Patrycja ŻESŁAWSKA • Iwona ZAWIEJA • Małgorzata WORWĄG

AIR QUALITY IN POLAND AND THE POTENTIAL OF ELIMINATION OF ODOURS FROM ORGANIC WASTE: A REVIEW OF THE LITERATURE

Patrycja ŻESŁAWSKA (ORCID: 0009-0001-1764-6292) – Częstochowa University of Technology, Faculty of Infrastructure and Environment

Iwona ZAWIEJA (ORCID: 0000-0002-4480-8736) – Częstochowa University of Technology, Faculty of Infrastructure and Environment

Małgorzata WORWĄG (ORCID: 0000-0001-9029-8944) – Częstochowa University of Technology, Faculty of Infrastructure and Environment

Correspondence address:
J.H. Dąbrowskiego Street 69, 42-201 Częstochowa, Poland
e-mail: Patrycja.zeslawska@pcz.pl

ABSTRACT: In Poland, the problem of odour emissions is mainly associated with the agricultural sector, industry and municipal management. Odours pose a serious environmental challenge, negatively affecting both the quality of human life and the state of the environment. The aim of this article was to review the literature on the possibility of eliminating odours, in terms of sustainable development. The article describes the characteristics of air quality in Poland, taking into account selected odour compounds emitted into the atmosphere, assesses odour nuisance, paying particular attention to the characteristics of pollutants from animal husbandry and the possibility of elimination using the biofiltration process, in addition, the impact of air pollutants on human health and the functioning of ecosystems is determined, basic regulations and the possibility of odour management are detailed. It should be noted that animal husbandry is a key source of odour emissions. Technologies (including biofiltration) that rely on microorganisms to biologically break down pollutants can effectively reduce malodourous compounds emitted into the air. In the absence of unified standards and regulations relating to odourant emissions, it is crucial to carry out activities aimed at establishing clear air quality regulations. It is essential to reduce the negative effects of odourant emissions based on sustainable solutions.

KEYWORDS: odours, regulation, air pollution, sustainability

Introduction

Odours are a significant environmental problem, affecting both the quality of human life and the health of ecosystems (Blanes-Vidal et al., 2012). The sources of odours are diverse, resulting from the conduct of complex biological and chemical processes. They include both anthropogenic processes, resulting from human activities, and natural biological processes. Odourous emissions can come from such sources as waste processing plants, wastewater treatment plants, food industry plants, and the agricultural sector.

In Poland, air quality issues, including odour emissions, are increasingly being monitored and are a serious environmental problem. Unpleasant odours can lead to social conflicts, deterioration of the quality of life and health of residents. Odours negatively affect the environment, contributing to the degradation of local ecosystems. However, this issue is complex and involves both ecological, economic and social aspects. The analysis of the main sources of odour emissions, the assessment of their impact on the environment and strategies for odour disposal are issues that should be reflected in air quality regulations and standards. In the context of animal husbandry, including poultry, the main compounds emitted into the atmosphere are ammonia, hydrogen sulfide and volatile organic compounds. These compounds are formed by the decomposition of organic matter present in animal manure and other organic materials used in agricultural production (Hristov et al., 2013). One of the technologies used to reduce odour emissions is biofiltration. It involves filtering contaminated air through a layer of biological material. Effective biofiltration is made possible by the presence of microorganisms responsible for the decomposition of pollutants, including malodourous gases. Biofilters enjoy a high degree of effectiveness in reducing odours. The use of biofilters in the elimination of odours from animal husbandry can reduce odour nuisance and contribute to improving air quality (Grzelka et al., 2018). In Poland, the problem associated with the lack of regulations and legal standards regarding the issue of odourous emissions needs to be developed and normalised. It is necessary to introduce and enforce standards and regulations that will protect human health and the environment from the negative effects of odour emissions (Parzenta-Gabor et al., 2020).

The purpose of the article was to review the literature on the possibility of eliminating odours, in terms of sustainable development. Increasing the efficiency of the deodourization process, emission control, public education and effective enforcement are key elements of air quality management strategies, in the context of odour emissions.

Air quality in Poland – characteristics of selected compounds

Air pollution is defined by the World Health Organisation as polluted air, the chemical composition of which negatively affects humans, animals, plants and other elements of the ecosystem, such as water or soil (Kowalska, 2020). Air quality is an important element that determines the conditions of human life, the functioning of the ecosystem, the animal and plant world. The above factors significantly affect global climate change. According to the European Environment Agency, in Europe the most problematic atmospheric pollutants include particulate matter (PM10 and PM2.5), nitrogen dioxide and tropospheric ozone. Due to high levels of air pollution, globally nearly half a million people die each year, while in Poland the figure is in the order of 47,000 people a year. Recent years have shown that air quality standards have been exceeded almost all over Poland. Exceeded norms relating to the concentration of PM10 particulate matter occurred in 91% of the measurement zones, especially in the Silesian, Lodz and Lesser Poland Voivodeships. Poland, relative to other European countries, ranks very low on air quality lists. Both the pollution of PM10, PM2.5 as well as polycyclic aromatic hydrocarbons (PAHs) or sulfur dioxide reach, especially in Upper Silesia, values much higher than in Western Europe (Kuchcik & Milewski, 2018). In Poland, thanks to measuring stations, it is possible to continuously monitor air quality. It is possible to monitor pollutants such as sulfur dioxide, nitrogen dioxide, ozone, PM10 particulate matter and PM2.5 particulate matter. Figure 1 shows the measurement data from 10:00-11:00 a.m. on 30.07.2024 for the air quality index in Poland, according to the Chief Inspectorate for Environmental Protection (Inspekcja Ochrony Środowiska, 2024). Interpreting the data in the figure, it can be concluded that the air quality on that day throughout the country was good or very good. The air quality standard in Poland (Table 1) is intended to

DOI: 10.34659/eis.2025.92.1.912

protect public health and the environment. Colour variation is part of an information system that helps the public understand the current state of air pollution.

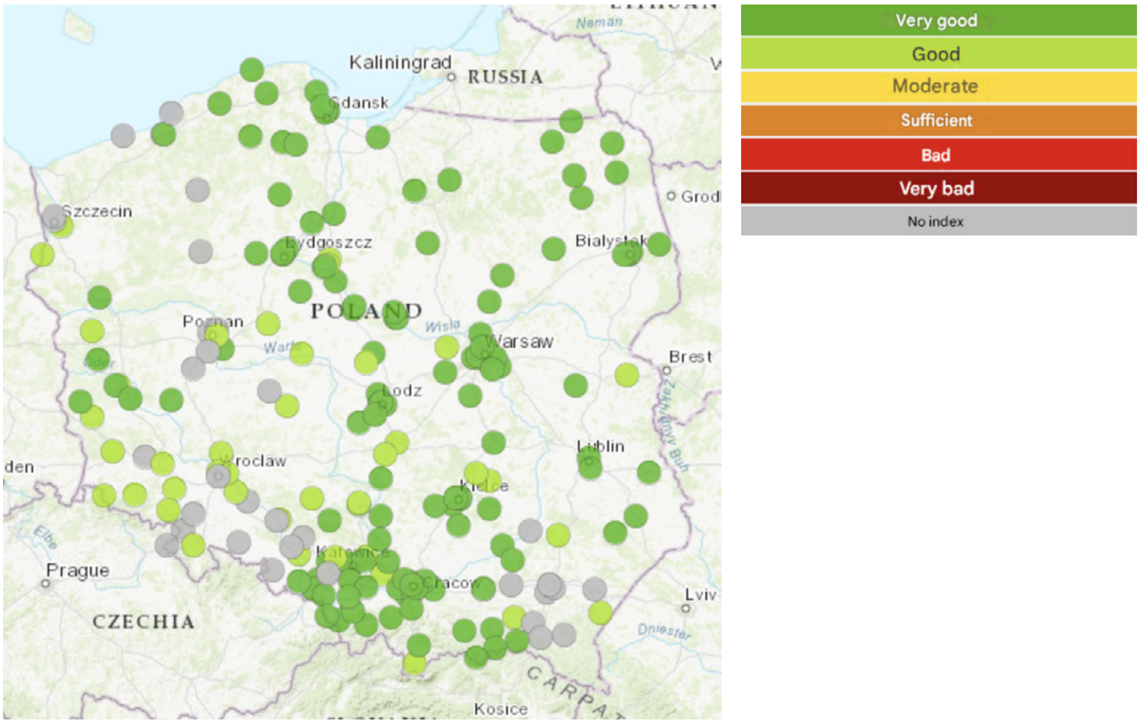

Figure 1. Air quality in Poland as of 30.07.2024 Source: Inspekcja Ochrony Środowiska (2024)

Table 1. Air quality standards in Poland

Category	Designation	Information
Very good	Dark green color	Air quality is good, air pollution is not a threat
Good	Green color	Air quality is satisfactory, air quality poses minimal risk
Sufficient	Yellow color	Air quality is acceptable, air pollution may pose risks to those at risk
Moderate	Orange color	Air quality is average, air pollution poses a risk to those at risk
Bad	Red color	Air quality bad, those at risk should not go outside
Very bad	Brown color	Air quality is dangerously bad, vulnerable people should absolutely avoid going outside

Source: Kostrz and Satora (2017).

