applied sciences

MDPI

Article

Evaluation of a Wet Acid Scrubber and Dry Filter Abatement Technologies in Pig Barns by Dynamic Olfactometry

Cecilia Conti, Emanuela Tullo *, Jacopo Bacenetti and Marcella Guarino

Department of Environmental Science and Policy, University of Milan, Via Celoria 2, 20133 Milan, Italy; cecilia.conti@unimi.it (C.C.); jacopo.bacenetti@unimi.it (J.B.); marcella.guarino@unimi.it (M.G.)
* Correspondence: emanuela.tullo@unimi.it

Abstract: Livestock activities, in particular swine farms, are sources of odorant compounds that cause conflicts with the neighboring population. Beside the effects on the neighborhood, excessive odor emission can cause discomfort to farm workers. In this context the APPROAch project, aims to test the application of two different air cleaning technologies (a wet acid scrubber and a dry filter) to reduce dust, ammonia and odors, in naturally ventilated pig facilities. The aim of the present study is to evaluate, in a pig farm, the odor removal efficiency of the two tested abatement technologies, based on air samples analyzed by dynamic olfactometry. Odor sampling was carried out at a pig facility involved in the project and brought to the lab within 30 h from sampling, as established by the European Standard EN 13725:2004. Odor concentration was evaluated by dynamic olfactometry using an Olfaktomat-n 6 (PRA-Odournet B.V.—Amsterdam, The Netherlands). The results show that the wet acid scrubber prototype presents an average odor removal efficiency of 16%, whereas dry filter has from limited to no effect. This efficiency could be considered as a good result for a prototype even if further analysis, with longer sampling periods are needed.

Keywords: odor; pig farming; wet acid scrubber; dry filter; dynamic olfactometry

check for updates

Citation: Conti, C.; Tullo, E.; Bacenetti, J.; Guarino, M. Evaluation of a Wet Acid Scrubber and Dry Filter Abatement Technologies in Pig Barns by Dynamic Olfactometry. *Appl. Sci.* **2021**, *11*, 3219. https://doi.org/10.3390/app11073219

Academic Editor: Selena Sironi

Received: 25 February 2021
Accepted: 30 March 2021
Published: 3 April 2021

1. Introduction

The expansion of residential centers has led to some problems of coexistence between the population and the production activities located in the same area [1]. Livestock activities or husbandries, in particular swine, dairy and poultry farms, are sources of odorant compounds that cause conflicts with the neighboring population [2,3]. The most common problem caused by odor issues is nuisance [4]. Moreover, extended exposure to malodors leads to a reduced quality of life and health [5]. In the agricultural sector, offensive odors are mainly generated by the incomplete anaerobic decomposition of manure and by manure management (storage, handling and land application) [6]. Ammonia (NH_3), hydrogen sulphide (H_2S) and volatile organic compounds (VOCs) are the principal odorous substances emitted by pig farms [7].

The compounds emitted from fattening swine houses vary, are complex and may result in odors nuisance. Representative VOCs emitted from swine facilities are mainly amines, sulfuric compounds, volatile fatty acids, phenolic compounds, carboxylic acids, esters, ketones, terpenes and aromatic compounds [8]. Few specific VOCs have been identified to be the dominant odorants on swine farms such as sulfuric compounds and ammonia, which are often identified as the predominant components of all odor compounds [9,10]. Beside the effects on the neighborhood, excessive odor from swine facilities can cause discomfort to workers, leading to low labor efficiency [11] and reduced well-being [12].

In air, odors are usually transported by dust particles [13], so they can travel for long distances before being deposited to the ground surface. The numerous complaints from people working and living nearby farms made it necessary to adopt strategies to reduce odor nuisance. As an example, Germany, The Netherlands, Austria and other countries have established guidelines based on separation distances between livestock units and residential areas, for determination of odor-annoyance-free level [14,15]. Alternatively, strategies for reducing odor emissions from livestock activities can be implemented in farms and can be divided into two main lines of action: (i) "upstream", aimed at reducing emissions before they are emitted; and (ii) "downstream", aimed at containing emissions, once produced. As an example, nutritional strategies [16] and building design [17,18] fall into "upstream" category, whereas the application of covering systems [19], manure treatments [20,21] or air treatment technologies [22] fall under "downstream". In particular, for what concerns air cleaning technologies, acid scrubbers, bio-scrubbers and biotrickling filters are considered effective techniques for odor removal in pig farms [23–25]. Biofilters, biotrickling filters, acid scrubbers and multi-stage air cleaning systems are also reported by Santonja et al. [13] in the JRC report entitled "Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs". In particular, for pig farms with a forced ventilation system, odor removal is reported to be, on average, 30% for acid scrubbers, 45% for biotrickling filters and 60% for bioscrubber.

