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Intensive Animal Farming Operations – a Preliminary Analysis of a Number of Farm Animals, Ammonia Emission Values Variability and Methods of Reducing Odor Emissions and Assessing Health Impact Taking into Account Possible Solutions in Poland and Ukraine

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Abstract: The article seeks to review the standards (emission and immission) and legal solutions relating to odour-active compounds, as well asanalyse the variability in the number of farmed animals and the emission of ammonia in Poland and Ukraine. Furthermore, the article characterizesodour emission factors, methods of health risk assessment, ways of limiting emission of odorous compounds from animal farming facilities. The analysis indicated the necessity of applying good practices available in reference documents – including those drawn up by environmental agencies – and scientific works, as such practices may significantly contribute to minimising the impact of animal farming facilities on people and the environment. The introduction of, inter alia, immission standards (reference values) expressed in ou_E/m^3 in the legal regimes of the EU and Ukraine would also render it possible to carry out an assessment of odours treated as a mixture present in ambient air and optimise the assessment of odour nuisance and thus the discomfort directly affecting the well-being and health of inhabitants of areas in the vicinity of farming facilities.

Keywords: animal farming, odour emission sources, health impact assessment, BAT

1. Introduction

Poland ranks sixth among food producers in the European Union (EU) and eighth among its exporters. Approximately 30% of operators involved in food and beverages production are processors of products of animal origin, of which 20% are meat companies and about 4% – dairy companies. The share of the meat industry in the marketed production of the food industry is estimated at about 30% (Institute of Agricultural and Food Economics 2018). In Ukraine, in turn – at the level of 13.1% (State Statistics Service of Ukraine 2016).

The agri-food industry is significantly diversified in terms of odour emissions and impacts on olfactory air quality. In Poland, agriculture accounts for 94% ammonia pollution, thus being the main emitter of this pollutant (Ministry of Climate 2020). Animal manure management (79%) and mineral fertiliser use (21%) are considered to be the dominant sources of ammonia emissions in agriculture. As regards Ukraine, in 2017-2018, the share of agriculture in NH_3 emissions ranged from 66.2% to 73.1% (State Statistics Service of Ukraine 2020), while animal manure management and fertiliser production accounted for, respectively, 61.2% and 38.8% (Pinchuk & Borodai 2019). Ammonia is the main odorant emitted from animal facilities. However, the presence of other odorous compounds with lower concentration, but also lower odour threshold values forces one to study odours as a mixture (Sówka 2011).

Ammonia and odour emissions from livestock buildings are considered to have the highest environmental impact, with odour emissions usually related to odour nuisance effects, while NH_3 emissions are considered to be a pollutant of regional impact. Ammonia plays an important role in the formation of fine particles in the atmosphere. NH_3 emissions lead to nutrient N-enrichments, acidification and euthropication in both terrestial and aquatic ecosystems. In the atmosphere, ammonia reacts with other compounds to form ammonium sulphide and ammonium nitrate aerosols, leading to the formation of $PM_{2.5}$ (Conti 2020, Schauberger et al. 2018). Ammonia emissions have been found to be correlated with climate change, with an increase in global temperature by 5 OC resulting in an increase in global NH_3 emissions by approx. 42% (Sutton et al. 2013, Schauberger et al. 2018), which in the future may result in the necessity to increase the distance of livestock buildings from residential and public buildings (Schauberger et al. 2018). The main sources of odour emissions from animal facilities are litter fermentation and decomposition, as well asthe decomposition of faeces and food residue. Odorous compounds are also generated by respiration, digestion and evaporation from the skin of livestock (Grzelka et al. 2018, Korczyński et al. 2010, Saba et al. 2003). Odorants typically identified in the context of animal husbandry and maintenance are ammonia andhydrogen sulphide – usually present in high concentrations. Other compounds worthy of mention are thiols, sulphides, phenols, ketones, aldehydes, aliphatic acids, esters, amines, heterocyclic compounds containing sulphur and nitrogen or aliphatic alcohols (Tymczyna et al. 2010). The composition of gases generated in animal facilities depends on many factors, mainly on the species and age of livestock (Korczyński et al. 2010). As regards the incidence of odour nuisance from livestock farming facilities, one should mention significant environmental and technical factors such as: temperature in the premises, humidity, speed of air movement, available space, type of flooring, type of litter used (or litter-free systems) and design of ventilation systems, as well as methods of handling the produced manure (Herbut et al. 2010). An equally important factor is the way the animals are fed, which involves a proper balance of forage to reduce the amount of protein in animal faeces and reduce their pH (Jugowar et al. 2010).

As regards Ukraine, cattle, pig and poultry farming are of key importance (Pinchuk & Borodai 2019).

Table 1. Livestock in Poland and Ukraine in 2019

Livestock	Total number, thsd. heads	Total number, thsd. heads
Cattle (of which cows)	6358 (2461)	3092.0
Sheep	273	1204.5
Pigs (of which sows)	10781 (755)	5727.4
Hens (of which laying hens)	178342 (53190)	220485.8
Geese	1061	4015.8
Turkeys	15939	1939
Ducks	5704	11418.3

(Commission Implementing Decision 2017, State Statistics Service of Ukraine 2020)

The so-called large industrial farms, i.e. farms with a capacity of more than 40,000 heads of poultry or 2,000 pigs (fattening pigs >30 kg or 750 sows) are deemed to be the source of the most considerable odour nuisance (Commission Implementing Decision 2017). Farms of this type are characterised by a highly industrialised livestock production profile and have significant environmental impacts, primarily as a result of very large quantities of natural fertilisers produced. Table 2 shows the emission factors of odours and ammonia depending on the type of animals reared, while Table 3 shows the odour threshold values. Table 4, in turn, summarises the example results of odour concentration measurements carried out for various livestock farming facilities.

Table 2. Values of odour and ammonia emission factors for different livestock groups and rearing types

Species	Rearing type	NH_3 emission factor, kg/head/year	Odour emission factor, $ou_E/(s\cdot animal)$	Source
Chicken	Laying hens – cage system	0.01 to 0.15	0.102 to 0.68	(Commission Implementing Decision 2017)
Chicken	Laying hens – cage-free system	0.019 to 0.36	0.102 to 1.5	(CID 2017)
Chicken	Broilers	0.004 to 0.18	0.032 to 0.7	(CID 2017)
Turkey	females	0.045 to 0.387	0.4	(CID 2017)
Turkey	males	0.138 to 0.68	0.71	(CID 2017)
Duck	total	0.05 to 0.29	0.098 to 0.49	(CID 2017)
Pig	Gestating sows – slurry	0.42 to 9.0	5.6 to 100	(CID 2017)
Pig	Weaners – slurry	0.03 to 0.8	1.1 to 12.1	(CID 2017)
Pig	Weaners – manure/combined generation	0.11 to 0.7	2.25 to 3	(CID 2017)
Pig	Fattening pigs – slurry	0.1 to 4.6	1.14 to 29.2	(CID 2017)
Pig	Fattening pigs – manure/combined generation	1.9 to 7.53	4.2 to 7	(CID 2017)

Table 2. cont.