Air quality indicators are a comprehensive system that converts measured pollutant concentrations into a single number that unifies values and facilitates reporting of air quality with impacts on human health (Shah & Patel, 2021). The Common Air Quality Index (CAQI) was proposed to facilitate real-time comparisons of air quality in European cities and regions. The index was developed as part of the CITEAIR project, funded by the European Union (van den Elshou et al., 2014). The CAQI index is calculated based on concentrations of key pollutants, which include nitrogen dioxide (NO_2), PM10 and PM2,5, ozone (O_3), carbon monoxide (CO) and sulfur dioxide (SO_2). Index values range from 0-100, with lower values characterising better air quality. The index is available in hourly and daily versions, taking into account and distinguishing roadside and urban background locations. CAQI defines two areas for monitoring pollution. The first relates to urban background areas, which represent the general state of air quality in populated areas. The second area focuses on monitoring roadside areas. The monitoring covers sites near streets that have significant traffic. The indicator is based on five classes of air quality: classes 1-3 characterise good air quality, class 4 and 5 refer to poor air quality. Class 4 poses a threat to vulnerable groups, while class 5 may pose a health risk to the general population. The main purpose of the CAQI air quality index is to draw the public's attention to urban air pollution, its sources and, at the same time, its indirect impact on quality of life (Miklińska et al., 2015).

The European Air Quality Index (EAQI) refers similarly to CAQI to the presentation of air quality based on various such as: PM10, PM2.5, NO_2, O_3, SO_2, CO. EAQI indices in relation to the CAQI index have a larger character, resulting from the presented results using not only current values, but also forecasts and monitoring ranges. The European Air Quality Index is a device that aims to aerate the air and distribute its quality to users in Europe. Available throughout Europe. EAQI indices allow for detailed information on the performance of air in individual countries, cities, and regions (Rios et al., 2024).

The Health Air Quality Index (HAQI) is a global air quality indicator that uses satellite data to assess air pollution concentrations worldwide. It enables monitoring of air quality in regions without traditional measurement stations. The HAQI is an indicator that provides a simple way of presenting the health risk resulting from predicted levels of air pollution (Duncan et al., 2021).

Odours

Odours are compounds that are a mixture of volatile chemicals, both organic and inorganic. Their presence is noticeable in areas adjacent to municipal landfills, livestock farms, sewage treatment plants, and refineries (Capelli et al., 2008). In recent years, the problem associated with the spread of malodourous substances has become increasingly troublesome, especially in industrialised countries. The problem stems from the proximity of urban areas to industrial and agricultural facilities, successively emitting odourants. Growing public awareness of environmental problems is also influencing the proclamation of opinions opposing odour emissions into the atmosphere, especially from facilities located near agglomerations. There are also growing expectations for effective management of odour emissions (Ranzato et al., 2012).

Odourous compounds include both organic compounds and inorganic molecules that affect odour levels (Table 2) (Zhu et al., 2016). Odours are a social problem and negatively affect human health and well-being, as well as ecosystem functioning (Conti et al., 2022). Prolonged exposure to a mixture of volatile compounds can lead to various diseases, including dermatitis, asthma, or neurological problems and damage (Piccardo et al., 2022). Odours emitted into the atmosphere include compounds such as esters, sulfides, aldehydes, mercaptans, amines and others. Nuisance compounds also include ammonia, scatol, pyridine, aldehydes, ketones and volatile fatty acids. High concentrations of the above-mentioned compounds cause poisoning of the human body. Odour nuisance is not only due to the presence of chemical compounds, but also to the presence of microorganisms that are involved in the decomposition of organic matter. Microorganisms such as *Pseudomonas, Flavobacterium*, proteins are responsible for the decomposition of hydrocarbons: *Micrococcus albus, Serratia maecescens* (Michalak et al., 2014; Ozonek et al., 2009; Kośmider, 2007).

Table 2. Division of odour compounds

Volatile inorganic compounds (VIC)	Volatile organic compounds (VOCs)
Hydrogen sulfide	Organic compounds of sulfur, alcohols, volatile fatty acids, alkanes, ketones, esters
Ammonia	

Source: Zhu et al. (2016).

Odours emitted into the atmosphere as a result of human activities are a significant environmental problem (Brancher et al., 2017). Odourants present in the atmospheric air are characterised by a very low threshold of odour sensitivity. Table 3 shows selected groups of compounds and their assigned odour sensibility thresholds.

Table 3. Odour sensitivity thresholds for selected compounds

Group of compounds	Odour perception threshold
Alcohols (methanol)	33 ppm
Acids (aceticide)	363 ppb
Aldehydes (formaldehyde)	0.83 ppm
Ketones (acetone)	13.5 ppm
Esters (ethyl acetate)	3.9 ppm
Sulfur compounds (dimethyl sulfide)	5.89 ppb
Amines (methylamine)	35 ppb

Source: Szulczyński et al. (2017).

Selected compounds emitted into the atmosphere

A compound that negatively affects air quality is hydrogen sulfide. Hydrogen sulfide is classified as a colourless, highly toxic gas with a specific unpleasant odour. In the environment, it is present in volcanic gases, oil or natural gas deposits. Hydrogen sulfide is produced by microorganisms in the process of decay and decomposition of proteins from organic matter (Janoszka et al., 2013). Hydrogen sulfide and organic sulfur compounds are good markers for odour emissions. This is due to their low threshold of odour sensitivity relative to other odourous compounds (Sobczyński et al., 2014). The odour threshold for hydrogen sulfide is 0.18 mg/m^3 and is detectable even at a very high dilution of 1/100,000 (1 cm^3 of H_2S per 100 dm^3 of air) (Stetkiewicz, 2011).

Another compound emitted into the air is ammonia. Ammonia in an aqueous environment exhibits an alkaline reaction. It is an important compound that affects climate, ecosystems and air quality. Ammonia plays a key role in the production of greenhouse gases, soil acidification and water eutrophication (Sanchis et al., 2019). The presence of ammonia in the air is relatively short, at about 17 hours. Ammonia emissions contribute to the formation of ammonium salts due to the reaction that occurs with acid gases (Gu et al., 2022). Atmospheric ammonia contributes to the formation of aerosols with other pollutants present in the air, for example PM2.5, nitrates and sulfates. According to Cao et al. (2021), reducing ammonia emissions has the effect of reducing and lowering PM2.5 concentrations (Cao et al., 2021). The presence of ammonia in the atmosphere from the agricultural sector is a major environmental problem worldwide. Global atmospheric emissions of ammonia have been estimated at 47 million tons. About 94% of global anthropogenic pollutants emitted into the atmosphere are associated with the agricultural sector. About 68% of these pollutants come from livestock farming and production, including manure storage and use (Steinfeld et al., 2006). Livestock production is associated with land processing. The functioning of the agricultural sector is associated with the use of about 28% of land in the European Union. According to Leip et al. (2015), the livestock industry, due to ammonia and nitrogen oxide emissions, is responsible for 78% of the loss of ecosystem biodiversity on land, 81% of global warming, 80% of soil acidification and air pollution 73% of nitrogen and phosphorus pollution of water. Ammonia emissions occur at every stage of animal farming and manure handling. Ammonia present in the air comes mainly from livestock feces (Soto-Herranz et al., 2021). Key factors affecting the intensity of emitted ammonia are temperature, rate of and quality of ventilation, feed composition, and species of animals raised (Santonja et al., 2017).

According to the Regulation of the Minister of the Environment of January 26, 2010 on reference values for certain substances in the air (Rozporządzenie, 2010), based on Article 222(2) of April 27, 2001 – Environmental Protection Law (Act, 2001), reference values for ammonia must not exceed 400 micrograms per cubic meter (μg/m^3) in one hour, while for the entire calendar year the value must not exceed 50 micrograms per cubic meter (μg/m^3). These values allow assessment of the maximum concentration of ammonia in the air, which is an important part of the standards affecting air quality, in terms of environmental protection and human health (Rozporządzenie, 2010).

DOI: 10.34659/eis.2025.92.1.912

Assessment of odour nuisance

Odour nuisance is a serious environmental problem in many areas, both urban and rural. Odour assessment and disposal are often overlooked in urban planning and development processes (Badach et al., 2018). The occurrence of odour nuisance compounds is difficult to assess directly in terms of quantity and olfactory sensation, so it is necessary to introduce objective methods to assess the impact of odour (Nicell, 2009). Odour emissions from industrial facilities cause opposition from communities living around them. Accordingly, odourous emissions are considered pollutants that require immediate attention due to the extensive social and environmental problems (Lebrero et al., 2011; Mudliar et al., 2010; Zarra et al., 2009; Talaiekhozani et al., 2016; Liu et al., 2018). The remedy is to implement a comprehensive odour management program that includes measurement, characterisation, control and continuous monitoring of odourant emissions. Odour assessment characterisation uses several methods (Bokowa, 2010). These include analytical, sensory and mixed (sensory-analytical) techniques (Munoz et al., 2010). According to Gostelow et al. (2001), the lack of a comprehensive theory of smell has led to two main classes of odour measurement. Analytical techniques are used and preferred in terms of repeatability of testing, as well as in terms of creating odour, emission and dispersion models. Sensory techniques present less accuracy and repeatability of results, due to the subjective evaluation of odour. Analytical techniques rely on the use of analytical instrumentation to identify and quantify stinky chemicals. Analytical techniques are characterised by repeatability and accuracy of measurements (Gostelow et al., 2001). Sensory analysis of odours allows assessment of the sensory component qualitatively and quantitatively using the human sense of smell as a detector. Sensory techniques measure the total impact of a given odour on human sensation (Gostelow et al., 2001). Technologies to reduce pollution associated with odourant emissions can be divided into two groups: techniques to immobilize the odourant compound from the emitted gas stream and techniques to prevent emissions (Wysocka et al., 2019). Odour neutralisation methods can also be divided into two techniques: wet, which includes biological treatment and photocatalysis, and dry i.e.: adsorption, application of UV light, thermal oxidation (Yang et al., 2016; Zarra et al., 2019). Of the aforementioned techniques, wet techniques are most commonly used as odour reduction methods (Mauer et al., 2016; Yang et al., 2016; Couvert et al., 2006). In odour control and treatment, the first element is to identify and determine the gas or gases responsible for the odour and measure concentration levels. These factors are the basis in selecting the method needed to minimise odour emissions (Brancher et al., 2017; Mauer et al., 2016; Laor et al., 2014). A method of assessing odour nuisance that combines both analytical and sensory techniques is the "electronic nose" (ENose). ENose detects the existence of a gas in the air, which allows it to be used in situ for continuous air quality monitoring (Deshmukh et al., 2015; Neumann et al., 2013). Dodd and Persuad developed the electronic nose in 1982. The devices were designed to mimic the human sense of smell. The devices can detect volatile aromatic compounds from a variety of sources (Deshmunk et al., 2015). Electronic noses are combined with various online assistive technologies to provide more reliable results. They can be integrated with other monitoring systems, such as meteorological instruments. The technique is developing rapidly and is increasingly being used to evaluate the effectiveness of the deodorisation process of odour compounds produced by various human activities (Szulczyński et al., 2017). According to Szulczynski et al. (2017), the use of "electronic noses", due to the specifics of their operation, can be an effective solution in terms of complementing odourant measurement techniques. Limitations on the use of electronic noses are due to the lack of defined regulations and their standardisation. The use of ENose is justified because the development of methods for the analysis of odourant compounds involves the need for such meters (Szulczyński et al., 2017).

