the odor from livestock production amounts to 8 ou_E/m^3 [36]. England and Germany have not specified maximum odor concentrations. Only the minimum distance of residential areas from odor emission sources is specified, taking into account the animal species, the maintenance system, and feeding system [37-40]. However, Japan, South Korea,

Table 2. Odor emission factors for pigs (dry sows, gestating and farrowing sows, weaners, and finishers).

Animal group	Odor emission factor			Housing system	Source
	($ou_E \cdot s^{-1} \cdot pig^{-1}$)	($ou_E \cdot s^{-1} \cdot kg^{-1}$)	($ou_E \cdot s^{-1} \cdot m^{-2}$)		
Dry sows	9.79-12.18*	-	-	no data	[53]
	-	-	(12.6)	partially slatted floor	[8]
	-19	-	-	partially slatted floor	[37]
	-19	-	-	partially slatted floor	[49]
	(44.6)	-	-	partially slatted floor	[54]
	10.9-24.1	-	-	partially slatted floor	[55]
Gestating and farrowing sows	31.44-39.56*	-	-	no data	[53]
	-	-	3.2-7.9	no data	[44]
	-	-	(4.8)	partially slatted floor	[8]
	-18	-	-	partially slatted floor	[37]
	(17.8)	-	-	partially slatted floor	[49]
	(17.2)	-	-	partially slatted floor	[54]
	-	-	10.2-57.6 (24.6)	fully slatted floor	[56]
	33.2-66.4	-	-	partially slatted floor	[55]
	6.3*	-	-	fully slatted floor with vacuum system	[57]
	18.7*	-	-	fully slatted floor	[29]
Weaners	3.18-7.70*	-	-	no data	[53]
	-	-	(8.66)	partially slatted floor	[8]
	-6	-	-	fully slatted floor	[37]
	5-16.3	-	-	fully slatted floor	[49]
	(3.3)	-	-	fully slatted floor	[54]
	-	-	7.7-93.2 (31.8)	fully slatted floor	[56]
	3.7-10.5	-	-	fully slatted floor	[55]
	-	0.01-0.02	-	fully slatted floor	[58]
	1.4-5.8*	-	-	fully slatted floor with vacuum system	[57]
Finishers	18.7-36.1	-	-	fully slatted floor	[59]
	5.5-18.57*	-	-	no data	[53]
	-	-	3.4-14.9	no data	[44]
	(5)	-	-	fully slatted floor	[60]
	-	-	(6.86)	fully slatted floor	[8]
	(22.5)	-	-	fully slatted floor	[37]
	(22.4)	-	-	fully slatted floor	[49]
	(25.4)	-	-	fully slatted floor	[54]
	-	-	26.3-120.5 (51.7)	fully slatted floor	[56]
	10.7-28.2	-	-	fully slatted floor	[55]
	-	0.15-0.19 (0.17)	-	partially slatted floor	[61]
	-	0.29-0.32 (0.31)	-	deep litter	[62]
	-	0.41-0.45	-	fully slatted floor	[62]

Table 2. Continued.

Animal group	Odor emission factor			Housing system	Source
	($ou_E \cdot s^{-1} \cdot pig^{-1}$)	($ou_E \cdot s^{-1} \cdot kg^{-1}$)	($ou_E \cdot s^{-1} \cdot m^{-2}$)		
Finishers	-	0.04-0.16	-	fully slatted floor	[63]
	-	0.09-0.19	-	fully slatted floor	[64]
	5.8-10.6*	-	-	fully slatted floor	[57]
	13.1*	-	-	fully slatted floor with vacuum system	[57]
	3.8-7*	-	-	fully slatted floor	[29]
	5.9-17.9*	-	-	partially slatted floor	[29]
	3.9-6.9*	-	-	solid floor with litter	[29]

() – mean value, * – per animal place

Australia and New Zealand have all passed legislation to reduce odor emissions [41].