Species	Rearing type	NH_3 emission factor, kg/head/year	Odour emission factor, $ou_E/(s \cdot animal)$	Source
Domestic bovine	Dairy cows – slurry	41.8	–	(European Environment Agency 2019)
Domestic bovine	Dairy cows – manure	26.4	–	(EEA 2019)
Domestic bovine	Other bovine animals – slurry	15	–	(EEA 2019)
Domestic bovine	Other bovine animals – manure	10	–	(EEA 2019)
Domestic sheep	Total – manure	1.4	–	(EEA 2019)
Pig	Fattening pigs – slurry	6.5	–	(EEA 2019)
Pig	Fattening pigs – manure	5.6	–	(EEA 2019)
Pig	Sows – slurry	17.7	–	(EEA 2019)
Pig	Sows – manure	15.1	–	(EEA 2019)
Pig	Sows – outdoor rearing	9.3	–	(EEA 2019)
Chicken	Laying hens – manure	0.31	–	(EEA 2019)
Chicken	Laying hens – slurry	0.48	–	(EEA 2019)
Chicken	Broilers litter	0.17	–	(EEA 2019)
Turkey	litter	0.9	–	(EEA 2019)
Duck	litter	0.65	–	(EEA 2019)
Goose	litter	0.35	–	(EEA 2019)
Donkey	manure	15.8	–	(EEA 2019)
Horse	manure	15.8	–	(EEA 2019)
Goat	manure	1.4	–	(EEA 2019)

Table 3. Odour detection threshold values for substances emitted from livestock farming facilities

Chemical compound	Odour threshold value, (mg/m^3)	Source
Ammonia	0.5	(Czurejno 2005)
Ammonia	0.74	(Talaiekhozani at al. 2016)
Ammonia	1.10	(Nagata 2003)
Ammonia	4.07	(Devos at al. 1990)
Ammonia	0.0266	(Ruth 1986)
Ethylene	20.0	(Czurejno 2005)
Acetone	1.1	(Czurejno 2005)18]
Ethyl mercaptan	0.00004	(Czurejno 2005)8]
Ethyl mercaptan	0.48	(Talaiekhozani at al 2016)
Ethyl mercaptan	0.022	(Nagata 2003)
Ethyl mercaptan	0.00282	(Devos 1990)
Ethyl mercaptan	0.000032	(Ruth 1986)
Methyl mercaptan	0.000002	(Czurejno 2005)
Methyl mercaptan	2.16	(Talaiekhozani at al. 2016)
Methyl mercaptan	0.98	(Glindemann et al. 2006)
Methyl mercaptan	0.14	(Nagata 2003)
Methyl mercaptan	0.00209	(Devos 1990)
Methyl mercaptan	0.00004	(Ruth 1986)
Propyl mercaptan	0.404	(Talaiekhozani at al 2016)
Propyl mercaptan	0.404	(Nagata 2003)
Butyl mercaptan	0.01	(Talaiekhozani at al 2016)
Butyl mercaptan	0.01	(Nagata 2003)
Butyl mercaptan	0.00537	(Devos 1990)
Benzyl mercaptan	0.96	(Talaiekhozani at al 2016)
Benzyl mercaptan	0.96	(Nagata 2003)
Benzyl mercaptan	0.00813	(Devos 1990)
Benzene	1.8	(Czurejno 2005)
Benzene	12.0	(Devos 1990)
Acetaldehyde	0.014	(Czurejno 2005)

Table 3. cont.

Chemical compound	Odour threshold value, (mg/m^3)	Source
Ethyl alcohol	18.81	(Czurejno 2005)
Ethyl alcohol	55.0	(Devos 1990)
Ethyl alcohol	0.342	(Ruth 1986)
Butyl alcohol	1.2	(Czurejno 2005)
Butyl alcohol	2.57	(Devos 1990)
Isoamyl alcohol	0.1	Czurejno 2005)
Isoamyl alcohol	0.162	(Devos 1990)
Hydrogen sulphide	0.014	(Czurejno 2005)
Hydrogen sulphide	0.65	(Talaiekhozani at al 2016)
Hydrogen sulphide	0.97	(Glindemann et al. 2006)
Hydrogen sulphide	0.57 to 1.42.	(McGinley & McGinley 2004)
Hydrogen sulphide	0.57	(Nagata 2003)
Hydrogen sulphide	0.491-0.964.	(Mannebeck & Mannebeck 2002)
Hydrogen sulphide	0.0257	(Devos 1990)
Hydrogen sulphide	0.0007	(Ruth 1986)

Table 4. Odour concentration at various livestock farming facilities

Type of facilities		Odour concentration, ou_E/m^3
Pigsty	Weaned piglets	3473
	Fattening pigs	1019
	Sows	619
Poultry farm	Broilers	815

(Grzelka et al. 2018)

2. Characteristics of legal provisions on odorous compounds taking into account livestock farming

In Poland, legal provisions governing the issue of limiting human exposure to odours are laid down in several legal acts of the regulation rank. The Regulation of the Minister of Infrastructure of 12 April 2002 on technical conditions to be met by buildings and their location states that livestock buildings should be located at a distance of at least 8 metres from residential ones (Regulation of the Minister of Infrastructure 2015). The issue of location of livestock buildings is also addressed in the Regulation of the Minister of Agriculture and Food Economy of 7 October 1997 on technical conditions to be met by agricultural structures and their localization (Regulation of the Minister of Agriculture and Food Economy 2014). Said regulation establishes the obligation to include a row of medium- and high-growing vegetation between residential and livestock buildings in order to, *inter alia*, reduce odour nuisance. In addition, the mentioned Regulation also contains provisions stating that it is to store liquid animal faeces in sealed, closed containers in order to reduce ammonia and odour emissions.

In 2019, the draft of the first billrelating to the issue of odour nuisance, was published (Draft act on the minimum distance 2019). The draft act on the minimum distance for planned projects of the agricultural sector, the functioning of which may be associated with the risk of odour nuisance specifies that unless the investor obtains the prior consent of residents, newly-created projects related to livestock farming should be located at established minimum distances from residential buildings depending on the size of the stocking density of such a project:

– for animal production facilities with a stocking density of 210 livestock units (LU) to 500 livestock units (LU), the minimum distance shall be equal to the value of the LU;
– for facilities exceeding 500 LU, the minimum distance is 500 m.

These provisions were not intended to apply to existing livestock farming facilities. So far, the draft act has not been implemented.