The use of artificial neural networks (ANNs) in the ENose meter allows for pattern recognition that improves odour detection in "electronic noses". Artificial neural networks correspond to a miniature human brain, it is a biological model of the nervous system, consisting of neurons arranged in layers. Dharwl and Kaur report (Dharwal & Kaur, 2016) that artificial neural networks have applications in many different fields. The use of artificial neural networks allows the collection of more accurate measurement results and influences the reduction of measurement errors. The application of artificial neural networks in the issue of odour origin management has a wide range of applications. The main factors determining the functioning of artificial neural networks include the elements, structure and learning algorithm. Environmental odour management is categorised in terms of four different aspects: measurement, characterisation, continuous monitoring, and control and treatment. Figure 2 shows the application of artificial neural networks to environmental odour management issues (Zarra et al., 2019).

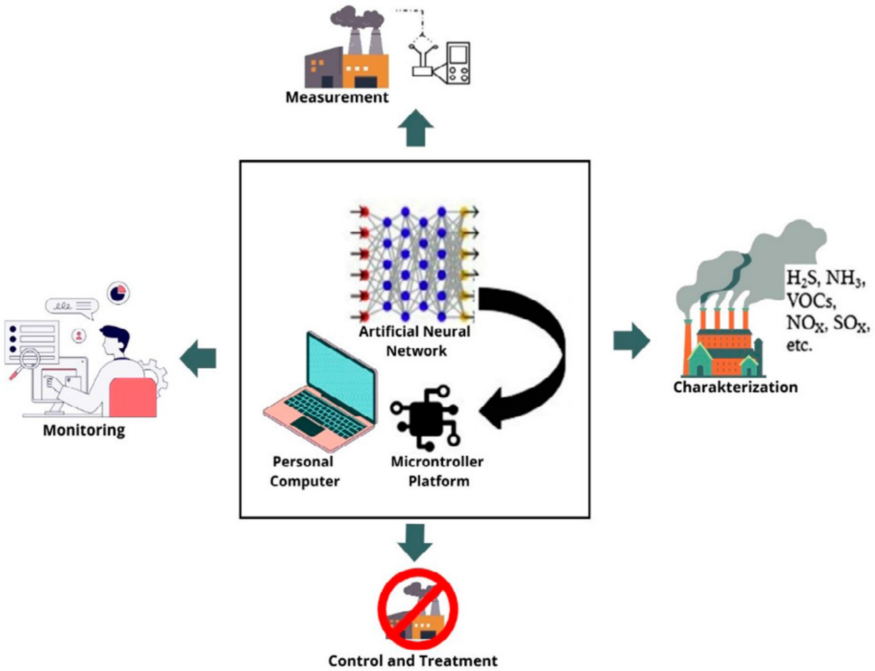

Figure 2. Application of artificial neural networks for environmental odour management
Source: Zarra et al. (2019).

Dynamic olfactometry, on the other hand, makes it possible to estimate odours from the environment and determine the odour threshold of a single substance (Maxeiner & Mannebeck, 2004). It is the most widely used method for evaluating gas samples for odour intensity, the amount of malodourous substances including odourants. Dynamic olfactometry is defined in the unit (1ouE/m^3), which corresponds to 1 m^3 of volumetric gas into which the odourant was introduced. The principle adopted in the method is based on a 50% probability of detecting malodourous substances by a selected team of experts (PN-EN 13725:2007; Szulczyński, 2021). The odour concentration measurements involve a team, which meets certain criteria of odour sensitivity and odour sensitivity. It is required that each member individually determines the reference substance n-butanol, the smell of which allows the panelists to tune their sense of smell (Lisman & Huszał, 2018). The following factors are key in the application of dynamic olfactometry: air sampling method, test site, selection of panelists, available technology, test site. The above-mentioned factors have standardised standards of repeatability and reproducibility. They are characterised by reliability in the presence of gases with higher concentrations. Dynamic olfactometry is not a suitable method for evaluating odour compounds at very low concentrations and noxious substances (Littarru, 2007). Olfactometric measurements are labor-intensive and time-consuming. In static methods, the air sample is diluted in a specific, fixed volume before being transferred to a panel that evaluates odour intensity. In contrast, dynamic methods, which are currently preferred, involve continuously mixing an odour sample of known flow rate with a corresponding volume of clean air, also of known flow rate. There are various standards that have been developed to regulate dynamic olfactometry processes (Littarru, 2007). In a study conducted by Littarrua (2007), which involved the use of dynamic olfactometry with an "electronic nose," odour disturbance from four identical biofilters for processing odorous emissions from a municipal waste organic fraction composting plant was evaluated. The biofilters processed emissions from composting plants with the same flow rate. The qualitative differences were the age of the composted waste. The measurement equipment included an array of 10 MOS sensors and Winmuster software, which allows prediction based on linear and nonlinear methods. In the study,

DOI: 10.34659/eis.2025.92.1.912

Littaurra used the CEN/TC 264/WG2 olfactometer standard and the ECOMA TO07 olfactometer with a panel of 8 panelists. Based on the results, it was concluded that dynamic olfactometry allows the determination of odour intensity, the use of an electronic nose in the study confirmed the correlation of the two methods and the possibility of frequent quantification of biofilter emission substances using ENose, which contributes to cost reduction. In addition, it has been observed that the combination of dynamic olfactometry and electronic nose makes it possible to estimate odour intensity in samples taken from the environment (Littarru, 2007; Boeker & Haas, 2007). Dynamic olfactometry is used to assess odour nuisance in many industrial fields. Spinaze (Spinazze et al., 2022) used this method in his research to evaluate odour samples from oil refineries. In addition, his study focused on the panelists' potential hazardous exposure to chemicals. The resulting concentration values were used for the toxicological risk assessment of occupational exposure of panelists participating in the olfactometric analysis of samples, from oil refineries.

The study shows that the use of dynamic olfactometry allows for case-by-case evaluation and estimation of the minimum dilution factor that can be applied to individual cases. The researchers' risk assessment is based on the specific time of exposure to a particular compound capable of causing toxic effects. In his research, Hove et al. (2017) conducted an extensive analysis of improving the repeatability of dynamic olfactometry. The methodology for testing odour emissions using dynamic olfactometry is included in the EN 13725:2022 standard, amending the EN 13725:2003 standard and covers the assessment of odour emissions in EU Member States. The changes included in the new standard address the issue of uncertainty and introduce concepts such as Secondary Odour Reference Mass (SROM). In accordance to the EN 13725:2022 standard, the research conducted by Hove et al. (2017) focused on improving the precision of dynamic olfactometry in laboratories and on an extensive simulation of the precision of olfactometry's application in the evaluation of n-butanol odour and odourants from pig farms. The study shows that the type of odour, the influence of the performance level of panelists, and the size of the panel under study affect the precise evaluation of n-butanol. The study concludes that for precise and reliable measurements using dynamic olfactometry, it is necessary to invest in panel size to improve the precision of the laboratory. In addition, it was found that dynamic olfactometry is widely used to assess the impact of odours and control emissions.

Odours are the cause of many air quality complaints and are a social problem (Aatamila et al., 2011; De Feo et al., 2013). The techniques used to price odours are constantly being upgraded and improved. As a result, numerous studies on odour reduction are being conducted; however, the problem of odour nuisance is still open (Brattoli et al., 2011; Sironi et al., 2010).

Characterization of pollution from animal husbandry/case study

Livestock farming and the production of animal products are the backbone of the global agricultural and food industry. Meeting the demand for livestock products is a challenge for producers, also posing huge environmental risks in terms of greenhouse gas emissions. The agriculture industry is the source of nearly 18% of greenhouse gas emissions (Hristov et al., 2013). A significant threat from livestock production is the emission of malodourous substances, including ammonia. Odours are concentrated locally and cause negative impacts on surrounding agglomerations (Blanes-Vidal et al., 2012). The agricultural sector and the industry associated with the processing of animal raw material is a major source of ammonia emissions into the environment. In 2019, it was reported that about 95% of total ammonia emissions came from the agricultural industry. Odour nuisance is associated with the emission of 164 different substances generated during animal husbandry (Kołodiejczyk et al., 2011).

