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Review

Greenhouse Gases and Ammonia Emission Factors from Livestock Buildings for Pigs and Dairy Cows

Wojciech Rzeźnik*, Paulina Mielcarek

Institute of Technology and Life Sciences
Biskupińska 67, 60-463 Poznań, Poland

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Abstract

The aim of this study was to review research papers with gas emission data from livestock buildings that were published between 1997 and 2015. The review focused on three gases: NH_3, N_2O and CH_4 and two animal species: pigs and dairy cows. The results of the review are presented in different units, which makes it difficult to compare the data. For this purpose, the gas emission factors were converted to 1 LU (livestock unit = 500 kg).

The median of NH_3 emission factors for pigs (45.6 g·day^{-1}·LU^{-1}) was almost twice that of dairy cows (26.7 g·day^{-1}·LU^{-1}). For N_2O the emission factor median for pigs (3.2 g·day^{-}1·LU^{-1}) was more than twice that of dairy cows (1.5 g·day^{-1}·LU^{-1}). Also for CH_4 , the median of emission factors for dairy cows (302.5 g·day^{-1}·LU^{-1}) was more than three times higher than the value for pigs (85 g·day^{-1}·LU^{-1}). The variation in the gas emission factor values for pigs and dairy cows is large. This may be due to the following reasons: geographical location, animal species, feed composition, housing and ventilation system or time of measurements. Therefore, there is a need to continue gas emission monitoring research in order to more precisely determine the values of these gas emission factors for pig and dairy production facilities. Measurement procedures should be standardized including the number of measuring days/months, frequency of sampling, measurement equipment and unit of gas emission factor units. Using common methodology for measuring gas emission will allow better comparisons between emission factors for livestock buildings and housing systems and between countries and animal species.

Keywords: greenhouse gases, ammonia, emission factor, pigs, dairy cow

Introduction

The impact of animal agriculture on the environment – especially on climate and ecosystems – is an important problem in the time of intensification and consolidation of livestock production. This consolidation creates both policy and scientific concerns. Agriculture, especially livestock production, is a significant source of gaseous pollutants. The most important are the two greenhouse gases methane (CH_4) and nitrous oxide (N_2O), plus ammonia (NH_3) [1-4].

*e-mail: w.rzeznik@itp.edu.pl

Methane is produced during anaerobic fermentation of organic compounds contained in feed and manure. It is emitted as a byproduct of enteric fermentation, wherein the carbohydrates are degraded by microorganisms in the digestive tract of animals (mainly ruminants) and during anaerobic decomposition of manure. The emission of nitrous oxide in agriculture is a process still not completely known. This gas is emitted from manure as an intermediate product of nitrification/denitrification in conditions of low oxygen availability [5-8]. Methane and nitrous oxide have high global warming potential, 23 and 296 times greater than carbon dioxide, respectively [9]. Ammonia is produced during decomposition of protein substances. This process occurs under anaerobic conditions and is intensified by high temperatures and humidity [4-5, 10]. NH_3 emission causes many negative environmental effects such as eutrophication and acidification of ecosystems [11-12], and decreases in biodiversity [13].

In "The role of livestock in climate change" the FAO reports that agriculture contributes to 18% of global anthropogenic emissions of greenhouse gases, including 9% of CO_2 emissions, 34% of CH_4 emissions, and 65% of N_2O emissions [14]. However, this calculation also included deforestation of certain areas of the world to provide feed (mainly grazing cattle). Whereas, according to data published by the FAO in "Agri-Environmental Indicators," this sector was responsible for 94.17% of global NH_3 emissions in 2009 [15]. The inventory of gaseous pollutants is carried out based on international methodology of the Intergovernmental Panel on Climate Change (IPCC) and the European Monitoring and Evaluation Programme (EMEP), for which the calculations mainly use standard (theoretical) emission factors of greenhouse gases and ammonia, whose values differ from factors obtained during research [16]. The differences may be due to various factors, including genetics of animals, diet, housing and manure management systems, ventilation system type, weather conditions, and building locations [17-19].

The aim of this study was to summarize and compare existing emission factors of CH_4, N_2O, and NH_3 from animal production facilities. This paper concerns emissions from livestock buildings for two species of animals: pigs and dairy cows. The data presented identifies housing systems, building types, the time (season) of data collection, and the country.