The adoption of measures for the reduction and mitigation of odor emissions not only allows conflicts between the residents of the neighboring areas and farmers to be reduced [6], but it also allows the air quality inside sheds to be improved, with positive effects on animal and workers [11].

The chemical-analytical techniques allow the identification and quantification of the odorous compounds, but to quantify the response (the perception of odor), sensory techniques are required [26]. Dynamic olfactometry, a sensorial technique, is the only internationally accepted method for measuring odor concentration [27]. It is regulated by the European standard EN 13725 [28] and it is based on the use of human panelists and an olfactometer. It is commonly used to assess the abatement efficiency of air treatment technologies [29,30]. The main advantage of this technique is the high sensitivity of the human nose [26]; moreover, it provides results that can be used as input data for dispersion modelling [31].

The APPROAch project, financed by Regione Lombardia through the European Agricultural Fund for Rural Development (EAFRD), aims to test the application of two different abatement technologies, a wet acid scrubber prototype using a citric acid solution and a commercial dry filter used in dusty industrial processes. The goal of the project is to reduce NH_3, dust and odor emissions in pig fattening barns, the buildings mostly affected by poor air quality.

Therefore, the aim of the present study is to evaluate, in a pig farm, the odor abatement efficiency of two different abatement technologies (a dry filter and a wet acid scrubber) based on air samples analyzed by dynamic olfactometry.

2. Materials and Methods

2.1. Animal Housing and Conditions

The measurements about the odor abatement efficiency of a dry filter and a wet acid scrubber were carried out in an intensive swine facility located in the province of Brescia (Italy) producing heavy pigs (> 160 kg) for traditional dry-cured hams.

More specifically, the pig barns were located in the Po Valley. The orientation of the farm is reported in Figure 1.

The barns were naturally ventilated. Animals were fed twice a day with liquid feed (morning and late afternoon) and had unlimited access to water. The trial was performed in three rooms (42.5 × 17 m) with the capacity of 640 pigs each (from 30 to 110 kg). Two different abatement systems were tested, in the first room a dry filter (DF), whereas in the second one a wet acid scrubber (WAS) was installed and both were compared to a control room (CR). The rooms were divided into 32 boxes (8.5 × 2.5 m each) and animals housed on a fully slatted floor. The manure was collected under the flooring surface and in a pit equipped with the vacuum system.

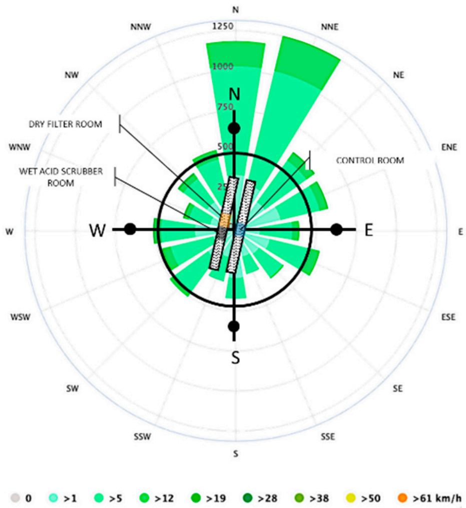

Figure 1. Orientation of the barns and prevailing winds.

The rooms equipped with the two different abatement systems presented the following characteristics: 32 windows, 2 doors and the inner volume of each room was around 3307.5 m^3.

During odor bags sampling collection, the ambient conditions (temperature and humidity) in the three experimental rooms were recorded.

2.2. Abatement Technologies

A dry filter system was provided by Zehnder Group USA (Buffalo, NY, USA), a company specialized in air treatment technologies and it was installed in the first room. It is a technology already used for the air treatment of industrial environments, such as bakery. The air is conveyed by a ventilation system through a series of filters that retain dust of different particle sizes. The filters are made of polypropylene fibers that use electrostatic charges to capture dust particles. The clean air is then returned to the barn by a blower. The operating principle of the dry filter is based on the interposition of serial filtering panels between the dusty zone and the clean zone. This arrangement, in addition to ensuring a remarkable separation capacity, allows filters to retain large amounts of dust. Usually, the dirty area is that in which the effluent enters the filter, while the clean one is downstream of the cells.

The maximum airflow rate was 6000 m^3 h^{-1} and the operating voltage was 320 W. The dry filter was sized 800 × 1390 × 1084 mm and it was installed in the middle of the barn, hanging from the ceiling 4 m above the ground.