The poultry sector has been characterised by very rapid growth in recent years. The chemicals and energy required to produce feed, and the accompanying harmful gases are responsible for climate change. Poultry farming is carried out in special poultry houses, characterised by a high density of animals, responsible for the emission of many odourous substances (Konkol et al., 2022). Significant elements affecting the formation of pollutants include high humidity, reduced air exchange, high temperature and fixed elements of livestock buildings, e.g. bedding, animals, nests (Stuper-Szablewska et al., 2018). The most important pollutants of poultry housing include particulate matter,

DOI: 10.34659/eis.2025.92.1.912

including dust, microorganisms and toxins formed in the process of their metabolism. Pollutants also include gases such as ammonia, carbon dioxide, volatile fatty acids and other trace gaseous compounds (about 100) (Hartung & Schulz, 2007). Table 4 shows the pollutants generated as a result of poultry farming in poultry houses.

Table 4. Examples of air pollution in poultry houses

Type of pollutant	Examples
Gases	Ammonia, hydrogen sulfide, carbon dioxide, carbon monoxide, osmogens
Bacteria/fungi	100 to 1,000 colony-forming units/liter of air 80 percent of the group staphylococcaceae/ streptocococcaceae
Ashes	About 90% is organic matter, particles contain antibiotic residues

Source: Hartung and Schulz (2007).

Physical pollution generated during poultry farming is a problem inherent in livestock production. The intensity of the pollution produced is due to the stocking density of the birds, the type of bedding used. Dust generated by the use of bedding contains microorganisms and their metabolites, which cause odour nuisance. Important factors that reduce the amount of contaminated dust include odourlessness or water absorption. Excessively dry bedding is unfavourable due to the high presence of dust and the higher incidence of fungal diseases. Adequate moisture content of bedding is between 65% and 75% dry matter (Stuper-Szablewska et al., 2018). A dangerous factor for the surrounding agglomerations is microbial pollution associated with poultry farming. Among the most common microorganisms in the air are granulocysts, bacilli and bacilli, as well as pathogenic microorganisms such as *Staphylococcus, Streptococcus, Bacillus* and *Clostri- dium*. Animal manure contains most of the developing microflora. Microorganisms spread with the air to surrounding buildings for up to 500 meters from livestock buildings. The soil around the farms is also subject to microbial contamination. Among the main nuisances reported by residents neighbouring poultry houses is discomfort caused by the odour nuisance. Ammonia, hydrogen sulfide, organic acids, or phenols are mainly responsible for unpleasant odours.

These compounds cause irritation and stimulation of the olfactory epithelium, thereby affecting the perception of odour. Ammonia and hydrogen sulfide are formed in livestock buildings as a result of microbial decomposition processes of urine and protein (Stuper-Szablewska et al., 2018). There has been a steady increase in livestock production in Poland and around the world, including the number of poultry farms. Breeding is focused on two main production groups. Breeding poultry for meat and laying hens for eggs (Windhorst, 2006). The high consumption of animal products contributes to the generation of huge amounts of waste requiring processing. Uncontrolled storage and improper management of waste generated by poultry production lead to many undesirable consequences. These include groundwater contamination, greenhouse gas emissions, and malodourous emissions, among others (Böjti et al., 2017). Factors affecting the composition of manure include the type of poultry raised, the amount of nutrients, or the composition of the feed (Böjti et al., 2017). Farmed chickens consume large amounts of protein and nitrogen-rich substances in their diet. The conversion of nitrogen contained in the feed is inefficient, and as much as 50-80% of it is excreted. Due to such high values of excreted nitrogen, chicken manure is rich in nitrogenous substances and other nutrients. Farms with a particular emphasis on livestock production pollute the air, causing environmental hazards. Animal husbandry plays an important role in this context, as it contributes to the emission of harmful gases (Marszałek et al., 2011). Figure 3 shows the factors that cause the formation of malodourous compounds in poultry farming production, the compounds formed, air treatment methods and the environmental impact. Elements affecting the formation of malodourous compounds, such as hydrogen sulfide, ammonia, volatile organic compounds, and greenhouse gases, are significantly affected by the type of feed used, manure, urine, and bacteria involved in the anaerobic decomposition of organic matter. Methods of air purification from malodourous compounds can be biofiltration, bio scrubbers, ozonation, or chemical oxidation. The use of effective methods of deodor-

DOI: 10.34659/eis.2025.92.1.912

ising compounds formed during poultry farming has a positive environmental effect and neutralises and minimises negative impacts on the ecosystem and humans.

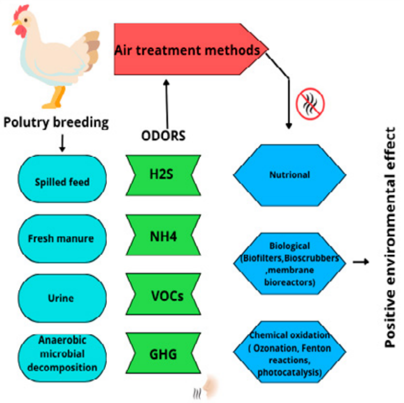

Figure 3. Methods of treating air from odours generated from poultry farming

Source: Konkol et al. (2022).

Deodorization of odours- biofiltration

Gaseous compounds from animal husbandry result from microbial decomposition of animal feces (including chicken manure), usually under anaerobic conditions. They are formed by the decomposition of carbohydrates and proteins (Gutarowska et al., 2014). A well-known method for reducing odourous or toxic substances is biofiltration. The use of microorganisms to clean the air of malodourous compounds occurs using biofilters or bio scrubbers. The mechanism of action of biofilters is the decomposition of odours by microorganisms into odour-neutral substances. Effective biofiltration is possible with the use of appropriate biofilter fillings (Kunowska-Slósarz et al., 2016). Biofiltration is one of the methods characterised by high efficiency and low process costs. The application of biofiltration is very wide, among others, it is used in municipal management, animal husbandry, agriculture, or waste management (Grzelka et al., 2018). The area of use of biofiltration is very wide and includes areas such as the processing of oily substances, wastewater treatment plants, feed mills, farms, slaughterhouses, paint shops (Chmiel & Palica, 2005). The main element that fills the biofilter is the filter bed, which is primarily responsible for the odour treatment process. The key parameter considered in the selection of the filter material is its porosity, which is responsible for effective filtration. The most common and most frequently selected filter materials are wood bark, peat, and sawdust. The organic nature of the filter material provides natural nutrients and access to nutrient compounds for the microorganisms residing in the biofilter (Miller et al., 2018). A negative aspect associated with the use of organic materials is structural stability compared to inorganic materials. The relatively short useful life of biological materials in a biofilter, e.g. compost or peat, increases the costs associated with disposal, maintenance, replacement. When compost is used to fill a biofilter, its efficiency and absorption capacity decreases by 72% after 7 months of the process (La et al., 2018). For the proper functioning of the biofilter and the viability of microorganisms, it is necessary to maintain appropriate parameters such as temperature, humidity, porosity, reaction. The humidity inside the bed should be in the range of 40-60%. It translates into biological activity of microorganisms. Too low humidity results in inhibition of biological activity of microorganisms, while too high humidity results in loss of ability to degrade malodourous compounds (Miller et al., 2018). Biofilters are capable of reducing emissions of many malodourous substances. Ammonia emissions are reduced by 51%, hydrogen sulfide by 80%, and odours by 67% (Konkol et al., 2022). Figure 4 shows a diagram illustrating the principle of the biofilter. Contaminated air through a system of pipes enters the chamber, which contains the filter material along with microorganisms. Through their presence, the decomposition of odour compounds and adsorption of airborne contaminants on the surface of the biomass takes place. The purified air passes through the biofilter column and then escapes outside the biofilter.

DOI: 10.34659/eis.2025.92.1.912

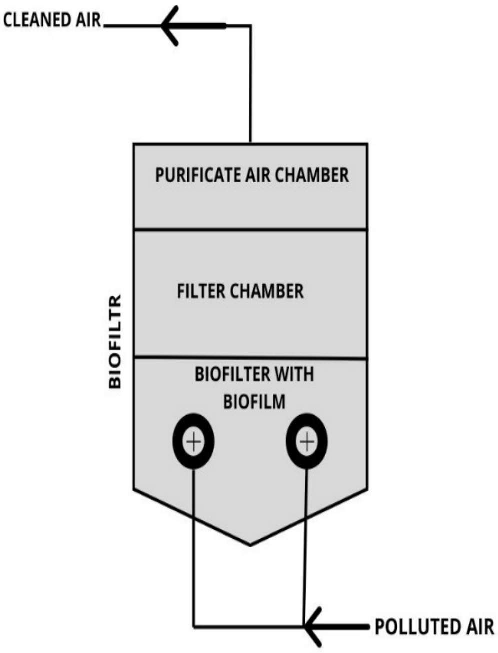

Figure 4. Diagram illustrating the principle of operation of the biofilter

Source: Vikrant et al. (2017).

The use of biofilters brings with it process requirements, which include (Ministerstwo Środowiska, 2016):

- constant odourant flow rate,
- continuous operating time,
- constant temperature,
- use of an appropriate substrate and moisture/ hydration,
- pH at a uniform level,
- systematic control of the biofilter.