Gas Emission Measurements

Gas emission factors from animal production can be determined using various methods regarding how gases and ventilation rates are measured and where, how frequent, and how long samples are collected. The data found in the literature are typically done under different conditions: laboratory (climatic chamber) [20-22], research farms (experimental room) [23-24], and commercial production (livestock building) [25-27].

Each of the data collected under the different conditions has advantages and disadvantages. Studies at the laboratory scale and at research production sites are more basic, or fundamental research. They enable scientists to do preliminary observations and assessment of the phenomena occurring in livestock buildings. During such data collection, the large number of parameters affecting the experiment are controlled and potential sources of uncertainties are easier to identify. Although the emission factors determined in that way are more precise, they do not completely represent the specifics during actual animal production conditions. The research usually lasts for a single production cycle for pigs [28-29] or for a selected few weeks or months for dairy cows [30-31]. Measurements in commercial production conditions usually increase the number of variables, which are difficult to control and affect the measured values. On the other hand, such experiments provide information about the impact of the season and the time of day on gas emissions, because they are conducted in real time and under real weather conditions. This type of research is generally made within shorter time periods [21, 24], at selected periods of the year [26, 32-33], or sometimes during periods as long as a year [34-37].

Gas emissions from livestock buildings are a product of gas concentration and ventilation rates. In practice, there are two types of emissions: gross (based on the gas concentration inside a livestock building) and net (based on the difference in gas concentrations inside and outside the building), which are calculated from the equations:

$$E_{gross} = c_{in} \cdot V \quad (1)$$

$$E_{net} = (c_{in} - c_{out}) \cdot V \quad (2)$$

…where $E_{gross/net}$ is gross/net gas emission, c_{out} is gas concentration inside the building, c_{in} is gas concentration outside the building, and V is ventilation rate.

Net emissions are most often reported and represent true emissions from livestock production facilities. Gas concentrations are measured using various devices – from inexpensive and not very accurate methods such as detector tubes and infrared and electrochemical devices to expensive and accurate instruments like photo-acoustic spectrometers and chromatographs. In practice, the most popular are photo-acoustic spectrometers because of their mobility and accuracy.

Livestock buildings use two types of ventilation, gravitational (natural) and forced (mechanical), to remove moisture and heat and maintain air quality. The ventilation rate in buildings with mechanical systems can be determined basing on momentary percentage efficiency of the whole system that is provided by most climate controllers. Another way to calculate ventilation rate is based on the current-voltage characteristics of fans or on the curve of the temperature controlled ventilation system and temperature measurements. More complicated is determining the ventilation rates in buildings with gravitational systems. There are several methods described in the literature. One of them is the tracer gas method,

Table 1. Ammonia, nitrous dioxide, and methane emission factors for pigs.