There is no legislation on the limitation of odors in Poland, even though the authorities have been working on odor law since 2006. However, it has aroused controversy. The National Council of Agricultural Chambers has expressed disapproval of its assumptions, and the Polish Fur Breeder's and Producer's Association has explained protests as misunderstanding of the fact that "the smell of the countryside is completely different than that of the city." The Ministry of the Environment decided to stop work on the odor law because anti-odor rules are already present in other regulations. "Faster and better effects could bring conducting activities that make the already existing rules properly interpreted, respected, and enforced" – explains the ministry [42].

Discussion

There are many papers published in the last decades concerning odor emissions from livestock production. Most of the research was carried out in Europe and North America and involved three main animal species: poultry, swine, and dairy cattle. In Europe, the odor emission factors are expressed per 1 kg of animal body mass, less per 1 animal and occasionally per 1 production place. In the United States the odor emission factors are given per 1 m^2. The odor emission factors provided by the literature were systematized, taking into the account animal species, technology, and housing system. Their values are shown in Tables 1-3.

The mean values of odor emission factors for broilers related to 1 bird presented in papers are similar. Also, the factors expressed in $ou_E \cdot s^{-1} \cdot kg^{-1}$ have comparable values. In both cases, they are variable, as evidenced by the wide range of individual measurement results. Comparing the results of research carried out by Jiang and Sands [43], Zhu et al. [44], and Jacobson et al. [8] found more than 10 times difference in the values of the odor emission factors. This may result from different weather and microclimate conditions.

There are many studies on the topic of odors emitted from poultry houses for laying hens. Most of the presented results are expressed per 1 kg of animal body mass, which makes them easy to compare. Values of odor emission factors ranged from 0.01 to 0.89 $ou_E \cdot s^{-1} \cdot kg^{-1}$. The mean value is 0.28 $ou_E \cdot s^{-1} \cdot kg^{-1}$ and is highly variable (coefficient of variation 66%). The poultry houses were divided into two groups according to manure removal system and storage facilities. The first group is poultry houses equipped with a manure belt removal system and manure storage outside the building. The second group is the poultry houses where the manure was stored inside the building (deep liquid manure pit, litter-slatted, and litter-straw floor). Mean values of odor emission factor in the second group were higher than in the first and were equal to 0.42 and to 0.14 $ou_E \cdot s^{-1} \cdot kg^{-1}$, respectively. In accordance with the conclusions of Hayes et al. [47] and Navaratnasamy and Feddes [46], this is due to the increased air humidity inside the poultry houses and anaerobic digestion of manure. Analyzing the values of the odor emission factors per 1 m^2 demonstrated that they are similar and ranged from 0.6 to 3 $ou_E \cdot s^{-1} \cdot m^{-2}$.

There are many papers related to odor emissions from swine, first of all finishers. Research was carried out taking into account the production groups: dry sows, gestating and farrowing sows, weaners, and finishers (Table 2), mainly in partly or fully slatted floor buildings.

Most of the results for dry and farrowing sows are presented per 1 pig. Mean odor emission factors for these groups were comparable, and had values of 25 $ou_E \cdot s^{-1} \cdot pig^{-1}$ (from 10.9 to 44.6 $ou_E \cdot s^{-1} \cdot pig^{-1}$) and of 25.7 $ou_E \cdot s^{-1} \cdot pig^{-1}$ (from 17.2 to 66.4 $ou_E \cdot s^{-1} \cdot pig^{-1}$), respectively.

In the literature, odor emission factors for weaners are expressed primarily per 1 animal (pig). Their values ranged from 3.7 to 16.3 $ou_E \cdot s^{-1} \cdot pig^{-1}$, mean value 6.76 $ou_E \cdot s^{-1} \cdot pig^{-1}$. A wider range of odor emission factors were found for the results per 1 m^2, from 7.7 to 93.2 $ou_E \cdot s^{-1} \cdot m^{-2}$.