The advantages of using biofilters include very high treatment efficiency: soil filters – 99% efficiency, non-soil filters – 95% efficiency, as well as economic considerations. The biological method of air purification does not generate any other waste or leachate that will require disposal. Table 5 shows the properties of selected filter beds.

Table 5. Selected properties of materials used in the biofiltration process

Type of material	pH	Bulk density, kg/m^3	Porosity
Bark	6.5÷7.5	650÷750	0.4÷0.55
Peat	4.5÷5.5	100	0.85
Coniferous wood chips	about 6	250÷400	-
Compost	-	-	-
Coconut fiber	4.5	100÷250	-
Keramzyt	-	400	0.6÷0.7
Wood from the roots	-	-	-

Source: Grzelka et al. (2018).

Impact of air pollution on human health and ecosystem functioning

An adult inhales about 10-12m^3 of air per day. Along with the inhaled air, pollutants enter the body. Prolonged exposure to unpleasant odours causes deterioration in people's quality of life and well-being (Blanes-Vidal et al., 2012). Odours cause many negative effects, which include runny nose, cough, stress, irritability, depressive states or various allergic reactions. Compounds included in odours can cause stimulation of the trigeminal nerve resulting in irritation of the mucous membranes of the nose, throat, as well as the eyes (Schiffman & Wiliams, 2005). The emission of odourous compounds also causes a significant increase in psychosomatic symptoms, which mainly include difficulty with concentration, headaches, nausea and even problems leading to depression (Ilski, 2008; Michałek et al., 2014). Odours have multifaceted effects on the environment that go beyond odour nuisance. Chemicals present in odours can affect the microbial composition of soils. Their toxicity and bioavailability depend mainly on the chemical form of the compound and the amount in which it

DOI: 10.34659/eis.2025.92.1.912

is present in the environment (Mocek-Płóciniak, 2011). Odours containing toxic substances, such as hydrogen sulfide, directly affect living organisms. Hydrogen sulfide toxicity occurs at low concentrations and causes stress effects in animals and leads to disease. Intensive livestock production contributes to the pollution of the aquatic ecosystem through the emission of gaseous and solid pollutants. The easy permeability of odour pollution mainly affects standing water, rivers and lakes. Water pollution by nitrogen and phosphorus compounds leads to eutrophication and blooms (Czerwiński et al., 2017). Sulfur oxides contribute to the formation of acid rain, which, by lowering the pH, causes many negative effects, showing harmful effects on aquatic organisms, plants and invertebrates (Boggia et al., 2019).

Regulations and odour management

The emission of unpleasant odours and volatile odour compounds has become a global environmental problem. Odour nuisance and the number of complaints from people exposed to unpleasant odours have led to increased interest in the issue of standardisation and regulation of concentrations, incidence and intensity of emitted odourous substances. For this reason, it is necessary to develop effective air treatment methods that are economically viable and beneficial to the environment (Parzenna-Gabor et al., 2020). Human economic activity is a major source of environmental and health hazards, which requires corrective measures, including the need for necessary legal regulations (Kancelaria Senatu, 2014). Currently in Poland, there are no clear standards regulating odourous air emissions, which often leads to public dissatisfaction (Kancelaria Senatu, 2014). The need to establish legal norms in Poland for the control of odour nuisance is influenced by the fact that more than half of the complaints, petitions, comments addressed to the Provincial Environmental Inspectorate and the Chief Environmental Inspectorate relate to air pollution problems. The basic legal act regulating environmental protection issues in Poland, including with odour nuisance, is the Environmental Protection Law of April 27, 2001 (Act, 2001). The Ministry of Environment has taken a number of legislative initiatives in the aspect of odour nuisance, methods of assessing the odour quality of air under Article 222 of the above Act. The analysis of allegations regarding the correctness of the measurement methodology derived from standard EN13725:2007 "Air Quality-Determination of Odour Concentration by Dynamic Olfactometry," as well as the social assessment made regarding the issue, resulted in the abandonment of legislative work related to odourous air quality. Despite attempts to introduce odour nuisance regulations, work on the draft law on odour nuisance started in 2008 did not result in the implementation of new legislation.

As a result, new obligations were introduced and existing regulations were improved, targeting the activities of local governments and businesses. The Ministry of the Environment, in cooperation with the Ministry of Economy, the Ministry of Infrastructure and Development and the Ministry of Agriculture and Rural Development, in 2013-2014 conducted an analysis of existing regulations that dealt with odour nuisance. Among other things, it analysed issues concerning minimum distances of buildings, spatial planning from farms or production facilities (Ministerstwo Środowiska, 2016). Research on odour components and technologies for their reduction, such as biofiltration, is essential for the formulation of scientifically based standards and regulations. The introduction of regulations that take into account permissible levels of emissions of odourous compounds and control technologies will significantly affect air quality in Poland. Analysis of the effectiveness of the technologies used and their implementation at the level of local governments and businesses is crucial to develop regulations that care for the environment and protect public health.

European regulations and directives are also taken into account in assessing air quality in Poland. The CAFE Directive (Directive, 2008) concerns air quality in Europe. The directive sets limit levels for PM2.5 and PM10 particulate matter, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ground-level ozone (O_2), carbon monoxide (CO), volatile organic compounds (VOCs), and heavy metals. The provisions of the directive are key to the management and monitoring of air quality in Poland, including through the activities of the Chief Inspectorate for Environmental Protection. In Poland, the Chief Inspectorate for Environmental Protection carries out monitoring of air pollutants included in the directive within the framework of State Air Monitoring, which is based on the requirements of the CAFE Directive. This makes it possible to track pollution levels, sources of pollution and take corrective measures to

DOI: 10.34659/eis.2025.92.1.912

improve air quality. It is important to define and establish air quality objectives, which are defined in such a way as to avoid, prevent and reduce the harmful effects of polluted air on human health and the environment. The directive establishes measures to assess air quality in EU member states on the basis of common methods and criteria. Obtaining air quality data helps in implementing effective methods of counteracting air pollution, as well as long-term changes and improvements in the state of the air resulting from the implementation of national and European measures. Analysis of this information makes it possible to assess the effectiveness of measures and decisions to implement new solutions in environmental and air quality policy.

Directive 2024/2881 of the European Parliament and of the Council of October 23, 2024, on air quality and cleaner air for Europe (AAQD). The directive introduces new provisions for air protection monitoring and management, while merging the two existing directives (2008/50/EC and 2004/107/EC) into a single piece of legislation. The Directive was published on November 20, 2024, and aims to introduce regulations that will further gradually improve air quality and achieve levels of pollutant concentrations that, according to the best available and most up-to-date scientific sources, are considered harmful to human health, ecosystems, biodiversity, according to the Eighth EU Environment Action Program, and greater synergy between the Union's air quality policies.

The objectives will ultimately result in a non-toxic environment by 2050 at the latest. The directive sets new, lower permissible levels of pollutants that members will be obliged to comply with from 2030. The directive, in line with WHO recommendations, requires EU member states to set up measurement superstations in urban and non-urban areas to analyse and monitor pollutants hitherto not included in EU regulations, such as ultrafine particles of soot, ammonia and particulate matter potential.

Table 6. New limit levels set by the AAQD

Pollutant	Averaging Period	Current Standards	New Standards (from 2030)
PM10 [µg/m^3]	Annual average	40	20
	Daily average (permissible number of exceedance days)	50 (35 days/year)	45 (18 days/year)
PM2,5 [µg/m^3]	Annual average	20	10
	Daily average (permissible number of exceedance days)	None	25 (18 days/year)
Benzo(a)pyrene [ng/m^3]	Annual average	1	1,0
Nitrogen Dioxide [µg/m^3]	Annual average	40	20
	Daily average (permissible number of exceedance days)	None	50 (18 days/year)
	Hourly average (permissible number of exceedance hours)	200 (18 hours/year)	200 (1 hour/year)
Carbon Monoxide [mg/m^3]	Max. 8-hour running average	10	10
	Daily average (permissible number of exceedance days) z przekroczeniem)	None	4 (18 days/year)
Benzene [µg/m^3]	Annual average	5	3.4
Sulfur Dioxide [µg/m^3]	Annual average	20	20
	Daily average (permissible number of exceedance days)	125 (3 days/year)	50 (18 days/year)
	Hourly average (permissible number of exceedance hours)	350 (24 hours/year)	350 (3 hours/year)
Arsenic [ng/m^3]	Annual average	6 (target level)	6.0 (permissible level)
Cadmium [ng/m^3]	Annual average	5 (target level)	5.0 (permissible level)
Nickel [ng/m^3]	Annual average	20 (target level)	20.0 (permissible level)

Source: Directive (2024).

DOI: 10.34659/eis.2025.92.1.912

The new measures included in the directive aim to improve air quality, better understand the impact of air pollution on human health and the environment and improve mechanisms for informing the public about the dangers of high concentrations of pollutants in the air. Table 6 shows the new permissible levels of pollutants set by the AAQD. The change means, among other things, a reduction in the permissible average annual concentrations of PM10 from 40 to 20 μg/m^3, PM2.5 from 20 to 10 μg/m^3 and nitrogen dioxide from 40 to 20 μg/m^3.