Production group	Housing system	Measuring period; Country	Emission factor				Source
			Unit	NH_3	N_2O	CH_4	
Fatteners	Non- litter	no data; United Kingdom	g·day^{-1}·LU^{-1}		0.40 a) e)	85.0 a) e)	[45]
		no data; Holland	mg·h^{-1}·pig^{-1}			1269 a) e)	[46]
		no data; Germany	g·h^{-1}·LU^{-1}			0.75 a) e)	[47]
		no data; Germany	g·day^{-1}·LU^{-1}			102 a) e)	[48]
		5 week; Denmark	g·day^{-1}·LU^{-1}	20.0 g)		14 g)	[21]
		1 year; Germany	g·day^{-1}·LU^{-1}			46.8 a) e)	[34]
		4 months; Belgium	g·day^{-1}·pig^{-1}	6.2 a) f)	0.54 a) f)	16.3 a) f)	[24]
		V-VI,IX-X; Korea	mg·h^{-1}·pig^{-1}	309.2 a) e)			[49]
		IV-V,IX-XII; Italy	g·day^{-1}·LU^{-1}		3.26 a) e)	189.8 a) e)	[25]
		spring, autumn and summer; Sweden	g·h^{-1}·pig^{-1}	0.2 b) e)		1 b) e)	[26]
		1 year; Poland	kg·yr^{-1}·pig^{-1}	3.0 a) e)			[50]
		1 year; Slovakia	kg·yr^{-1}·pig^{-1}	2.1 a) e)			[36]
		1 year; Belgium	kg·yr^{-1}·pig^{-1}	2.2 a) e)	0.15 a) e)	10.4 a) e)	[51]
		VIII-IX; Denmark	mg·h^{-1}·pig^{-1}	265.6 a) f)			[52]
		VII-IX; Poland	g·day^{-1}·kg b.m.$^{-1}$		0.03 a) e)	0.7 a) e)	[53]
		VIII-XI; Denmark	g·day^{-1}·pig^{-1}	5.1 a) e)		3.0 a) e)	[54]
	Litter	no data; Belgium	g·day^{-1}·pig^{-1}		0.35 d) e)	1.58 d) e)	[55]
		no data; no data	g·day^{-1}·pig^{-1}			2.77 c) f)	[56]
		4 month; Belgium	g·day^{-1}·pig^{-1}	13.6 c) f)	0.03 c) f)	7.39 c) f)	[23]
		4 month; Belgium	g·day^{-1}·pig^{-1}	13.1 d) f)	1.11 d) f)	16.0 d) f)	[24]
		4 months; Belgium	g·day^{-1}·pig^{-1}	12.1 c) f)	1.50 c) f)	16.5 c) f)	[29]
		VII-IX; Poland	g·day^{-1}·kg b.m.$^{-1}$		0.05 c) e)	0.8 c) e)	[53]
		1 year; Poland	g·day^{-1}·LU^{-1}	47.6 c) e)	8.60 c) e)	199,8 c) e)	[57]
		1 year; China	g·day^{-1}·LU^{-1}	39.6 d) e)			[58]
Sows	Non- litter	no data; Holland	mg·h^{-1}·pig^{-1}			2406 b) e)	[46]
		IV-V,IX-XII; Italy	g·day^{-1}·LU^{-1}		1.69 a) e)	68.4 a) e)	[25]
		3 months; Belgium	g·day^{-1}·pig^{-1}	12.8 b) f)	0.47 b) f)	10.1 b) f)	[28]
	Litter	3 months; Belgium	g·day^{-1}·pig^{-1}	9.1 c) f)	2.3 c) f)	9.2 c) f)	[28]

I,II…XII – months of the year

a) fully-slatted floor, b) partly-slatted floor, c) deep litter , d) shallow litter, e) piggery, f) experimental room, g) climate chamber

in which carbon dioxide (CO_2), nitrous oxide (N_2O), or sulfur hexafluoride (SF_6) may be used as a tracer gas [33, 38-39]. In this method it is assumed that air is completely mixed in the space of the building, and theoretically should provide the most accurate results. This is rare in livestock buildings, so it is difficult to achieve uniform distribution of the tracer gas in the building [10]. A condition of precise measurement is accurate positioning of the gas-dosing devices and correct selection of sample points [40-42]. Additionally, this method is time-consuming and expensive.

Other methods are based on the balance of carbon dioxide (CO_2), moisture, or heat. They are simpler and less expensive. In these methods it is assumed that CO_2, moisture and heat are produced only by animals, which may increase the uncertainty of measurement. These methods should not be used in buildings with deep litter systems [41-44]. Determining the ventilation or air exchange rates provides the greatest uncertainly in the gas emission measurements for both mechanical and natural ventilation buildings.

Table 2. Ammonia, nitrous dioxide, and methane emission factors for dairy cows.