Wet acid scrubber is a technology already tested in pig farms with forced ventilation [32]. The scrubber involved in this study is a prototype. It presents two tanks of 50 L capacity each, the first one is filled with water, the second one with a citric acid solution (15% of citric acid). Passing through the tanks, odorous compounds, dust and NH_3 are trapped by the packing materials. The intensive contact between the air and sprayed liquid enables soluble pollutants to pass from gas to the liquid phase. Thus, the air gets withdrawn from the pigsty, it gets washed thanks to the passage through the two tanks and it is finally, returned to the shelter. With respect to sulfuric acid, commonly used in air scrubber systems, citric acid presents the advantage of being safer to handle and harmless for pigs and workers [33]. The prototype was installed in the middle of the room at 4.8 m above the ground, to fulfill the idea to collect and release the cleaned air directly inside the barn, differently from what normally happens in forced ventilation system. In this latter case, treated air is released outside the piggeries, to reduce odor and NH_3 emissions in the environment and avoid problems with residents located in the neighboring areas [23]. The maximum air flow rate of the prototype was 6700 m^3 h^{-1}, with a 4 Kw fan and two pumps with the capacity of 0.75 Kw.

2.3. Odor Sampling and Dynamic Olfactometry Analysis

Odor sampling was carried out at the pig facility. For each of the 5 sampling trials, in DF, WAS and CR rooms, 5 air samples were collected in the middle of the CR or in the proximity of air cleaning systems to test their abatement efficiency. To perform the analysis, air samples were collected in 30 L Nalophan® bags equipped with a Teflon™ inlet tube by means of a vacuum pump. Each sampling lasted 3 min. In Figure 2 is provided a photo of the sampling system.

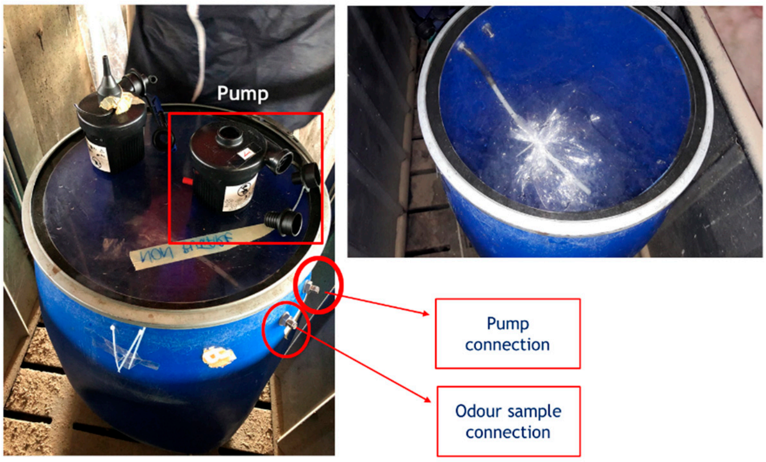

Figure 2. Sampling system.

The sampling period lasted for three months, from September to November 2020, details of performed activities are reported in Table 1.

Table 1. Details of performed activities.

Trial	Date	Description of Activities
1	7 September	Sampling on farm in WAS and CR
	8 September	Dynamic olfactometry analysis
	9 September	Sampling on farm DF and CR
	10 September	Dynamic olfactometry analysis
2	15 September	Sampling on farm in WAS and CR
	16 September	Dynamic olfactometry analysis
	17 September	Sampling on farm DF and CR
	17 September afternoon	Dynamic olfactometry analysis
3	17 September	Sampling on farm in WAS and CR
	18 September	Dynamic olfactometry analysis
	21 September	Sampling on farm DF and CR
	22 September	Dynamic olfactometry analysis
4	29 October	Sampling on farm in WAS and CR
	30 October	Dynamic olfactometry analysis
	2 November	Sampling on farm DF and CR
	2 November afternoon	Dynamic olfactometry analysis
5	24 November	Sampling on farm WAS, DF and CR
	24 November afternoon	Dynamic olfactometry analysis
	25 November	Dynamic olfactometry analysis

Odor samples from treatments and control rooms were collected in different dates, to avoid an excessive number of odor samples need to be analyzed in dynamic olfactometry laboratory.