Summary

Farming, industry, human anthropogenic activities and natural factors are the causes of odour emissions, which are a significant environmental and social problem. The complexity of odour issues, their composition, specificity, toxicity and nuisance, as well as their negative impact on the ecosystem and human life, requires special attention both scientifically and legislatively. The presented case study on odour emissions from livestock farming illustrates the specificity of the compounds that make up the odours generated in the farming process. It makes it possible to determine the impact of the odours emitted in this case on the surroundings and the environment. Poland lacks precise legal regulations on odour issues, which indicates the need for standards and specific guidelines to help manage odour nuisance. The use of biofiltration is effective and justified due to the reduction of odour emissions. It is a step towards sustainable development and environmental protection. Air quality in Poland needs to be improved, so the application of remedial strategies on this issue is justified. The specificity of odours is problematic, so it is important and necessary to establish appropriate legislation that takes into account the issue of odours, the impact on the environment and the local community.

The contribution of the authors

Research concept and design, P.Ż., I.Z. and M.W.; collection and/or assembly of data, P.Ż.; writing the article, P.Ż.; critical revision of the article, P.Ż., I.Z. and M.W.; data analysis and interpretation, I.Z.; final approval of the article, P.Ż. and I.Z.

References

Aatamila, M., Verkasalo, P. K., Korhonen, M. J., Suominen, A. L., Hirvonen, M. R., Viluksela, M. K., & Nevalainen, A. (2011). Odour annoyance and physical symptoms among residents living near waste treatment centres. Environmental Research, 111(1), 164-170. https://doi.org/10.1016/j.envres.2010.11.008

Act from 27 April 2001. Environmental Protection Law. Journal of Laws No. 62, item 627. https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20010620627 (in Polish).

Badach, J., Kolasińska, P., Paciorek, M., Wojnowski, W., Dymerski, T., Gębicki, J., ... & Namieśnik, J. (2018). A case study of odour nuisance evaluation in the context of integrated urban planning. Journal of Environmental Management, 213, 417-424. https://doi.org/10.1016/j.jenvman.2018.02.086

Blanes-Vidal, V., Suh, H., Nadimi, E. S., Løfstrøm, P., Ellermann, T., Andersen, H. V., & Schwartz, J. (2012). Residential exposure to outdoor air pollution from livestock operations and perceived annoyance among citizens. Environment International, 40, 44-50. https://doi.org/10.1016/j.envint.2011.11.010

Boeker, P., & Haas, T. (2007). The measurement uncertainty of olfactometry. Gefahrstoffe – Reinhaltung der Luft, 67(7-8), 331-340. (in German).

Boggia, A., Paolotti, L., Antegiovanni, P., Fagioli, F. F., & Rocchin, L. (2019). Managing ammonia emissions using no-litter flooring system for broilers: Environmental and economic analysis. Environ Sci Policy, 101, 331-340. https://doi.org/10.1016/j.envsci.2019.09.005

Böjti, T., Kovács, K. L., Kakuk, B., Wirth, R., Rákhely, G., & Bagi, Z. (2017). Pretreatment of poultry manure for efficient biogas production as monosubstrate or co-fermentation with maize silage and corn stover. Anaerobe, 46, 138-145. https://doi.org/10.1016/j.anaerobe.2017.03.017

Bokowa, A. H. (2010). The review of the odour legislation. Chemical Engineering Transactions, 23, 31-36. https://doi.org/10.3303/CET1023006

Brancher, M., Griffiths, K. D., Franco, D., & de Melo Lisboa, H. (2017). A review of odour impact criteria in selected countries around the world. Chemosphere, 168, 1531-1570. https://doi.org/10.1016/j.chemosphere.2016.11.160

Brattoli, M., De Gennaro, G., De Pinto, V., Loiotile, A. D., Lovascio, S., & Penza, M. (2011). Odour detection methods: Olfactometry and chemical sensors. Sensors, 11(5), 5290-5322. https://doi.org/10.3390/s110505290

Cao, Y., Bai, Z., Misselbrook, T., Wang, X., & Ma, L. (2021). Ammonia emissions from different pig production scales and their temporal variations in the North China Plain. Journal of the Air & Waste Management Association, 71(1), 23-33. https://doi.org/10.1080/10962247.2020.1815895

Capelli, L., Sironi, S., Del Rosso, R., Céntola, P., & Il Grande, M. (2008). A comparative and critical evaluation of odour assessment methods on a landfill site. Atmospheric Environment, 42(30), 7050-7058. https://doi.org/10.1016/j.atmosenv.2008.06.009

Chmiel, K., & Palica, M. (2005). Modelowanie procesu biofiltracji. Rocznik Ochrona Środowiska, 7, 143-171. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BPW8-0003-0098 (in Polish).

Conti, C., Guarino, M., & Bacenetti, J. (2022). Measurements techniques and models to assess odour annoyance: A review. Environment International, 134, 105261. https://doi.org/10.1016/j.envint.2019.105261

Couvert, A., Charron, I., Laplanche, A., Renner, C., Patria, L., & Requieme, B. (2006). Treatment of odourous sulphur compounds by chemical scrubbing with hydrogen peroxide – application to a laboratory plant. Chemical Engineering Science, 61(22), 7240-7248. https://doi.org/10.1016/j.ces.2006.07.030

Czerwiński, J., Kalinowski, J., Paprocka, S., & Babicz, M. (2017). Wpływ intensywnego chowu trzody chlewnej na środowisko przyrodnicze oraz zdrowie człowieka. In B. Nowakowicz-Dębek & W. Chabuz (Eds.), *Biogospodarka i Środowisko*. *ŚRODOWISKO – ZWIERZĘ – PRODUKT* (pp. 59-68). Lublin: Wydwnictwo Uniwersytetu Przyrodniczego w Lublinie. (in Polish).

De Feo, G., De Gisi, S., & Williams, I. D. (2013). Public perception of odour and environmental pollution attributed to MSW treatment and disposal facilities: A case study. Waste Management, 33(4), 974-987. https://doi.org/10.1016/j.wasman.2012.12.016

Deshmukh, S., Bandyopadhyay, R., Bhattacharyya, N., Pandey, R. A., & Jana, A. (2015). Application of electronic nose for industrial odours and gaseous emissions measurement and monitoring – an overview. Talanta, 144, 329-340. https://doi.org/10.1016/j.talanta.2015.06.050

Dharwal, R., & Kaur, L. (2016). Applications of artificial neural networks: A review. Indian Journal of Science and Technology, 9(47), 1-8. https://dx.doi.org/10.17485/ijst/2016/v9i47/106807

Directive (EU) 2024/2881 of the European Parliament and of the Council of 23 October 2024 on ambient air quality and cleaner air for Europe (recast), Pub. L. No. 32024L2881, 2881 OJ L (2024). https://eur-lex.europa.eu/eli/dir/2024/2881/oj/eng

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, Pub. L. No. 32008L0050, 152 OJ L (2008). https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX:32008L0050

Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), Pub. L. No. 32010L0075, 334 OJ L (2010). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0075

Duncan, B. N., Malings, C. A., Knowland, K. E., Anderson, D. C., Prados, A. I., Keller, C. A., ... & Ensz, H. (2021). Augmenting the standard operating procedures of health and air quality stakeholders with NASA resources. GeoHealth, 5(9), e2021GH000451. https://doi.org/10.1029/2021GH000451

Gostelow, P., Parsons, S. A., & Stuetz, R. M. (2001). Odour measurements for sewage treatment works. Water Research, 35(3), 579-597. https://doi.org/10.1016/S0043-1354(00)00313-4

Grzelka, A., Pawnuk, M., Sówka, I., & Miller, U. (2018). Analiza wybranych materiałów złóż biofiltracyjnych. Aktualne problemy w inżynierii i ochronie atmosfery, 82-89. https://bibliotekanauki.pl/chapters/16728997.pdf (in Polish).

Gu, M., Pan, Y., Sun, Q., Walters, W., Song, L., & Fang, Y. (2022). Is fertilization the dominant source of ammonia in the urban atmosphere? Science of the Total Environment, 838, 155890. https://doi.org/10.1016/j.scitotenv.2022.155890

Gutarowska, B., Matusiak, K., Borowski, S., Rajkowska, A., & Btycki, B. (2014). Removal of odourous compounds from poultry manure by microorganisms on perlite–bentonite carrier. Journal of Environmental Management, 141, 70-76. https://doi.org/10.1016/j.jenvman.2014.03.017

Hartung, J., & Schulz, J. (2007). Risks caused by bio-aerosols in poultry houses. *Proceddings of the International Conference: Poultry in the 21st Century, Avian Influenza and Beyond,* Bangkok, Thailand, 1-11. https://www.somersbyschoolofarts.org/uploads/1/0/7/1/107142079/bio_risks_2.pdf

Hove, N. C. Y., Demeyer, P., Van der Heyden, P., Van Weyenberg, S., & Van Langenhove, H. (2017). Improving the repeatability of dynamic olfactometry according to EN 13725: A case study for pig odour. Biosystems Engineering, 161, 70-79. https://doi.org/10.1016/j.biosystemseng.2017.06.004

Hristov, A. N., Oh, J., Firkins, J. L., Dijkstra, J., Kebreab, E., Waghorn, G., ... & Tricarico, J. M. (2013). Special topics – Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. Journal of Animal Science, 91(11), 5045-5069. https://doi.org/10.2527/jas.2013-6583

Ilski, K. (2008). Semiotyka zapachów w starożytności. Symbolae Philologorum Posnaniensium Graecae et Latinae, 18, 473-489. https://repozytorium.amu.edu.pl/bitstreams/20e310e8-d662-430a-a4d3-b5772f98ad8d/download (in Polish).

Inspekcja Ochrony Środowiska. (2024, July 30). *Bieżące dane pomiarowe.* https://powietrze.gios.gov.pl/pjp/current (in Polish).