The odor emission factors for finishers are related to 1 pig and in later papers to 1 kg of animal body mass. The calculated mean factor value is 20.36 $ou_E \cdot s^{-1} \cdot pig^{-1}$ and the results of individual measurements ranged from 10.7 to 36.1

Table 3. Odor emission factors for dairy cattle.

Odor emission factor			Housing system	Source
($ou_E{\cdot}s^{-1}{\cdot}cow^{-1}$)	($ou_E{\cdot}s^{-1}{\cdot}kg^{-1}$)	($ou_E{\cdot}s^{-1}{\cdot}m^{-2}$)		
-	-	0.3-1.8	no data	[44]
-	-	0.7-4.0	cubicles partially slatted	[8]
-	-	1.3-3.0	no data	[65]
49.5-168.4	-	-	deep litter	[66]
(35.6)	-	-	no data	[36]
-	0.02-0.06	-	cubicles partially slatted	[67]
22.6-387.1	0.04-0.61	3.1-35.8	cubicles	[68]
28.9-396.6	0.05-0.62	1.9-25.8	deep litter	
6.8-97.7	0.01-0.15	1-14.5	shallow litter	

() – mean value

Table 4. Odor emission factors converted to 1 LU.

Animal species	Animal group	Odor emission factor range ($ou_E{\cdot}s^{-1}{\cdot}LU^{-1}$)	Mean value ($ou_E{\cdot}s^{-1}{\cdot}LU^{-1}$)	Coefficient of variation (%)
Poultry	Broilers	46-417	178	72
	Laying hens	3-445	141	83
Swine	Dry sows	36-147	83	53
	Gestating and farrowing sows	34-133	51	63
	Weaners	5-54	20	14
	Finishers	17-225	89	60
Cattle	Dairy cattle	5-310	89	74

$ou_E{\cdot}s^{-1}{\cdot}pig^{-1}$. For odor emission factors per 1 kg of animal body mass the mean value was equal to 0.14 $ou_E{\cdot}s^{-1}{\cdot}kg^{-1}$ (from 0.04 to 0.45 $ou_E{\cdot}s^{-1}{\cdot}kg^{-1}$). Comparison of the odor emission factor values for weaners and finishers proved that regardless of the unit of factors, they are higher for finishers than for weaners, and only Jacobson et al. [8] obtained different results.

There are only a few papers about odor emissions from dairy cattle. There is little interest in the issue of odor emission from dairy cattle barns. This may be caused by construction of semi-open modern barns that provide a large air exchange and reduce the odor concentration in air removed from them. The range of published odor emission factors is very wide: 6.8-396.6 $ou_E{\cdot}s^{-1}{\cdot}cow^{-1}$, 0.01-0.62 $ou_E{\cdot}s^{-1}{\cdot}kg^{-1}$, and 0.3-35.8 $ou_E{\cdot}s^{-1}{\cdot}m^{-2}$.

Expression of odor emission factors in different units makes them difficult for honest comparison. In this study odor emission factors expressed in $ou_E{\cdot}s^{-1}{\cdot}animal^{-1}$ and in $ou_E{\cdot}s^{-1}{\cdot}kg^{-1}$ for each species were converted into 1 LU (livestock unit=500 kg). Converted odor emission factors were done on the base of animal body mass from analyzed papers conversion to 500 kg. The specific coefficients from Eurostat used in the case lack information about animal body mass [69]. It allowed for a comparison of odor emissions factors between animal species and animal groups. Converted values of factors are presented in Table 4.