After sampling, the bags were protected from light and analyzed within the 30 h maximum storage time, to reduce the risk of sample modification, as established by the European Standard EN 13725:2004. A total of 100 bags of air were analyzed out by dynamic olfactometry to measure the odor concentration. In the laboratory, samples bags were connected to the olfactometer, an instrument which dilutes the samples according to given ratios with reference air, which is made odor- and humidity-free through filtration with silica gel. Then, it presents odor, at the different concentration levels, to a group of evaluators. According to the European Standard EN 13725:2004, four qualified panelists were selected for the olfactometric analysis.

The outcome is the odor concentration of the sample, which is expressed in European odor units per cubic meter (ouE m^{-3}). This represents the number of dilutions with neutral (odorless) air needed for the sample to reach its odor detection threshold concentration. The odor detection threshold corresponds to the level at which the odor is perceived by 50% of the panelists. Only people with an average sensitivity to *n*-butanol within the range of 20–80 ppb can be selected as panelists [28]. In order to ensure reliable and repeatable results, the EN 13725:2004 fixes precise criteria for the standard deviation of the individual's responses, which should be verified periodically. For this case study, the panel was tested with *n*-butanol at the beginning of each session, to fulfill the ISO EN 13725:2004 requirements of precision under repeatability conditions (r) and accuracy (A_{od}). The assessors were the same for all dynamic olfactometry sessions to avoid bias linked to variations in panel members composition.

In total analyses were performed in 5 trials. The subdivision in 10 olfactometric sessions was foreseen to solve the problem linked to the maximum sample limit of the dynamic olfactometry lab. Indeed, due anti-COVID procedures, panelists and the permanence in the lab were reduced to the minimum. Thus, sampling and analysis were performed according the following scheme:

- Sampling on farm in WAS and CR;
- Dynamic olfactometry analysis;
- Sampling on farm DF and CR;
- Dynamic olfactometry analysis.

The olfactometer applied for the laboratory analysis was an Olfaktomat-n 6 (PRA-Odournet B.V.—Amsterdam, The Netherlands). The operative method used was the forced choice method; the olfactometer presents more active ports and the odor goes out only from one of them. Role of the panelists was to smell the air and to identify the port containing an odorant and to indicate whether their choice was a guess, inkling or certain on a tablet. Panelist choices were then collected to the Olfaktomat-n 6 software and presentations of dilutions as well as odor concentrations calculated according to EN 13725.

Olfactometric analysis consisted in two repetitions for each sample. This means that for each bag two measurements were executed. So, each odor concentration value was calculated as the geometric average of 2 repeated measures. The final total number of valid samples was 84 (removing outliers). The reduction of the number of samples was linked to damages occurred to Nalophan® bags during transport and to invalid measures. A measure was considered invalid when an assessor recognized the odor earlier or later than the other panelists.

3. Results and Discussion

3.1. Environmental Parameters

Table 2 shows the outdoors weather conditions during the sample collection trials, in particular referring to temperature (T), humidity (RH), wind speed and direction. These data were retrieved from the regional environmental protection agency's database (ARPA Lombardia, 2020).

Table 2. Mean meteorological data.

Sampling Date	T, °C	RH, %	Wind Speed, m/s	Wind Direction
7 September	22	84	1.78	SSW
9 September	23	80	1.43	E
15 September	24	72	1.61	E
17 September	24	70	1.26	S
21 September	19	96	1.55	SSE
29 October	11	95	1.12	WSW
2 November	11	100	0.70	S
24 November	4	89	1.21	WSW

Table 3 summarizes the average temperature (T), relative humidity (RH) and windows conditions in the three experimental rooms during sampling.

Table 3. Average environmental conditions inside the barns.

Sampling Date	T, °C	RH, %	Windows
7 September	20.1	81.1	Open 70%
9 September	20.6	77.2	Open 90%
15 September	21.2	73.0	Open 80%
17 September	21.1	72.8	Open 60%
21 September	18.7	84.6	Open 80%
29 October	17.2	84.1	Open 10%
2 November	19.3	81.0	Open 5%
24 November	10.7	83.2	Open 50%

In the farm considered, windows opening was automatized as they started opening when inside temperature and/or relative humidity (RH) was higher than 20 °C and 80%, respectively.

Despite a large variation of outdoor temperature, the indoor temperature remained in a narrow interval, ranging from 21.2 °C to 16.5 °C, except for the 24th November, when slurry pits were emptied and windows were manually opened, despite the outside temperature (+4 °C), to preserve animals and operators welfare.