Janoszka, K., Wziątek, A., & Gromiec, J. P. (2013). Ocena metod monitoringu stężeń siarkowodoru w powietrzu. Medycyna Pracy, 64(3), 449-454. https://doi.org/10.13075/mp.5893.2013.0038 (in Polish).

Kancelaria Senatu. (2014). *Regulacje prawne dotyczące przeciwdziałania uciążliwościom zapachowym (odorom) w wybranych krajach Unii Europejskiej.* https://www.senat.gov.pl/gfx/senat/pl/senatekspertyzy/2781/plik/oe_222_do_internetu.pdf (in Polish).

Kołodziejczyk, T., Jugowar, J. U. L., & Piotrkowski, M. (2011). Emisja odourów z kurników. Problemy Inżynierii Rolniczej, 19(1), 135-141. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BAR0-0062-0015?q=bwmeta1.element.baztech-volume-1231-0093-problemy_inzynierii_rolniczej-2011-r__19_nr_1;14&qt=CHILDREN-STATELESS (in Polish).

Konkol, D., Popiela, E., Skrzypczak, D., Izydorczyk, G., Mikula, K., Moustakas, K., ... & Chojnacka, K. (2022). Recent innovations in various methods of harmful gases conversion and its mechanism in poultry farms. Environmental Research, 214, 113825. https://doi.org/10.1016/j.envres.2022.113825

Kośmider, J. (2007). Pomiary stężenia zapachowego metodą olfaktometrii dynamicznej zgodnie z PN-EN 13725:2007. Wodociągi–Kanalizacja, 10, 34-35. https://zut.edu.pl/fileadmin/pliki/odory/pdf/WOD_KANAL_2007_Pomiary.pdf (in Polish).

Kostrz, M., & Satora, P. (2017). The Compounds Responsible for Air Pollution. Ecological Engineering & Environmental Technology, 18(6), 89-95. https://doi.org/10.12912/23920629/79820

Kowalska, F. (2020). Zanieczyszczenie powietrza istotnym zagrożeniem dla zdrowia mieszkańców polskich miast. Refleksje. Pismo naukowe studentów i doktorantów WNPiD UAM, 21, 71-84. https://doi.org/10.14746/r.2020.1.6 (in Polish).

Kuchcik, M., & Milewski, P. (2018). Zanieczyszczenie powietrza w Polsce – stan, przyczyny i skutki. Studia KPZK, 182, 341-364. https://journals.pan.pl/dlibra/publication/123414/edition/107643/content (in Polish).

Juklińska, K., Wolska, L., & Namieśnik, J. (2015). Air quality policy in the US and the EU – a review. Atmospheric Pollution Research, 6(1), 129-137. https://doi.org/10.5094/APR.2015.015

Kunowska-Słósarz, M., Gurdała, J., Gołębiewski, M., & Przysucha, T. (2016). Metody zmniejszania emisji odourów w budynkach inwentarskich i ich otoczeniu. Wiadomości Zootechniczne, 54(1), 118-126. https://wz.iz.edu.pl/files/WZ_2016_1_art15.pdf (in Polish).

La, H., Hettiaratchi, P. A., Achari, G., & Dunfield, P. F. (2018). Biofiltration of methane. Bioresource Technology, 268, 759-772. https://doi.org/10.1016/j.biortech.2018.07.043

Laor, Y., Parker, D., & Pagé, T. (2014). Measurement, prediction, and monitoring of odours in the environment: A critical review. Reviews in Chemical Engineering, 30(2), 139-166. https://doi.org/10.1515/revce-2013-0026

Lebrero, R., Bouchy, L., Stuetz, R., & Muñoz, R. (2011). Odour assessment and management in wastewater treatment plants: A review. Critical Reviews in Environmental Science and Technology, 41(10), 915-950. https://doi.org/10.1080/10643380903300000

Leip, A., Billen, G., Garnier, J., Grizzetti, B., Lassaletta, L., Reis, S., ... & Westhoek, H. (2015). Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environmental Research Letters, 10(11), 115004. https://doi.org/10.1088/1748-9326/10/11/115004

Lisman, S., & Huszał, A. (2018). Analiza możliwości zastosowania zmodyfikowanego prototypu przystawki odourymetrycznej INiG–PIB na potrzeby wykonywania pomiarów metodą olfaktometrii dynamicznej. Nafta-Gaz, 74(11), 839-845. http://dx.doi.org/10.18668/NG.2020.01.07 (in Polish).

Littarru, P. (2007). Environmental odours assessment from waste treatment plants: Dynamic olfactometry in combination with sensorial analysers "electronic noses". Waste Management, 27(2), 302-309. https://doi.org/10.1016/j.wasman.2006.03.011

Liu, Y., Lu, W., Wang, H., Huang, Q., & Gao, X. (2018). Odour impact assessment of trace sulfur compounds from working faces of landfills in Beijing, China. Journal of Environmental Management, 220, 136-141. https://doi.org/10.1016/j.jenvman.2018.04.122

Marszałek, M., Banach, M., & Kowalski, Z. (2011). Wpływ gnojowicy na środowisko naturalne – potencjalne zagrożenia. Journal of Ecology and Health, 15, 66-70. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BAR8-0011-0003 (in Polish).

Mauer, D. L., Koziel, J. A., Harmon, J. D., Hoff, S. J., Rieck-Hinz, A. M., & Andersen, D. S. (2016). Summary of performance data for technologies to control gaseous, odour, and particulate emissions from livestock operations: Air management practices assessment tool (AMPAT). Data in Brief, 7, 1413-1429. https://doi.org/10.1016/j.dib.2016.03.070

Maxeiner, B., & Mannebeck, D. (2004). Round robin test olfactometry 2003. Gefahrstoffe – Reinhaltung der Luft, 64(3), 118-123. https://www.scopus.com/inward/record.url?eid=2-s2.0-1542284579&partnerID=10&rel=R3.0.0 (in German).

Michalak, A., Krzeszowiak, J., & Pawlas, K. (2014). Czy ekspozycja na nieprzyjemne zapachy (odoury) szkodzi zdrowiu człowieka? Environmental Medicine, 17(4), 76-81. https://bibliotekanauki.pl/articles/1177686.pdf (in Polish).

Miller, U., Pawnuk, M., Nych, A., & Sówka, I. (2018). Wstępna ocena wpływu zapachu własnego wybranych materiałów stosowanych w biofiltracji na efekty dezodouryzacji. In J. Kuropka, K. Gaj & I. Sówka (Eds.), *Aktualne problemy w inżynierii i ochronie atmosfer* (pp. 136-143). Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej. (in Polish).

Ministerstwo Środowiska. (2016). *Kodeks przeciwdziałania uciążliwości zapachowej.* https://www.gov.pl/web/klimat/uciazliwosc-zapachowa (in Polish).

Mocek-Płóciniak, A. (2011). Wpływ metali ciężkich na mikroorganizmy oraz aktywność enzymatyczną gleby. Roczniki Gleboznawcze, 62(4), 211-220. https://www.researchgate.net/publication/340233529_WPLYW_METALI_CIEZKICH_NA_MIKROORGANIZMY_ORAZ_AKTYWNOSC_ENZYMATYCZNA_GLEBY_IMPACT_OF_HEAVY_METALS_ON_MICROORGANISMS_AND_THE_SOIL_ENZYMATIC_ACTIVITY (in Polish).

Mudliar, S., Giri, B., Padoley, K., Satpute, D., Dixit, R., Bhatt, P., ... & Vaidya, A. (2010). Bioreactors for treatment of VOCs and odours – a review. Journal of Environmental Management, 91(5), 1039-1054. https://doi.org/10.1016/j.jenvman.2010.01.006

Munoz, R., Sivret, E. C., Parcsi, G., Lebrero, R., Wang, X., Suffet, I. M., & Stuetz, R. M. (2010). Monitoring techniques for odour abatement assessment. Water Research, 44(18), 5129-5149. https://doi.org/10.1016/j.watres.2010.06.013

Neumann, P. P., Hernandez Bennetts, V., Lilienthal, A. J., Bartholmai, M., & Schiller, J. H. (2013). Gas source localization with a micro-drone using bio-inspired and particle filter-based algorithms. Advanced Robotics, 27(9), 725-738. https://doi.org/10.1080/01691864.2013.779052

Nicell, J. A. (2009). Assessment and regulation of odour impacts. Atmospheric Environment, 43(1), 196-206. https://doi.org/10.1016/j.atmosenv.2008.09.033

Ozonek, J., Korniluk, M., & Piotrowicz, A. (2009). Uciążliwość zapachowa zakładów utylizacji odpadów zwierzęcych. Rocznik Ochrona Środowiska, 11, 1191-1199. https://bibliotekanauki.pl/articles/1819746 (in Polish).

Parzentna-Gabor, A., Barbusiński, K., & Kasperczyk, D. (2020). Usuwanie odourów i lotnych związków organicznych w Kompaktowych Bioreaktorach Trójfazowych. In M. Bogacka & K. Pikoń (Eds.), *Współczesne Problemy Ochrony Środowiska i Energetyki* (pp. 123-130). Gliwice: Katedra Technologii i Urządzeń Zagospodarowania Odpadów, Politechnika Śląska. https://www.academia.edu/download/63799790/2020_wspolczesne_problemy_srodowiska_Sensula_WilczynskI_Toton_Piotrowska_BiomonitorinObrzarowPrzemyslowych20200701-84003-14es17b.pdf#page=124 (in Polish).