In Poland, there are no legal provisions in the context of agriculture that would set i.e. limit values of odour emissions as a mixture. However, entrepreneurs pursuing agricultural activity in Poland – an EU Member State – should follow the recommendations provided in the Best Available Techniques (BAT) Conclusions for Intensive Rearing of Poultry or Pigs (Commission Implementing Decision 2017). The document sets forth principles for intensive pig and poultry farming in terms of, among others, farm management, animal feeding, manure collection and storage, and limit levels of emissions to air, including ammonia emissions. The BAT conclusions concern activities involving more than 40,000 places for poultry, more than 2,000 places for fattening pigs (over 30 kg) or more than 750 places for sows. The document emphasizes the obligation to periodically monitor odour emissions, *inter alia*, by using dynamic olfactometry in accordance with the PN-EN 13725 norm (PN-EN 13725). In addition, the installation owner is to set up, implement and regularly review an odour management plan. In order to prevent odour emissions and their impacts, BAT recommends for newly-built facilities to ensure adequate distances from sensitive receptors requiring protection or to apply one or a combination of other remedies, including the use of air cleaning systems or special recommendations for animal housing and floors.

Most European countries, including Poland and Ukraine, have not yet developed national odor emission standards for livestock farming. However, gas emission rates can be rigorously compared to legal regulations regarding air quality guidelines. The concentration of some specific and most common odor substances, such as hydrogen sulfide or ammonia can be compared with individual gas levels of airborne emission regulations. Ammonia and hydrogen sulfide are often more thoroughly investigated in previous studies as they can cause serious adverse health and environmental-related damage (Ruth 1986, Chen et al. 2021).

In Poland, limit values for odorants – ammonia and hydrogen sulphide – are established in the Regulation of the Minister of the Environment of 26 January 2010 on reference values for certain substances in the air (Regulation of the Minister of the Environment 2010). They are juxtaposed in Table 5. Limit concentration values for ammonia and hydrogen sulphide set forth in the State sanitary rules for ambient air protection in residential areas are presented in Table 6 (Legislation of Ukraine 1997). Poland and Ukraine lack set standards for livestock farming regarding odour concentration values expressed in units: ou_E/m^3.

Table 5. Reference values for ammonia and hydrogen sulphide set forth in the Regulation of the Minister of Environment of 26 January 2010 on reference values for certain substances in the air

Substance	Average concentration for a period of	
	one hour, μg/m^3	one year, μg/m^3
Ammonia	400	50
Hydrogen sulphide	20	5

(Regulation of the Minister of the Environment 2010)

Table 6. Reference values for ammonia and hydrogen sulphide set forth in the State sanitary rules for ambient air protection in residential areas (from pollution by chemical and biological substances) (Legislation of Ukraine 1997).

Substance	Maximum concentration limit [μg/m^3]		
	Maximum concentrations average for the period of 20-30 minutes	Average concentration for a period of 24 hours	Class of risk
Ammonia	200	40	4
Hydrogen sulphide	8	–	2

(Legislation of Ukraine 1997)

3. Analysis of the variability in the number of farmed animals and the emission of ammonia in Poland and Ukraine in 2000-2019

Data related to the number of farmed animals and emission values has been analysed on the basis of the information available in statistical yearbooks (GUS 2004-2020). The analysis of the data shows that the number of farmed animals in the years 2000-2019 in Poland and Ukraine differs depending on their type. In the case of poultry farming, an upward trend is noticeable in both Poland and Ukraine, from 50 to 180 million heads and from 120 to 220 million heads, respectively, with clear peaks in 2002 in Poland (as many as 220 million heads), and in 2013 in Ukraine (over 230 million heads) (Fig. 1a).

In the case of sheep farming, no significant changes in the number of animals were observed in Poland between 2000 and 2019: on average there were about 0.300 million heads. In Ukraine, in turn, a systematic decrease in the number of sheep reared may be observed, from about 2 to 1.3 million head (Fig. 1b).

A downward trend is also clearly visible in pig farming. Both in Poland and Ukraine, the number of animals reared decreased from 8 to 6 million and 17 to 11 million heads, respectively (Fig. 1c).

In the farming of cattle, including cows, a decrease in the number of animals was observed. However, in this case the changes were not so explicit. In Poland, between 2000 and 2004, the number of cattle decreased from 6 to 5 million, nd later increased gradually to about 6.5 million heads. In contrast, over these 20 years only a marginal decrease was recorded (from 3 to 2.5 million heads). In Ukraine, the decline was far more significant, from about 9.5 to 3 million heads. The number of cows reared there also systematically decreased (from 5 to less than 2 million heads) (Fig. 2).

Ammonia emissions from agriculture 2008 and 2016, including animal husbandry, both in Poland and Ukraine showed little change and remained at the level of 13-15 million tons of ammonia, with an observed temporary pick-up in Ukraine in 2010-2013 (to just below 20 million tons of NH_3), which may have been partly due to an increase in the number of poultry reared in those years (Fig. 3).

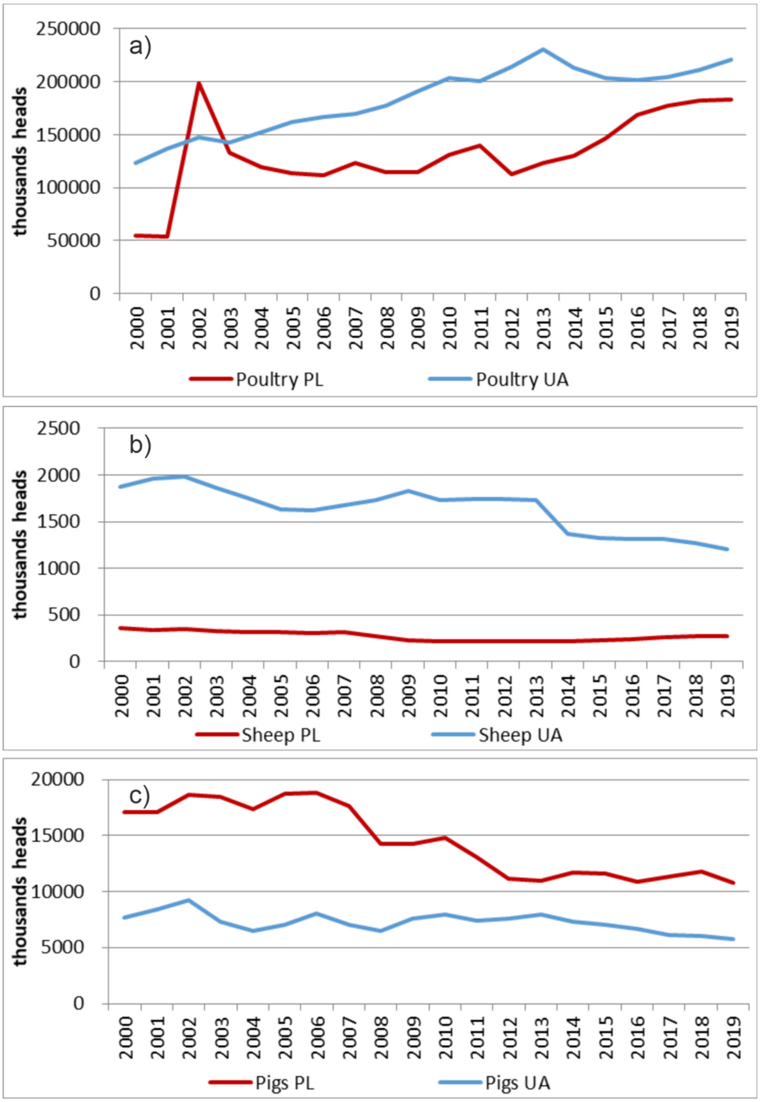

Fig. 1. Number of farmed animals (poultry- a), sheep -b, pigs -c) in 2000-2019 in Poland and Ukraine (source: authors' study based on (GUS 2004-2020))