3.2. Olfactometric Measurements

In Table 4 the average odor concentrations (ouE m^{-3}) ± standard deviation, for each session, measured by olfactometric analysis for DF, WAS and CR, are presented. In order to satisfy the requirements of EN 13725, the panel was tested using *n*-butanol for accuracy and repeatability before each olfactometric session. Accuracy (A_{od}) ranged from 0.098 to 0.160 and repeatability (r) ranged from 0.268 to 0.322, with a 95% confidence interval, confirming the panel selection criteria.

Table 4. Average ± standard deviation odor concentrations (ouE m^{-3}) for each abatement system and for the control room.

Session	Wet Acid Scrubber	Dry Filter	Control
1 (7–10 September 2020)	1102 ± 175	2285 ± 446	3260 ±1168
2 (15–17 September 2020)	2617 ± 562	11,220 ± 1490	10,131 ± 1572
3 (17–22 September 2020)	8287 ± 2064	10,001 ± 567	10,131 ± 1572
4 (29 October–2 November 2020)	34,123 ± 4317	38,339 ± 10,078	34,112 ± 3860
5 (24–25 November 2020)	104,329 ± 9112	163,478 ± 36,340	57,911 ± 23,101

As expected, odor concentration increases during time in correspondence of an increasing animal live weight. Pig weight at the beginning of the cycle was 28 kg and the average daily gain was 0.93 kg. November sessions odor concentration measured by dynamic olfactometry was higher than September ones.

Generally, WAS registered lowest values compared to DF and CR, except for the last session. The 24th of November, slurry pits in WAS and DF rooms were emptied during collection of air samples, substantially increasing the ouE m^{-3} measured. Nevertheless, WAS always presents lower odor concentration values than DF room and, excluding session 5, also lower than CR.

Results show a detected odor concentration for all analyzed samples between 1102–163,478 ouE m^{-3}. Environmental conditions inside and outside the rooms could have influenced the final result. Although samples were collected always in the morning around 10 a.m., away from meals, to have repeatable test conditions, external variables, such as windows opening and pits emptying, certainly affected the results. In laboratory, uncertainties associated with odor quantification, were reduced using the same olfactometer and the same panel. Assessors were selected only using *n*-butanol as a standard reference odorant; although, as underlined by Hove et al. [34], this gas does not reflect the characteristics and intensities of odors associated with pig farming. Consequently, knowing the major odorous compounds associated to swine facilities, is crucial for developing odor control strategies. For this purpose, gas chromatography coupled to mass spectrometry (GC-MS) is frequently used to identify and quantify key odorous compounds. As suggested by Hove et al. and by Gralapp et al. [34,35], panelists should be trained also to recognize "pig odor". Although, in this case study, assessors were not trained to recognize the "pig odor", they demonstrated consistency in their responses as, during olfactometric sessions, they recognize it at the same dilution. Moreover, it can also be considered that each session was a training for the following one as panelists and odor were always the same for all the experimental periods.

Each room was compared to the others to evaluate the odor abatement efficiency (WAS Vs. DF, WAS Vs. CR and DF Vs. CR). In Table 5, the percentage reduction for each comparison is reported.

Table 5. Odor abatement efficiency comparison among the three rooms (WAS, DF and CR). WAS = Wet acid scrubber room; DF = dry filter room; CR = control room.

Session	WAS vs. DF	WAS vs. CR	DF vs. CR
1	−52%	−66%	−30%
2	−77%	−74%	+11%
3	−17%	−18%	−1%
4	−11%	0%	+12%
5	−36%	+80% [1]	+182% [1]

[1] pit evacuated.

The WAS system presents, for all session, higher odor abatement efficiency compared to DF system, ranging from −11% to −77%, with an average of −39%. In addition, compared to CR, WAS technology reduces the odor concentration by an average of about 16%, while excluding the session 5, when pits were emptied, this value increases to 53%. DF abatement system resulted to be not an effective strategy to reduce odor concentration, even if dust is a carrier of odorous compounds. Compared to CR it presents the highest removal efficiency of 30% in the first session and lower in the following ones. This can be explained by the fact that the propylene filters of the DF system were replaced in July and, therefore, their dust removal efficiency could be affected. Even if biofilters have been demonstrated to be the most effective end-of-pipe technique to reduce odors [9], the use of a DF technology could be an advantage because of the high maintenance requirements of biofilters. Biofilters need an accurate control of the medium moisture of the packing material is required for a correct functionality [36,37], other than of temperature and nutrients to guarantee the survival of the bacterial population [13]. Moreover, they have the disadvantage of producing N_2O emissions if nitrifying bacteria are present [22].