Production group	Housing system	Measuring period; Country	Emission factor				Source
			Unit	NH_3	N_2O	CH_4	
Dairy cows	Non-litter	II-V; United Kingdom	g·h^{-1}·LU^{-1}	1.02 [a) d)]			[59]
		I,II,XI,XI; Germany	g·day^{-1}·LU^{-1}		1.6 [a) d)]	232 [a) d)]	[30]
		winter; Germany	g·h^{-1}·LU^{-1}	1.62 [a) d)]		16.2 [a) d)]	[33]
		2 months; Poland	kg·yr^{-1}·cow^{-1}			119.2 [a) e)]	[22]
		I-III, XII; Sweden	g·h^{-1}·LU^{-1}	1 [b) d)]		11.4 [b) d)]	[60]
		1 year; USA	kg·day^{-1}·cow^{-1}	0.13 [b) d)]	0.01 [b) d)]	0.5 [b) d)]	[35]
		summer, winter; Germany	g·h^{-1}·LU^{-1}	7 [b) d)]	2.4 [b) d)]	32.9 [b) d)]	[32]
		II-V; Sweden	g·h^{-1}·LU^{-1}	0.90 [b) d)]		11.1 [b) d)]	[61]
		1 year; China	kg·yr^{-1}·cow^{-1}			132.5 [a) d)]	[62]
		V,VII,XI; Canada	g·h^{-1}·LU^{-1}			18.1 [a) d)]	[63]
		1 year; Switzerland	g·h^{-1}·LU^{-1}	1.6 [b) d)]			[42]
		1 year; Germany	g·day^{-1}·LU^{-1}	34.4 [a) d)]		353.1 [a) d)]	[37]
		no data; Spain	g·h^{-1}·cow^{-1}	0.15 [f)]		19.1 [f)]	[20]
		II-IV,IX-X; Canada	g·h^{-1}·LU^{-1}	0.54 [a) d)]	0.04 [a) d)]	13.1 [a) d)]	[64]
		II,III,VII,VIII; Denmark	g·day^{-1}·LU^{-1}	12.2 [a) d)]		205.7 [a) d)]	[27]
		1 year; Germany	g·h^{-1}·LU^{-1}	1.67 [b) d)]		12.4 [b) d)]	[65]
		V,VII,VIII; Sweden	g·day^{-1}·LU^{-1}		1.4 [c) d)]	160 [c) d)]	[66]
		IX-X; USA	g·day^{-1}·LU^{-1}		0.69 [c) d)]	290 [c) d)]	[67]
	Litter	I,XI; Nederland	g·day^{-1}·cow^{-1}	32 [d)]	1.8 [d)]	800 [d)]	[31]
		2 months; Poland	kg·yr^{-1}·cow^{-1}			123.5 [e)]	[22]
		spring, fall; Canada	g·day^{-1}·LU^{-1}			354 [b) d)]	[68]

I,II…XII – months of the year

[a)] slatted floor with deep pit, [b)] solid floor with scraper, [c)] solid floor with flushing, [d)] barn, [e)] climate chamber

Determining Gas Emission Factors

The results of gas emissions from livestock buildings most often are presented as emission factors. Gas emission is usually expressed per animal (WE_{animal}) or per kg of animal body mass (WE_{1kg}), and rarely per area (m^2) of livestock building (WE_{1m^2}). The gas emission factors are calculated using the following equations:

$$WE_{animal} = \frac{E}{n} \tag{3}$$

$$WE_{1kg} = \frac{E}{n \cdot m} \tag{4}$$

$$WE_{1m^2} = \frac{E}{a} \tag{5}$$

… where E is total gas emission from a livestock building, n is the number of animals, m is animal body mass, and a is livestock building area.

Frequently emissions are expressed per LU (livestock unit = 500 kg) instead of per kg of animal body mass. Presenting results of gas emission measurements from livestock buildings as emission factors enables a comparison of the research results or prediction of emissions from other buildings. Additionally, the conversion of gas emissions on a per kg of animal body mass or per LU and per m^2 basis allows us to compare between different production groups or animal species. Caution is necessary when doing these conversions, making sure that animal body mass and or building area are reported and thus known in the published papers to make valid comparisons.

Determining gas emission factors from livestock buildings requires long-term measurements with high precision and reliable instruments. Emissions should be measured in different seasons to observe their seasonality and diurnal variation. Only measurements carried out continuously for several seasons in different housing systems make it possible to calculate valid emission factors that may be used to estimate emissions from other buildings.

Table 3. Converted gases emission factors.

Production group	Housing system	Converted emission factor ($g \cdot day^{-1} \cdot LU^{-1}$)			Source
		NH_3	N_2O	CH_4	
Fatteners	Non-litter		0.4	85.0	[45]
				217.5	[46]
				18.0	[47]
				102.0	[48]
		20.0		14.0	[21]
				46.8	[34]
		45.8	4.0	120.3	[24]
		49.4			[49]
			3.3	189.8	[25]
		32.6		168.0	[26]
		58.7			[50]
		41.1			[36]
		43.1	3.0	203.5	[51]
		45.0			[52]
			13.5	357.5	[53]
		36.0		21.3	[54]
	Litter		2.5	11.3	[55]
				19.9	[56]
		97.1	0.2	52.8	[23]
		96.7	8.2	118.3	[24]
		89.3	11.1	120.0	[29]
			23.5	404.5	[53]
		47.6	8.6	199.8	[57]
		39.6			[58]
Sows	Non-litter			412.4	[46]
			1.7	68.4	[25]
		63.9	2.4	50.6	[28]
	Litter	45.3	11.4	46.0	[28]
Dairy cows	Non-litter	24.5			[59]
			1.6	232.0	[30]
		38.9		389.5	[33]
				272.0	[22]
		24.3		272.6	[60]
		108.3	8.3	375.0	[35]
		169.0	57.6	789.6	[32]
		21.7		266.4	[61]
				302.5	[62]
				434.4	[63]
		37.2			[42]
		34.4		353.1	[37]
		3.0		382.0	[20]
		12.8	0.9	314.4	[64]
		12.2		205.7	[27]
		40.1		297.6	[65]
			1.4	160.0	[66]
			0.7	290.0	[67]
	Litter	26.7	1.5	666.7	[31]
				282.0	[22]
				354.0	[68]