The values of the odor emission factors fall within a wide range. They were highly variable for almost all animal groups. The coefficient of variation ranged from 53 to 83%, except weaners (coefficient of variation 14%). This may be caused by different research conditions: climate, weather conditions, housing system, odor sampling time, etc. Most research was conducted seasonally (less than a year). In addition, due to the specificity of measurements, the odor concentration should be tested by the same panelists. It reduces the number of measurements to 8 per day. Therefore, odor measurements represent only part of a day. So the calculated odor emission factors do not completely reflect diurnal fluctuations and seasonal variations, which affect the odor emission. The factors of air pollutant emissions and odor are typically used to assess the environmental impact of livestock production and should reflect a year-long average values of air pollutants emissions.

The highest mean values of odor emission factors were for poultry. The ranges and coefficient of variations were nearly the same. The difference was in mean value. The odor emission factor for broilers was 178 $ou_E \cdot s^{-1} \cdot LU^{-1}$ and for laying hens 141 $ou_E \cdot s^{-1} \cdot LU^{-1}$. However, in fact the mean odor emission factors for laying hens should be higher, because in many poultry houses the manure was removed outside the buildings and presented results did not take into account emissions from manure storage facilities. Lower values of odor emission factor were for finishers, dairy cattle, and dry sows, and it was 89 $ou_E \cdot s^{-1} \cdot LU^{-1}$, 89 $ou_E \cdot s^{-1} \cdot LU^{-1}$, and 83 $ou_E \cdot s^{-1} \cdot LU^{-1}$, respectively, but the ranges were different. The widest was from dairy cattle, then for finishers and dry sows. Such a large range for dairy cattle may be a consequence of dairy barn design. A lot of them were naturally ventilated, which makes it difficult to precisely determine ventilation rate. There are only a few methods to estimate this parameter, but they have some sources of inaccuracy, so the uncertainties of calculated odor emission factors are high. Besides, many dairy cattle barns had paddocks for cows, which also complicates determination of odor emissions. The smallest odor emission factors were for gestating and farrowing sows (51 $ou_E \cdot s^{-1} \cdot LU^{-1}$) and weaners (20 $ou_E \cdot s^{-1} \cdot LU^{-1}$).

Conclusions

You can find many publications concerning odor emissions from agriculture. The aim of these studies was to identify the main sources of odors and to determine the odor emission factors. The analysis of odor emission factors was made including three main species of animals: poultry, swine, and dairy cattle.

Published results of the studies were summarized taking into account the production group and housing system. The odor emission factors are expressed per 1 kg of animal body mass, 1 animal, 1 m^2, and 1 of production place. The values varied in a wide range for each animal species and production group. For example, the range for broilers is from 0.05 to 1.22 $ou_E \cdot s^{-1} \cdot bird^{-1}$, for laying hens from 0.01 to 0.89 $ou_E \cdot s^{-1} \cdot kg^{-1}$, for weaners from 7.7 to 93.2 $ou_E \cdot s^{-1} \cdot m^{-2}$, and for dairy cattle from 6.8-396.6 $ou_E \cdot s^{-1} \cdot cow^{-1}$.

Due to the different units of odor emission factors, incomplete data about number and mass of animals in the analyzed studies, values of odor emission factors were converted to 1 LU (livestock unit=500 kg), setting their ranges and mean values. The calculated mean odor emission factors was the largest for poultry, then for swine and dairy cattle, but the coefficient of variation for all animal species was high. Such a variability could be caused by weather and microclimate conditions, housing system, and the measurement methods (season, sampling time, and points etc.). Therefore, it is reasonable to continue research in livestock buildings to determine precisely the values of odor emission factors for all groups of animals. The best simultaneous research for each animal species is to reduce uncertainties related to weather and location. It is necessary to develop the common unified methods for air sample collection as well as unified unit of odor emission factor. Expressing it per 1 kg of animal body mass or 1 LU seems to be the most appropriate and creates the possibility of objective comparison of odor emission factors. This may be useful in development of any legal regulations in this regard.

Additionally, future studies should also focus on the parameters that affected odor emission from livestock production. This will allow for indication of the design and technological solutions that minimize the negative impact of livestock buildings on the environment.

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