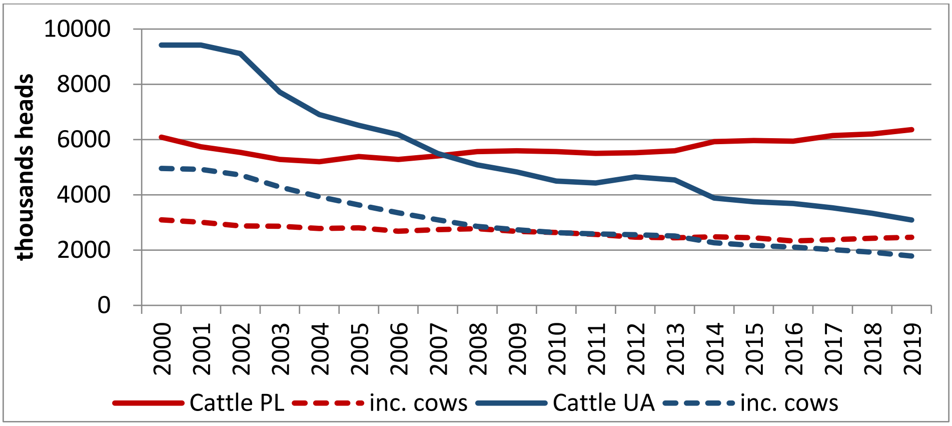

Fig. 2. Number of farmed animals in 2000-2019 in Poland and Ukraine
(source: authors' study based on (GUS 2004 -2020))

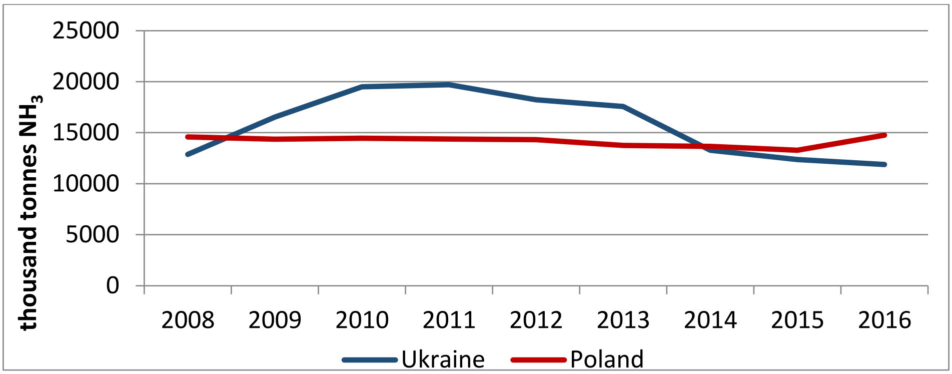

Fig. 3. Ammonia emissions from agriculture in 2008-2016 in Poland and Ukraine
(source: authors' study based on (GUS 2004 -2020)

An analysis of the most current data on the number of animals reared in each voivodeship and oblast in 2019 makes it possible to distinguish several areas characterized by more intensive animal farming, regardless what animal is considered. In Poland, these are the following voivodeships: Mazowieckie, Podlaskie, Wielkopolskie, and Lubuskie, while in Ukraine, the Vinnytsia, Kyiv, Cherkasy, Dnipropetrovsk, Lviv, Khmelnytskyi, and Kharkiv oblasts. (Fig. 4-5).

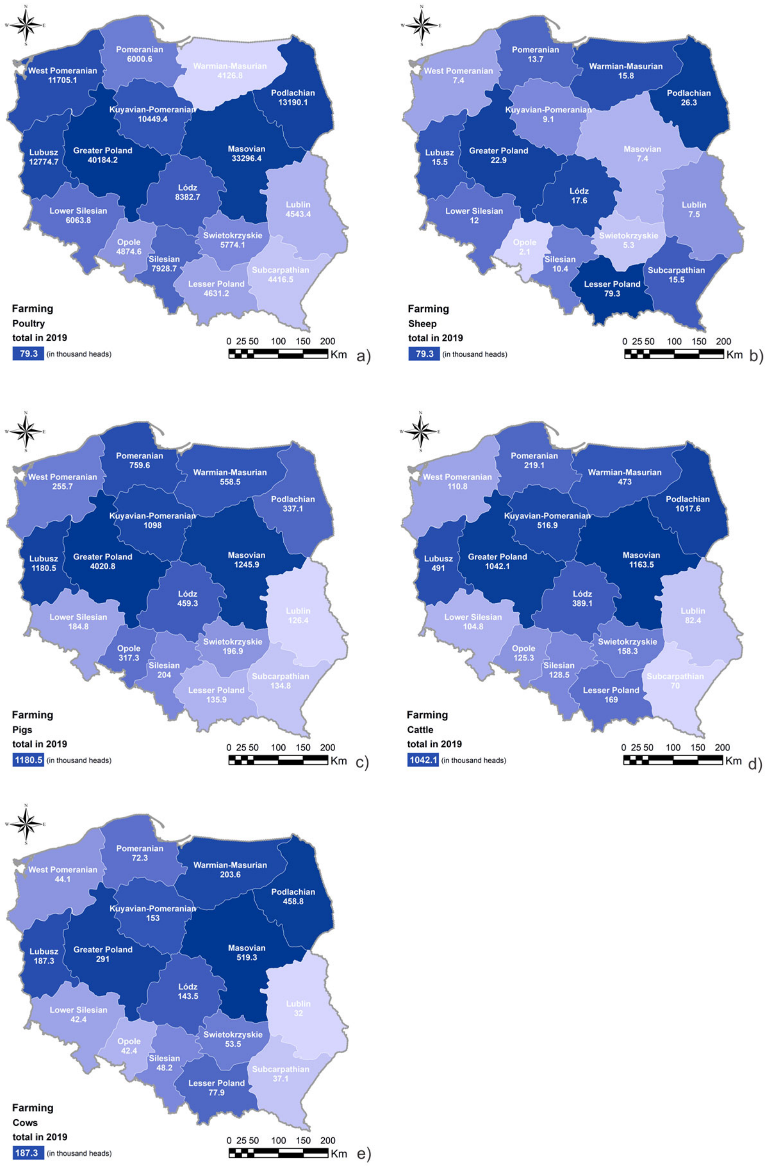

Fig. 4. Spatial distribution of the number of poultry (a), sheep (b), pigs (c), cattle (d) and cows (e) reared in 2019 in Poland (source: authors' study based on (GUS 2020))