The concentration of odor was reduced by WAS technology. The removal of odor-carrying particles might be explained by capture of soluble compounds in the two tanks, such as N-containing compounds (e.g., NH_3). It is well known that wet and acid scrubber represent an effective strategy to reduce NH_3 emissions, thanks to the intensive contact between the air and liquid phase, NH_3 is trapped by the acid solution leading to the production of ammonium salt [13]. Considering that the trial was conducted in a naturally ventilated pig facility, an average of 16% odor removal efficiency could be considered a good result. Wet and acid scrubber are normally used in facilities provided with forced ventilation and removal efficiencies are calculated considering the difference in the odor concentration between the inlet and outlet air from the scrubber. An average odor removal of 27% for acid scrubbers in forced ventilation was reported by Melse and Ogink [25] and, Van der Heyden et al. [22], in their review, indicated removal efficiencies ranging from negative values up to 80%, for all types of air scrubbers. Variations are principally linked to the type of air scrubber and the method chosen for the analyses. In addition, Melse and Mol [23] highlighted that odor removal efficiency presents a large variation attributable to variations in the composition of the air not completely reflected by the olfactometric measurement, by the functioning of the filter itself or by the methodology used. Moreover, the use of citric acid instead of sulfuric acid could have affect the results. Further studies on citric acid abatement efficiency are necessary, as its application is poorly studied [21]. Finally, it should be considered that acid scrubbers are more effective at removing NH_3 than odors [38].

4. Conclusions

The odor abatement efficiency using two different abatement technologies (a dry filter and a wet acid scrubber) was evaluated with dynamic olfactometry methodology. The results show that the wet acid scrubber prototype presents an average odor removal efficiency of 16%, whereas dry filter has from limited to no effect, representing a promising achievement for the prototype and for its installation in naturally ventilated pig farms. The above-mentioned odor abatement efficiency could be considered as a good result for a prototype, even if further analysis with longer sampling periods is needed.

The aim of the present study was to determine the odor removal efficiency inside the barns, but in the future, it could be certainly interesting to evaluate the effects of abatement systems also in neighboring areas through the use of air dispersion models, in particular considering the well-known problem of conflicts with citizens living nearby livestock activities. In addition to air dispersion models, also field inspection could be applied to provide the characterization of odor exposure in a defined assessment area.

Since dynamic olfactometry is time-consuming, a discontinuous measurement method and it does not provide any information on quality, origin, offensiveness or intensity of a smell, a combined analytical-olfactory approach could be useful. Indeed, both gas chromatography and electronic nose could be applied, for this purpose, to identify which odorous compounds characterize pig facilities and how the abatement technologies can affect them.

In conclusion, there is not one best method for measuring odors. Each situation should be individually evaluated by considering the applicability and limitations of each method and the aim that needs to be reached. In most cases, an integrated approach combining different methods and techniques is the best solution to depict exhaustively the problem and define a good strategy for its management.

Author Contributions: C.C. writing—original draft preparation, formal analysis, investigation, data curation; E.T. writing—review and editing, formal analysis, data curation; J.B. supervision; M.G. writing—review and editing, funding acquisition. All authors have contributed equally to this work. All authors have read and agreed to the published version of the manuscript.

Funding: The APPROAch project "Sistemi filtranti per la riduzione di polveri, odori e ammoniaca e per migliorare il benessere di animali e operatori all'interno delle porcilaie" was financed by Regione Lombardia in the context of Sub-Measure 16.1 of the Rural Development Program 2014–2020.