Piccardo, M. T., Geretto, M., Pulliero, A., & Izzotti, A. (2022). Odour emissions: A public health concern for health risk perception. Environmental Research, 204, 112121. https://doi.org/10.1016/j.envres.2021.112121

PN-EN 13725:2007: Jakość powietrza – oznaczanie stężenia zapachowego metodą olfaktometrii dynamicznej. (in Polish).

Ranzato, L., Barausse, A., Mantovani, A., Pittarello, A., Benzo, M., & Palmeri, L. (2012). A comparison of methods for the assessment of odour impacts on air quality: Field inspection (VDI 3940) and the air dispersion model CALPUFF. Atmospheric Environment, 61, 570-579. https://doi.org/10.1016/j.atmosenv.2012.08.009

Rios, V., Barba, I., Gianmoena, L., & Pascual, P. (2024). Clearing the smog ceiling: The impact of women's political empowerment on air quality in European regions. European Journal of Political Economy, 85, 102551. https://doi.org/10.1016/j.ejpoleco.2024.102551

Rozporządzenie Ministra Środowiska z dnia 26 stycznia 2010 r. w sprawie wartości odniesienia dla niektórych substancji w powietrzu. (Dz. U. z 2010 r., nr 16 poz. 87). https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20100160087 (in Polish).

Sanchis, E., Calvet, S., Del Prado, A., & Estellés, F. (2019). A meta-analysis of environmental factor effects on ammonia emissions from dairy cattle houses. Biosystems Engineering, 178, 176-183. https://doi.org/10.1016/j.biosystemseng.2018.11.017

Santonja, G. G., Georgitzikis, K., Scalet, B. M., Montobbio, P., Roudier, S., & Sancho, L. D. (2017). *Best available techniques (BAT) reference document for the intensive rearing of poultry or pigs.* Luxembourg: Publications Office of the European Union. https://dx.doi.org/10.2760/0063411

Schiffman, S. S., & Williams, C. M. (2005). Science of odour as a potential health issue. Journal of Environmental Quality, 34(1), 129-138. https://doi.org/10.2134/jeq2005.0129a

Shah, D. P., & Patel, P. (2021). A comparison between national air quality index, India and composite air quality index for Ahmedabad, India. Environmental Challenges, 5, 100356. https://doi.org/10.1016/j.envc.2021.100356

Sironi, S., Capelli, L., Céntola, P., Del Rosso, R., & Pierucci, S. (2010). Odour impact assessment by means of dynamic olfactometry, dispersion modelling and social participation. Atmospheric Environment, 44(3), 354-360. https://doi.org/10.1016/j.atmosenv.2009.10.029

Sobczyński, P., Sówka, I., Nych, A., Traczewska, T., & Kaźmierczak, B. (2014). *Emisja siarkowodoru jako wskaźnik uciążliwości zapachowej oczyszczalni ścieków*. Wrocław: Politechnika Wrocławska, Zakład Ekologistyki, Instytut Inżynierii Ochrony Środowiska. (in Polish).

Soto-Herranz, M., Sánchez-Báscones, M., Antolín-Rodríguez, J. M., & Martín-Ramos, P. (2021). Pilot plant for the capture of ammonia from the atmosphere of pig and poultry farms using gas-permeable membrane technology. Membranes, 11(11), 859. https://doi.org/10.3390/membranes11110859

Spinazzè, A., Polvara, E., Cattaneo, A., Invernizzi, M., Cavallo, D. M., & Sironi, S. (2022). Dynamic olfactometry and oil refinery odour samples: Application of a new method for occupational risk assessment. Toxics, 10(5), 202. https://doi.org/10.3390/toxics10050202

Steinfeld, H., Gerber, P., Wassenaar, T. D., Castel, V., & De Haan, C. (2006). *Livestock's long shadow: Environmental issues and options.* Rome: Food & Agriculture Organization of the United Nations.

Stetkiewicz, J. (2011). Siarkowodór. Podstawy i Metody Oceny Środowiska Pracy, 4(70), 97-117. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-eefb5d57-3864-4aaa-814f-9317954e401f (in Polish).

Stuper-Szablewska, K., Szablewski, T., Nowaczewski, S., & Gornowicz, E. (2018). Zagrożenia chemiczne i mikrobiologiczne związane z hodowlą drobiu. Environmental Medicine / Medycyna Środowiskowa, 21(4), 53-63. https://doi.org/10.19243/2018407 (in Polish).

Szulczyński, B. (2021). *Nowe sposoby instrumentalnego określania wybranych cech zapachu za pomocą technik czujnikowych* [Doctoral Disserattion]. Politechnika Gdańska. (in Polish).

Szulczyński, B., Wasilewski, T., Wojnowski, W., Majchrzak, T., Dymerski, T., Namieśnik, J., & Gębicki, J. (2017). Different ways to apply a measurement instrument of E-nose type to evaluate ambient air quality with respect to odour nuisance in a vicinity of municipal processing plants. Sensors, 17(11), 2671. https://doi.org/10.3390/s17112671

Talaiekhozani, A., Bagheri, M., Goloi, A., & Khoozani, M. R. T. (2016). An overview of principles of odour production, emission, and control methods in wastewater collection and treatment systems. Journal of Environmental Management, 170, 186-206. https://doi.org/10.1016/j.jenvman.2016.01.021

Van den Elshout, S., Léger, K., & Heich, H. (2014). CAQI common air quality index – update with PM2.5 and sensitivity analysis. Science of the Total Environment, 488, 461-468. https://doi.org/10.1016/j.scitotenv.2013.10.060

Vikrant, K., Kim, K. H., Szulejko, J. E., Pandey, S. K., Singh, R. S., Giri, B. S., ... & Lee, S. H. (2017). Bio-filters for the treatment of VOCs and odours – A review. Asian Journal of Atmospheric Environment, 11(3), 139-152. https://doi.org/10.5572/ajae.2017.11.3.139

Windhorst, H. W. (2006). Changes in poultry production and trade worldwide. World's Poultry Science Journal, 62(4), 585-602. https://www.researchgate.net/publication/231897082_Changes_in_poultry_production_and_trade_worldwide

Wysocka, I., Gębicki, J., & Namieśnik, J. (2019). Technologies for deodourization of malodourous gases. Environmental Science and Pollution Research, 26, 9409-9434. https://doi.org/10.1007/s11356-019-04195-1

Yang, S., Li, Y., Wang, L., & Feng, L. (2016). Use of peroxymonosulfate in wet scrubbing process for efficient odour control. Separation and Purification Technology, 158, 80-86. https://doi.org/10.1016/j.seppur.2015.12.010

Zarra, T., Galang, M. J. G., Ballesteros, F., Belgiorno, V., & Naddeo, V. (2019). Environmental odour management by artificial neural network – A review. Environment International, 133, 105189. https://doi.org/10.1016/j.envint.2019.105189

Zarra, T., Naddeo, V., & Belgiorno, V. (2009). A novel tool for estimating the odour emissions of composting plants in air pollution management. Global Nest Journal, 11(4), 477-486. https://doi.org/10.30955/gnj.000484

Zhu, Y. L., Zheng, G. D., Gao, D., Chen, T. B., Wu, F. K., Niu, M. J., & Zou, K. H. (2016). Odour composition analysis and odour indicator selection during sewage sludge composting. Journal of the Air & Waste Management Association, 66(9), 930-940. https://doi.org/10.1080/10962247.2016.1188865

Patrycja ŻESŁAWSKA • Iwona ZAWIEJA • Małgorzata WORWĄG

JAKOŚĆ POWIETRZA W POLSCE I POTENCJAŁ ELIMINACJI ODOURÓW Z ODPADÓW ORGANICZNYCH: PRZEGLĄD LITERATURY

STRESZCZENIE: W Polsce problematyka emisji substancji złowonnych związana jest głównie z sektorem rolnym, przemysłem i gospodarką komunalną. Odoury stanowią poważne wyzwanie środowiskowe, wpływając negatywnie zarówno na jakość życia ludzi, jak również na stan środowiska. Celem niniejszego artykułu było dokonanie przeglądu danych literaturowych na temat możliwości eliminacji odourów w kontekście zrównoważonego rozwoju. W artykule opisano charakterystykę jakości powietrza w Polsce, biorąc pod uwagę wybrane związki złowonne emitowane do atmosfery, dokonano oceny uciążliwości zapachowej, zwracając szczególną uwagę na charakterystykę zanieczyszczeń pochodzących z hodowli zwierząt i możliwości ich eliminacji z wykorzystaniem procesu biofiltracji, ponadto określono wpływ zanieczyszczeń powietrza na zdrowie ludzi i funkcjonowanie ekosystemów, szczegółowo opisano podstawowe regulacje prawne oraz możliwości zarządzania odourami. Należy podkreślić, że hodowla zwierząt jest kluczowym źródłem emisji odourów. Technologie (między innymi biofiltracja), które polegają na wykorzystaniu mikroorganizmów do biologicznego rozkładu zanieczyszczeń, mogą skutecznie redukować związki złowonne emitowane do powietrza. W związku z brakiem ujednoliconych norm i przepisów, odnoszących się do emisji odourantów, kluczowe jest prowadzenie działań mających na celu ustanowienie klarownych regulacji prawnych dotyczących jakości powietrza. Niezbędne jest ograniczenie negatywnych skutków emisji odourów, opartych na rozwiązaniach zgodnych z założeniami zrównoważonego rozwoju.

SŁOWA KLUCZOWE: odoury, regulacje prawne, zanieczyszczenia powietrza, zrównoważony rozwój

DOI: 10.34659/eis.2025.92.1.912