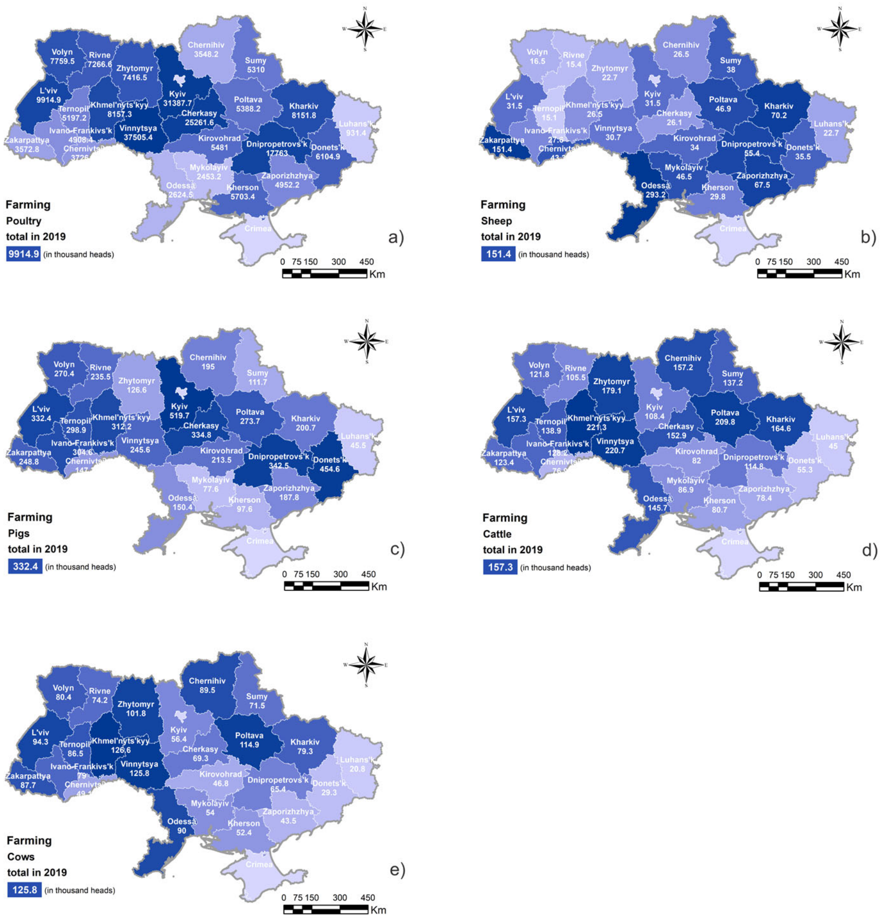

Fig. 5. Spatial distribution of the number of, poultry (a), sheep (b), pigs (c), cattle (d) and cows (e) reared in 2019 in Ukraine (source: authors' study based on (State Statistics Service of Ukraine 2016))

4. Identification of factors determining emissions of odour-active pollutants and their sources in livestock farming

The operation of livestock farming facilities often entails the generation of odorous pollutants, including ammonia – most commonly associated with livestock farming. The total number of odorants emitted as a result of farming is still unknown. However, the data available in the literature on the subject suggests that formation of as many as 168 different compounds of odorous nature (O'Neill & Phillips 1992). In the case of agricultural and livestock activities, the formation of odorous compounds is mainly the result of enzymatic and microbial decomposition of organic matter contained in litter and animal faeces. Odorous compounds are also formed due to reactions occurring in the digestive systems of livestock and as part of processes of respiration and evaporation through the surface of their skin (Grzelka et al. 2018, Korczyński et al. 2010, Saba et al. 2003).

The amount and type of odorous compounds produced by animal farming are contingent on many factors. The basic parameters are the environmental and technical conditions prevailing in animal farming facilities. The environmental conditions outside livestock buildings also play an important role in the case of odour and ammonia emissions, according to research (Gang et al. 2010), seasonal changes in emissions have been found. Other authors suggests that as the temperature outside increases, there is a noticeable increase in daily NH_3 emissions from dairy barns (Ngwabie et al. 2011). The emission of odorants depends on the prevailing temperature, humidity, animal density, type and frequency of changing the litter used, type of flooring and frequency of removing animal faeces (Grzelka et al. 2018, Sówka et al. 2020). Table 7 summarises the main factors determining the amount of odorous compounds emissions from animal farming activities (Úbeda et al. 2013, Sówka et al. 2020).

Another factor determining the formation of gaseous pollutants, including odorants, is the optimisation of animal nutrition. Adequate feed balancing makes it possible to reduce the amount of protein in the faeces and to ensure optimal pH (Jugowar et al. 2010, Sówka et al. 2020, Grela et al. 2010). Animal feeds are formulated in a way that provides the right amount of carbohydrates for the species and life stage of the animal to meet its energy needs. Therefore, animal feed is usually produced from grasses or soya, often containing excess protein which results in an increased excretion of nitrogen, mainly in the form of urea which is the main source of NH_3 emissions from animal faeces (Webb et al. 2005). In addition, with appropriate animal nutrition resulting in a reduction in faecal pH, the potential for NH_3 emissions may also be relatively reduced (Misselbrook et al. 1998). The Nitrogen content in the faeces of non-ruminants may be reduced by adjusting the protein concentration in the feed to meet the needs of the animal at different stages of its life cycle. Protein intake can be further reduced through optimising the essential amino acid content by adding synthetic amino acids to the feed to reduce total protein intake (Kay & Lee 1997).

Table 7. Factors determining the amount and type of odorants formed in animal facilities (Grzelka et al. 2018, Herbut et al. 2010, Jugowar et al. 2010, Sówka et al. 2020, Úbeda et al. 2013, State Statistics Service of Ukraine 2020, Gang et al. 2010, Ngwabie et al. 2011)

	Environmental conditions	Animal feeding	Animal characteristics	Animal faeces/manure
Factors	– particulate matter concentration – temperature – humidity – air flow speed – air exchange rate – weather conditions outside the livestock buildings	Feed composition: – protein content – quantity and type of amino acids – content of non-starch polysaccharides	– animal species – animal age – animal number – animal genotype – animal health status – animal behaviour – male:female ratio	– frequency of manure removal – emission area – manure collection system – type of litter – physical and chemical properties

As yet, no reliable and effective techniques have been worked out for reducing emissions from naturally ventilated buildings – i.e., among others, those commonly used for cattle rearing – where manure is discharged as slurry. However, in the case of a litter system, increasing the amount of straw used for litter purposes may have a beneficial effect on NH_3 emissions (Webb et al. 2005, Balsdon et al. 2002). It is also possible to curb emissions from buildings by reducing the area available to animals and thus reducing the floor area contaminated by faeces; this, however, entails a deterioration in animal welfare (Webb et al. 2005). Moreover, keeping litter moisture as low as possible on the floors of buildings housing broilers by minimising water leakage (e.g. by installing special nipple drinkers) also helps to minimise NH_3 emissions (Elwinger & Svensson 1996). Research has also been conducted in the context of using special additives for litter. It is believed that polyphenols contained in tea extracts can absorb ammonia and hydrogen sulphide particles by a chemical reaction. Tan et al. (Tan et al. 2019) havedemonstrated experimentally that the addition of tea leaves, sawdust, rice husks and straw to chicken faeces effectively inhibited ammonia emissions. Compared with pure chicken manure without litter, the inhibitory effect of addition of tea leaves, straw, rice husk and sawdust on NH_3 emission after 72 hours reached 94.58%, 88.85%, 84.00% and 80.40%, respectively. A significant difference was recorded as regards the inhibition ability of the four types of litter where tea leaves proved the most effective.