Emission Factors of NH_3, N_2O, and CH_4

Many papers concerning greenhouse gases and ammonia emissions from livestock production have been published in recent years. Most of the research was done in Europe and concerns mainly pigs and dairy cows. Some of it was done in North America and Asia (mainly in China). The values of gas emission factors for pigs are shown in Table 1, and for dairy cows in Table 2.

Most studies for pigs were conducted in non-litter housing systems (with fully or partly slatted floors) due to the popularity of these housing systems in Western Europe, where the research was mainly conducted. The non-litter housing systems were characterized by lower emissions of greenhouse gases and ammonia, but also lower standards of animal welfare compared with the litter systems. Little research concerned litter housing systems, which are still the most popular in Central and Eastern Europe. In published papers the gas emission factors are predominantly from fattener production and much less for sows.

Taking into account the time of research, only 20-30% of published gas emission factors were calculated based on the measurement results collected during the whole year, with the remainder carried out during a selected season or even a single month.

Also, for dairy cows the studies in non-litter housing systems were dominant, which are considered prospective solutions. Most of the studies were carried out in production conditions during which NH_3 and CH_4 emissions were primarily measured. About 70-80% of the measurements were made in selected periods, and the calculated emission factors do not represent an average value for the whole year.

The emission factors for NH_3, N_2O, and CH_4 presented in Tables 1 and 2 were converted to the same unit ($g \cdot day^{-1} \cdot LU^{-1}$), which allowed showing their variability and comparing them between animal species. The gas emission factors expressed for one animal were converted based on the average animal body mass during the study. When the animal body mass was not given, the conversion was made according to the animal conversion factors from the Polish Council of Ministers' Regulation of 9 November 2010 (1 fattener = 0.14 LU , 1 sow = 0.3 LU, 1 cow = 1 LU) [69]. Although this may introduce errors, it is necessary so that comparisons between studies can be made. The converted emission factors of NH_3, N_2O, and CH_4 are presented in Table 3.

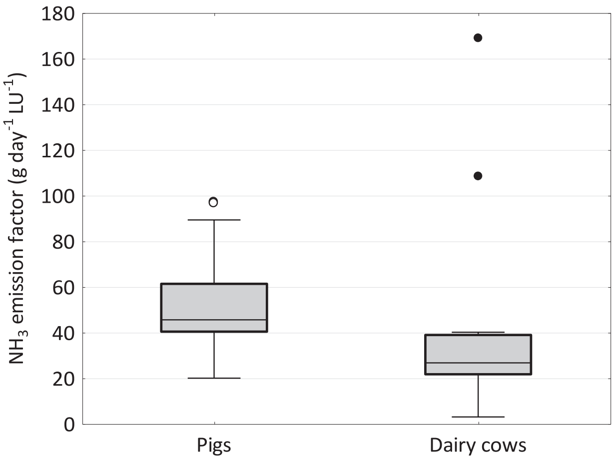

Fig. 1. The distribution of NH_3 emission factors.

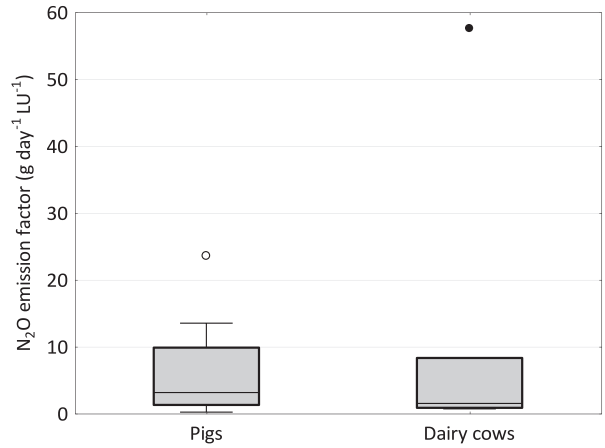

Fig. 2. The distribution of N_2O emission factors.