Institutional Review Board Statement: Not applicable, this study was conducted in a pig farm, sampling air without handling or stressing the animals.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hayes, J.E.; Stevenson, R.J.; Stuetz, R.M. The impact of malodour on communities: A review of assessment techniques. *Sci. Total Environ.* **2014**, *500*, 395–407. [CrossRef] [PubMed]
2. Dunlop, M.W.; Blackall, P.J.; Stuetz, R.M. Odour emissions from poultry litter–A review litter properties, odour formation and odorant emissions from porous materials. *J. Environ. Manag.* **2016**, *177*, 306–319. [CrossRef]
3. Trabue, S.; Scoggin, K.; Tyndall, J.; Sauer, T.; Hernandez-Ramirez, G.; Pfeiffer, R.; Hatfield, J. Odorous compounds sources and transport from a swine deep-pit finishing operation: A case study. *J. Environ. Manag.* **2019**, *233*, 12–23. [CrossRef] [PubMed]
4. Invernizzi, M.; Capelli, L.; Sironi, S. Proposal of odor nuisance index as urban planning tool. *Chem. Senses* **2017**, *42*, 105–110. [CrossRef] [PubMed]
5. Hooiveld, M.; van Dijk, C.E.; van der Sman-de Beer, F.; Smit, L.A.M.; Vogelaar, M.; Wouters, I.M.; Heederik, D.J.; Yzermans, C.J. Odour annoyance in the neighbourhood of livestock farming—Perceived health and health care seeking behaviour. *Ann. Agric. Environ. Med.* **2015**, *22*, 55–61. [CrossRef] [PubMed]
6. Blanes-Vidal, V.; Suh, H.; Nadimi, E.S.; Løfstrøm, P.; Ellermann, T.; Andersen, H.V.; Schwartz, J. Residential exposure to outdoor air pollution from livestock operations and perceived annoyance among citizens. *Environ. Int.* **2012**, *40*, 44–50. [CrossRef]
7. Martel, M.C.; Lemay, S.P.; Predicala, B.Z.; Girard, M.; Belzile, M.; Feddes, J.; Hogue, R.; Godbout, S. Detailed study of odor from pig buildings to improve understanding of biotrickling filter performance. *Trans. ASABE* **2017**, *60*, 2151–2162. [CrossRef]
8. Nie, E.; Zheng, G.; Ma, C. Characterization of odorous pollution and health risk assessment of volatile organic compound emissions in swine facilities. *Atmos. Environ.* **2020**, *223*, 117233. [CrossRef]
9. Chen, L.; Hoff, S.J. Mitigating odors from agricultural facilities: A review of literature concerning biofilters. *Appl. Eng. Agric.* **2009**, *25*, 751–766. [CrossRef]
10. Maurer, D.L.; Koziel, J.A.; Kalus, K.; Andersen, D.S.; Opalinski, S. Pilot-scale testing of non-activated biochar for swine manure treatment and mitigation of ammonia, hydrogen sulfide, odorous volatile organic compounds (VOCs), and greenhouse gas emissions. *Sustainability* **2017**, *9*, 929. [CrossRef]
11. Huang, H.; Miller, G.Y.; Ellis, M.; Funk, T.; Hollis, G.; Zhang, Y.; Heber, A.J. Odor management and swine finishing building characteristics: Costs and effectiveness. In Proceedings of the Air Pollution from Agricultural Operations-III, Raleigh, NC, USA, 12–15 October 2003; American Society of Agricultural and Biological Engineers: San Jose, MI, USA, 2003; p. 323.
12. Nimmermark, S. Odour influence on well-being and health with specific focus on animal production emissions. *Ann. Agric. Environ. Med.* **2004**, *11*, 163–173.
13. Santonja, G.G.; Georgitzikis, K.; Scalet, B.M.; Montobbio, P.; Roudier, S.; Sancho, L.D. *Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs*; EUR 28674 EN; Publications Office of the European Union: Seville, Spain, 2017. [CrossRef]
14. Guo, H.; Jacobson, L.D.; Schmidt, D.R.; Nicolai, R.E.; Janni, K.A. Comparison of Five Models for Setback Distance Determination. In Proceedings of the 2001 ASAE Annual Meeting, Sacramento, CA, USA, 28 July–1 August 2001; American Society of Agricultural and Biological Engineers: San Jose, MI, USA, 1998; p. 1.
15. Piringer, M.; Knauder, W.; Petz, E.; Schauberger, G. Factors influencing separation distances against odour annoyance calculated by Gaussian and Lagrangian dispersion models. *Atmos. Environ.* **2016**, *140*, 69–83. [CrossRef]
16. Leek, A.B.G.; Hayes, E.T.; Curran, T.P.; Callan, J.J.; Beattie, V.E.; Dodd, V.A.; O'Doherty, J. V The influence of manure composition on emissions of odour and ammonia from finishing pigs fed different concentrations of dietary crude protein. *Bioresour. Technol.* **2007**, *98*, 3431–3439. [CrossRef]
17. Létourneau, V.; Duchaine, C.; Belzile, M.; Girard, M.; Lemay, S.P.; Godbout, S. Bench-Scale Pig Buildings: Validation of a Model for Studying Airborne Contaminants of Concern for Human and Animal Health. *Trans. ASABE* **2020**, *63*, 541–548. [CrossRef]
18. Yi, Q.; Janke, D.; Thormann, L.; Zhang, G.; Amon, B.; Hempel, S.; Nosek, Š.; Hartung, E.; Amon, T. Airflow Characteristics Downwind a Naturally Ventilated Pig Building with a Roofed Outdoor Exercise Yard and Implications on Pollutant Distribution. *Appl. Sci.* **2020**, *10*, 4931. [CrossRef]
19. Guarino, M.; Fabbri, C.; Brambilla, M.; Valli, L.; Navarotto, P. Evaluation of simplified covering systems to reduce gaseous emissions from livestock manure storage. *Trans. ASABE* **2006**, *49*, 737–747. [CrossRef]
20. Bacenetti, J.; Sala, C.; Fusi, A.; Fiala, M. Agricultural anaerobic digestion plants: What LCA studies pointed out and what can be done to make them more environmentally sustainable. *Appl. Energy* **2016**, *179*, 669–686. [CrossRef]
21. Fangueiro, D.; Ribeiro, H.; Vasconcelos, E.; Coutinho, J.; Cabral, F. Treatment by acidification followed by solid–liquid separation affects slurry and slurry fractions composition and their potential of N mineralization. *Bioresour. Technol.* **2009**, *100*, 4914–4917. [CrossRef]