In order to reduce odour emissions from livestock farming, it is also necessary to ensure adequate frequency of faeces removal and, in the case of slatted system, to ensure that the slatted floor scrapers operate smoothly enough to continuously discharge the faeces produced. Currently, increasingly popular solutions to reduce emissions include the use of special bacterial inoculations of litter, which, according to literature reports, allows for nitrogen compound emissions reduction by up to 50%. Herbut et al. (Herbut et al. 2010) conducted research aimed at recognising the scope and scale of emission of zoonotic odorants from livestock housing facilities with the most commonly used systems of keeping pigs and cattle. The research was conducted in special climate chambers in which similar microclimatic conditions were maintained for each group of animals and each type of litter used. The highest level of total odorant emission for pigs was recorded for the slatted system, followed by the deep litter system (Table 8). Ammonia was found to constitute the highest share in the total emissions. Also in the case of studies with cows, significant differences in emissions were recorded depending on the housing system. The highest emission values of all groups of compounds were recorded in the litter-free rearing and in the deep sawdust litter system. The lowest emission factors were recorded for shallow straw litter. The research showed that the decisive factor for the emission of odorants is the share of anaerobic conditions. Straw is characterised by its pore structure allowing natural aeration and a higher share of aerobic processes, which explains why the lowest values were recorded for shallow straw litter.

According to the studies presented in the paper up to 30 different gases may be formed during litter-free rearing of pigs, with hydrogen sulphide and ammonia being the most prevalent ones. Gases (mainly methane and carbon dioxide) are formed in animal facilities as a result of animals breathing and fermentation. According to the study on a complex of pig houses, given the capacity of 54 thousand pigs/year, during one hour there may be formed: 83.4 billion microorganisms, 0.6 kg/m^2 of dust and 14.4 kg/m^2 of ammonia. Increasing the number of animals to 108 thousand head/year using outdated rearing technologies led to air pollution and the spread of odours over a distance of up to 5,000 m, and at a capacity of 10 thousand head/year – over a distance of up to 3,000 m (Report on research work 2019, Annotated report of research work 2019).

Table 8. Emission of main groups of odorants from rearing of fattening pigs and lactating cows depending on rearing system used (kg/animal place/year) (Herbut et al. 2010)

Group of compounds	Fattening pigs			Lactating cows			
	Shallow litter	Deep litter	Slatted	Shallow litter	Deep straw litter	Deep saw-dust litter	Litter-free
	kg/animal place/year						
Ammonia	2.31	3.67	5.24	72.5	47.1	63.7	90.9
Hydrogen sulphide	0.084	0.108	0.322	0.379	0.019	0.351	0.473
Sulphur dioxide	0.043	0.071	0.048	24.1	19.3	28.4	56.1
Aldehydes	0.02102	0.02656	0.03489	0.2973	0.1902	0.2456	0.3723
Alcohols	0.0072	0.00983	0.01564	0.1240	0.072	0.0983	0.176
Ketones	0.01401	0.01585	0.01962	0.1696	0.1401	0.1585	0.2380
Organic acids	0.00586	0.00673	0.008407	0.782	0.58867	0.67363	1.0352
Thiols	0.05606	0.06423	0.07789	0.07142	0.05606	0.06423	0.08190
Phenols	0.2053	0.22342	0.3891	0.2984	0.2053	0.22342	0.40924
Amines	0.0724	0.07792	0.1292	1.0001	0.724.	0.7792	1.4708
Esters	0.00694	0.00716	0.00978	0.0823	0.0694	0.0716	0.1230

The BAT Reference Document for Intensive Rearing of Poultry or Pigs (Commission Implementing Decision 2017) describes an innovative litter-free rearing system (called AFS – AviHome Flooring System) developed by Avi-Home LLC, a US company, in collaboration with the University of Maryland. The system consists of two layers of pH-neutral polymer flooring with an air plenum in between. The top layer is perforated to allow the downward wicking of moisture from the liquid part of the faeces and evaporating, thus producing dry manure with low ammonia content. The AviHome Floor System (AFS) was developed to reduce ammonia production and emissions by accelerating the evaporation of water from the manure, thereby removing it from the uric acid breakdown process. Curbing the nitrification process reduces the number of bacteria in manure, resulting in improved animal welfare and meat production (Commission Implementing Decision 2017, Boggia et al. 2019).

A study conducted on a farm with 20,000 broilers showed a drastic reduction in ammonia due to this method (Harter-Dennis 2010).

Manure storage is recognised as a significant element in total farm emissions. Ammonia emissions from livestock buildings as a result of the deposition on manure onto cultivated fields are considered to be the most significant sources of odour from the operation of livestock farming facilities. Ammonia emissions are considered dangerous because ammonia can cause soil acidification and eutrophication (Marcinkiewicz & Kolomiets 2015).

Furthermore, NH_3 emissions attributed to the storage of animal manure are also an important element. Typically, once removed from livestock facilities, slurry is stored in concrete, steel or wooden tanks, or in earth-banked lagoons. In the case of storing in open lagoons orlarge-quantity field usage, local communities living near industrial farms suffer from a distinctive unpleasant odour (Marcinkiewicz & Kolomiets 2015). Reducing the concentration of odorous emissions and their spread contributes to alleviating the social tensions of the population living in the vicinity of livestock facilities and manure-fertilised cultivated fields. Lagoons, due to their large surface-to-volume ratio, have a significantly higher potential for NH_3 emissions. Table 9 juxtaposes techniques for reducing NH_3 emissions from faeces storage along with their estimated effectiveness (Webb 2005).

Table 9. The effectiveness of techniques for reducing NH_3 emissions from animal faeces storage (Webb 2005)

Technology	Effectiveness (%)
Maintaining low surface to tank volume ratio	20-50
Permanent roofing/tent structure over the tank	80
Formation of a natural crust	35-50
Flexible, floating covers made of plastic	60
Use of LECA (expanded clay aggregate) for insulation	40

Reducing the volume-to-surface ratio of a manure storage tank may significantly curb NH_3 emissions. For example, for a slurry volume of 1000 m^3, increasing the tank wall height from 3 to 5 m may reduce NH_3 emissions by 1/3 (Webb 2005). The most effective way to reduce NH_3 emissions is to install covers (Webb 2005, Sommer et al 1993). The cover prevents the volatilisation of odorous compounds from above the slurry surface. Said covers are used for above-ground, usually circular tanks made of steel sheets or concrete. However, unsealing of the cover must be ensured to prevent the accumulation of methane gas inside, hence this solution will not eliminate the emission of odorous compounds completely (Webb 2005, Sommer et al 1993). Other methods, such as maintaining a natural or artificial crust on the surface of the stored slurry, give poorer results and are more difficult in terms of management – yet they are also cheaper. Cattle slurry usually forms a natural crust if DM is > 7% and mixing is minimised. With a view to avoiding damage to the crust, tanks must be filled with manure from below. Frequent mixing and emptying should be avoided if possible, as these operations increase NH_3 emissions from slurry (Webb 2005).