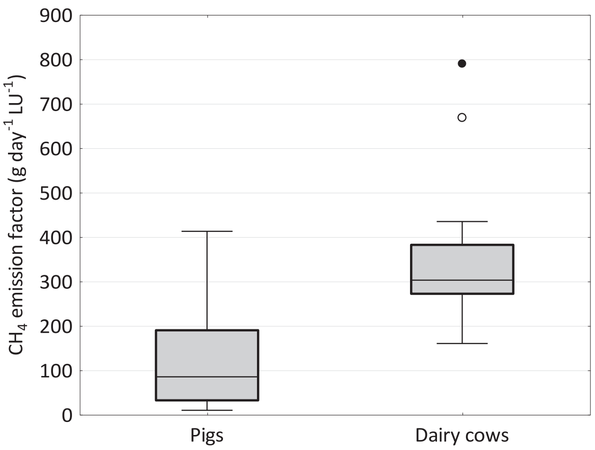

Fig. 3. The distribution of CH_4 emission factors.

The distribution of emission factors is shown in Figs 1-3. The bottom and top of box plots indicate the first quartile (Q1) and third quartile (Q3), respectively. The lines dividing the boxes show the median, and the whiskers indicate the minimum and maximum non-outlier values. The symbol "○" represents outliers and "●" extreme values.

The values of converted emission factors of CH_4 and NH_3 differ depending on the animal species. The median of NH_3 emission factors for pigs (45.6 g·day^{-1}·LU^{-1}) was almost twice that for dairy cows (26.7 g·day^{-1}·LU^{-1}). A similar pattern was observed for N_2O. The emission factor median for pigs (3.2 g·day^{-1}·LU^{-1}) was more than twice that of dairy cows (1.5 g·day^{-1}·LU^{-1}). For CH_4, the median of emission factors for dairy cows (302.5 g·day^{-1}·LU^{-1}) was more than three times greater than for pigs (85.0 g·day^{-1}·LU^{-1}). The differences of the gas emission factor values between the analyzed animal species result from many factors, including specifics of digestive systems, feed composition, building type, manure handling systems, and more.

The ranges of the converted gas emission factors were also different. For pigs it varied from 20.0 to 89.3 g·day^{-1}·LU^{-1}, 0.2 to 13.5 g·day^{-1}·LU^{-1}, and 9.6 to 412.4 g·day^{-1}·LU^{-1} for NH_3, N_2O, and CH_4, respectively. The emission factors for dairy cows ranged from 3.0 to 40.1 g·day^{-1}·LU^{-1}, 0.7 to 8.3 g·day^{-1}·LU^{-1}, and 160.0 to 434.4 g·day^{-1}·LU^{-1} for NH_3, N_2O, and CH_4, respectively.

Despite the use of indirect methods of determining the ventilation rate in dairy barns, which is generally characterized by greater uncertainty, ranges of emission factors of NH_3, N_2O, and CH_4 were less for dairy cattle than pigs. The analysis showed a small number of outliers or extreme results, although the studies were carried out in different locations, housing systems, and duration and time of measurement.

Conclusions

Numerous papers in the literature give emissions of greenhouse gases and ammonia from livestock buildings, but the variations are large. This may be due to many reasons: geographical location, animal species, feed composition, housing and ventilation systems, and duration and time of measurements. Therefore, there is a need for experimental verification of standard emission factors used for national reporting of greenhouse gases and ammonia emissions. However, the research carried out for this purpose should be based on standardized procedures. They should primarily specify the number of measurement days during the year and specific rules for their choice. The criterion of selection of measurements days should not only allow for certain distribution during the year, but also consider weather conditions. Also, location of measurement points of gas concentration inside and outside the livestock building, sampling time and duration, measuring equipment, and method of determining the ventilation rate should be specified.

Moreover, the unit of gas emission factors should be standardized. The most appropriate seems to be a unit related to animal body mass (per kg or LU). An important element of the research is also the choice of livestock buildings, which should represent the most popular housing systems used in the country.

The emission factors will then represent the average annual emission factor more accurately, along with the national structure of livestock housing systems. Using standardized methodology will allow scientists, engineers, and other stakeholders to compare gas emission factors between livestock buildings, housing systems, countries, and animal species. In addition, the method of ventilation rate estimation for gravitationally systems needs to be improved.

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