5. Methods used in health impact assessments

Individual branches of the animal breeding/husbandry industry create a spectrum of environmental impacts, including odour nuisance, which can bring about health effects due to the emission of odorous compounds. Studies on the health effects of odours are especially difficult to conduct because odours have an individual and discretionary nature. Excessive levels of odour nuisance may cause significant impairment in the quality of life of those exposed to it. Odour-active compounds can be immunosuppressive, e.g. in the case of respiratory diseases (Mitloehner & Schenker 2007). Previous studies (Schulze et al. 2011) demonstrate that odorous substances including ammonia, hydrogen sulphide and others can cause ailments and diseases among people exposedStimulation of the trigeminal nerve, which may occur during exposure to odorants, causes irritation of the mucous membranes of the nose (rhinitis), throat (pain or scratching in the throat), eyes (tearing) and may trigger defensive reactions from the respiratory tract (coughing, shortness of breath, shallow breathing). On the other hand, psychosomatic symptoms such as insomnia, panic attacks, photophobia, and decreased psychophysical performance are largely determined by one's personality traits, and may be caused by general everyday problems or the stress resulting, for example, from exposure to unpleasant odours. These symptoms are not, however, an effect of the toxicity of a particular chemical compound (Michalak et al. 2014). Another effect of exposure to odorous compounds may also be an increased risk of aggravated cardiovascular ailments for people suffering from cardiovascular diseases such as ischemic heart disease (EPA 2000 2001, Pohl et al. 2017).

Schiffmann et al. (Schiffman et al. 2004) describe three possible paths for the emergence of ailments as a result of exposure to odours:

- the emergence of health effects once toxicity thresholds for the emitted odorous substances are exceeded;
- the appearance of health ailments once the olfactory threshold is exceeded;
- the appearance of health problems following exposure to a mixture of odours, one of which is responsible for the indicated ailments.

Intensive livestock farming contributes to high concentrations of NH_3 inside livestock housing. Both, NH_3 concentration and exposure time determine negative health effects on farm workers and livestock. According to the recommendations of the US National Institute for Occupational Safety and Health, it is estimated that the maximum level of ammonia concentration in the air safe for human health is 25 ppm for the exposure time of 8-10 h. Furthermore, according to the American Conference of Governmental Industrial Hygienists, the maximum safe time of staying in the concentration of 35 ppm is only 15 minutes.

The concentration of NH_3 in the air causing an immediate risk to health and life even at momentary exposure is 300 ppm (Ritz et al. 2004, ACoGIH 2001) Numerous studies also suggest the ammonia is harmful for animals. Exposure to ammonia in poultry houses can increase the risk of disease among birds (Carlile 1984, Beker 2004, Miles et al. 2002, Anderson 1964). Studies (Miles et al. 2002) indicate that – for animal health reasons – ammonia concentrations inside poultry houses should not exceed 25 ppm. However symptoms of reduced health and growth, including increased susceptibility to Newcastle disease, may already be seen at 20 ppm. It has also been demonstrated that broilers reared in 25 ppm ammonia conditions gain noticeably lower body weights, partly due to lower feed intake. Exposure to 46-102 ppm caused eye damage in the form of keratoconjunctivitis (Carr & Nicholson 1980). Other symptoms of ammonia toxicity in poultry include tracheal irritation, air sac inflammation, conjunctivitis and dyspnoea (Carlile 1984).

One of the methodologies most commonly used to assess the health effects of emitted odorous substances is the risk assessment proposed by the US Environmental Protection Agency (US EPA) using the so-called Hazard Index (HI) (EPA 1986, EPA 2000). This method consists in estimating the level of human exposure to a given agent (pollutant) scaled according to a certain threshold level of exposure, so-called acceptable or safe for health. In the event of HI > 1 there is a potential health hazard. The formula by which HI is calculated is shown below.

$$HI= 〖CE〗\_1/ 〖DR〗\_1 + 〖CE〗\_2/ 〖DR〗\_2 +\cdots+ 〖CE〗\_n/ 〖DR〗\_n \qquad (1)$$

where:
CE1 is defined as the exposure level to the first chemical substance in the mixture,
DR1 is the acceptable exposure level to the first chemical substance,
CE2 and DR2 are the respective levels for chemical substance 2.
Each specific factor is called a hazard quotient (HQ).

Pohl et al. (Pohl et al. 2017) conducted a study to estimate local community exposure and assess the potential health hazard to the population living near 10 large poultry farms (concentrated animal feeding operation: CAFOs) located in Poland. The AERMOD model and hazard index (HI) estimation were used for the purpose of risk assessment. HI calculations were performed for a group of air pollutants characteristic of CAFO-type facilities, including ammonia, followed by a simulation of pollutant dispersion in the AERMOD model. The data obtained suggest that odour-causing pollutants emitted from CAFOs, such as hydrogen sulphide and ammonia, can exceed background concentrations by more than an order of magnitude in residential areas within a kilometre radius of the surveyed farms, eventually falling to background levels several kilometres from the source. However, studies have not identified significant health hazards from the analysed substances.

In studies conducted in the Lower Saxony region (Schulze et al. 2011), researchers carried out stationary grid measurements of NH_3 concentrations to assesst exposure to high ammonia concentrations in concentrated animal feeding operations (CAFOs). The collected data was then interpolated with GIS (Geographic Information System) tools using the IDW (Inverse Distance Weighting) method. Additionally, a survey was carried out among the resident population in the area to estimate the prevalence of respiratory health problems. Furthermore, a randomly selected group of residents were invited for lung function and blood tests. The results showed that ammonia emissions from CAFOs can contribute to respiratory ailments as well as increase the risk of allergic reactions.

The survey method was also used in a study on the relationship between odour exposure and somatic effects conducted in North Rhineland-Westphalia (Steinheider 1990) where field studies of odour nuisance in accordance with the methodology in VDI-3940 were also applied. Here, the field studies were carried out to assess the incidence of odour nuisance, the so-called odour hours. The survey concerned people living in the vicinity of two facilities, specialising in pig farming and producing substrate for mushroom growing, respectively. The study showed that excessive exposure to odours can cause (apart from irritation symptoms) somatic complaints, especially those related to the digestive system, such as nausea, vomiting, loss of appetite, and sleep disturbances.

6. Solutions to curb the impact of odour-active compounds emitted by animal farming facilities

The basic principles for reducing odour emissions in livestock farming include (EPA 2001): reducing the formation of odorous substances in slurry, reducing the rate of spread from surface sources, reducing the exposed surface area of slurry, including stored slurry, soiled surfaces, grids, etc., as well as utilizing feed additives, slurry additives and ventilation air extraction and treatment (secondary methods). Indirect methods affecting the reduction of pollutant emissions to air include bedding-related techniques such as aeration and drying of litter, underfloor heating, as well as the use of chemical and microbiological preparations disinfecting the litter and binding ammonia (Korczyński et al. 2010). Ammonia emissions can also be curbed during storing, warehousing and applying slurry and manure in the field (air-tight sealing of tanks, lowering the temperature, soil application (Lisowska-Mieszkowska 2014). An important aspect of avoiding the negative environmental impact of animal farming is proper spatial planning. Proper location of livestock facilities can prove effective in preventing odour nuisance. The use of buffer zones and protective green belts (VEB – Vegetative Environmental Buffers) can also limit the spread of pollutants in the air and thus reduce the range of negative impacts (Kunowska-Ślósarz et al. 2016).

Within the framework of the general BAT conclusions (Commission Implementing Decision 2017), for intensive poultry or pig farming, the implementation of an odour management plan is includedfor facilities demonstrating a potential or identified issue with odour nuisance. Such an odour management plan is a part of an environmental management system aimed at improving the overall environmental performance of the farms. Said an odour management plan should include: a protocol containing appropriate actions and timelines, a protocol for conducting odour monitoring, a protocol respondnig to identified odour nuisance, an odour prevention and elimination programme, a review of historical odour incidents and remedies and the dissemination of odour incident knowledge. The odour prevention programme aims to identify sources of odorous substances, monitor odour emissions, determine the contribution of individual sources and introduce measures to prevent or reduce odour emissions. In addition, the document identifies techniques to prevent or reduce odour emissions, such as:

- ensuring an adequate distance between the farm/plant and the sensitive receptors;
- one of foolowing: keeping the animals and surfaces dry and clean or reducing the emitting surface of manure or removing manure frequently to an external (covered) manure store or reducing the temperature of the manure and of the indoor environment or decreasing the air flow and velocity over the manure surface or keeping the litter dry and under aerobic conditions (for litter-based systems);
- optimising the discharge conditions of exhaust air by: increasing the outlet height or increasing the outlet ventilation velocity, or placing barriers (e.g. planting vegetation) to reduce the dispersion of odours in the air over longer distances, or using deflector covers in order to divert exhaust air towards the ground, or directing odour emissions in parts of the farm further away from the sensitive receptor, or aligning the ridge axis of a naturally ventilated building transversally to the prevailing wind direction;
- using air cleaning systems, such as bioscrubbers/biotrickling filters or biofilters, or a two-stage or three-stage air cleaning system;
- covering slurry or solid manure during storage or locating the store taking into account the general wind direction and adopting measures to reduce odour spread, such as natural barriers or minimising the stirring of slurry;
- processing manure with aerobic digestion (aeration) of slurry or composting solid manure or with anaerobic digestion;
- manure landspreading using a band spreader, shallow/deep injector to incorporate manure as soon as possible.

BAT also provides the following methods for reducing emissions of ammonia – one of the key odorants emitted in livestock farming – from solid manure storage: reducing the ratio between the emitting surface area and volume of the solid manure heap; covering solid manure heaps; storing dried solid manure in a barn. For farms where manure processing is used, in order to reduce (i.a.), odour emissions, the following techniques are recommended: mechanical separation of slurry (e.g. by using screw press or decanter-centrifuge separators, coagulation-flocculation, separation by sieves, using filter pressing); anaerobic digestion of manure in a biogas installation; use of an external tunnel for manure drying; aerobic digestion (aeration) of manure; composting solid manure.

Monitoring odour emissions regularly is recommended as part of an odour management plan. To this end, it is possible to apply EN standards (e.g. EN 13725: Air quality. Determination of odour concentration by dynamic olfactometry) (PN-EN 13725, 2007) or alternative methods for which there are no EN standards, ISO standards, national or international standards that ensure the acquisition of data of equivalent scientific quality In addition, ammonia emissions should be monitored by mean of estimation through a mass balance based on excretion and the total (or total ammoniacal) nitrogen content at each manure management stage,calculation by means of measurement of ammonia concentration and the ventilation rate using ISO, national or international standard methods or other methods ensuring the data is of equivalent scientific quality or estimation by using emission factors. It is also necessary to carry out a one-time verification of the air cleaning system by measuring ammonia, odour and/or dust under practical farm conditions according to a prescribed measurement protocol and using EN or other standard methods (ISO, national or international) ensuring data of an equivalent scientific quality and a daily control of the effective function of the air cleaning system (e.g. by continuously recording operational parameters or using alarm systems).

Methods of reducing emissions from livestock facilities through gas treatment mainly include (Economic Commission for Europe 2014) sorption techniques and biological methods. Sorption techniques include absorption and adsorption, which are highly effective in controlling organic odours, including volatile organic compounds and may also be used to reduce emissions of inorganic compounds such as ammonia (Kwaśny & Balcerzak 2014]). On the other hand biological methods allow for elimination of both odours and other pollutants found in the treated gases, such as: aliphatic, aromatic, aerobic, sulphur, nitrogen, and chlorine compounds. Biological gas treatment is most commonly implemented in installations such as : bioscrubbers, biotricklers, and biofilters.

7. Conclusions

Intensive livestock farming is, doubtlessly, a source of odorous emissions. Individual odorous substances and their mixtures present in the air/environment may cause discomfort, irritation and annoyance among residents living in the vicinity of livestock farming facilities, and in extreme cases even trigger a disease – especially if the chemical compound concentrations are elevated, the exposure time is long, andif the frequency of episodes is high. The elderly, children and people from high-risk groups are particularly vulnerable to such negative effects. Therefore, actions such as monitoring and control of odour-active compounds by reference to certain standards, application of good practices and preventive measures to mitigate the risk of odour emissions are crucial. Said actions have been recommended and described in scientific studies, by environmental agencies including the Environmental Protection Agency, and in BAT reference documents. Proper location of farming facilities in relation to residential buildings is a key factor in preventing odour nuisance. There are many factors determining the amount and type of pollutants generated during farming and keeping of animals, including the followingenvironmental and technical conditions in livestock farming facilities: the prevailing temperature, humidity, care for the welfare of animals, including their proper density, appropriate way of air exchange in the interior of the facility, type and frequency of litter replacement, type of flooring, method of feeding and type of food, frequency of animal faeces removal, the method of their storage, disposal or use as agricultural products. The application of appropriate standards and solutions available in Europe and worldwide allows – and in the case of countries outside the European community such as e.g. Ukraine may allow – to minimise the negative impact of livestock farming facilities, including the exposure of humans and animals to abnormal concentrations of odorous compounds. A holistic approach to analyses and evaluations of odorous air quality or odour nuisance, and thus the impact on the comfort of human life and health, should include, inter alia, standards (emission as well as immission) expressed in ou_E/m^3 and opinions (in line with the current or proposed standards for sociological studies) of residents living in the vicinity of livestock farming facilities.

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