22. Van der Heyden, C.; Demeyer, P.; Volcke, E.I.P. Mitigating emissions from pig and poultry housing facilities through air scrubbers and biofilters: State-of-the-art and perspectives. *Biosyst. Eng.* **2015**, *134*, 74–93. [CrossRef]
23. Bibbiani, C.; Russo, C. Odour emission from intensive livestock production system: Approaches for emission abatement and evaluation of their effectiveness. *Large Anim. Rev.* **2012**, *18*, 135–138.
24. Melse, R.W.; Mol, G. Odour and ammonia removal from pig house exhaust air using a biotrickling filter. *Water Sci. Technol.* **2004**, *50*, 275–282. [CrossRef] [PubMed]
25. Melse, R.W.; Ogink, N.W.M. Air scrubbing techniques for ammonia and odor reduction at livestock operations: Review of on-farm research in the Netherlands. *Trans. ASAE* **2005**, *48*, 2303–2313. [CrossRef]
26. Conti, C.; Guarino, M.; Bacenetti, J. Measurements techniques and models to assess odor annoyance: A review. *Environ. Int.* **2020**, *134*, 105261. [CrossRef]
27. Brinkmann, T.; Both, R.; Scalet, B.M.; Roudier, S.; Sancho, L.D. *JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations*; EUR 29261 EN; Publications Office of the European Union: Seville, Spain, 2018; p. 155.
28. CEN—Committee for European Normalization. *EN 13725:2004 Air Quality—Determination of Odour Concentration by Dynamic Olfactometry*; CEN: Brussels, Belgium, 2004.
29. Bax, C.; Sironi, S.; Capelli, L. How can odors be measured? An overview of methods and their applications. *Atmosphere* **2020**, *11*, 92. [CrossRef]
30. Hansen, M.; Jonassen, K.; Feilberg, A. Evaluation of abatement technologies for pig houses by dynamic olfactometry and on-site mass spectrometry. *Chem. Eng. Trans.* **2014**, *40*, 253–258.
31. Sironi, S.; Capelli, L.; Céntola, P.; Del Rosso, R.; Pierucci, S. Odour impact assessment by means of dynamic olfactometry, dispersion modelling and social participation. *Atmos. Environ.* **2010**, *44*, 354–360. [CrossRef]
32. Zhao, Y.; Aarnink, A.J.A.; De Jong, M.C.M.; Ogink, N.W.M.; Koerkamp, P.W.G.G. Effectiveness of multi-stage scrubbers in reducing emissions of air pollutants from pig houses. *Trans. ASABE* **2011**, *54*, 285–293. [CrossRef]
33. Jamaludin, Z.; Rollings-Scattergood, S.; Lutes, K.; Vaneeckhaute, C. Evaluation of sustainable scrubbing agents for ammonia recovery from anaerobic digestate. *Bioresour. Technol.* **2018**, *270*, 596–602. [CrossRef]
34. Hove, N.C.Y.; Demeyer, P.; Van der Heyden, C.; Van Weyenberg, S.; Van Langenhove, H. Improving the repeatability of dynamic olfactometry according to EN 13725: A case study for pig odour. *Biosyst. Eng.* **2017**, *161*, 70–79. [CrossRef]
35. Gralapp, A.K.; Powers, W.J.; Bundy, D.S. Comparison of olfactometry, gas chromatography, and electronic nose technology for measurement of indoor air from swine facilities. *Trans. ASAE* **2001**, *44*, 1283. [CrossRef]
36. Dumont, E.; Hamon, L.; Lagadec, S.; Landrain, P.; Landrain, B.; Andres, Y. NH3 biofiltration of piggery air. *J. Environ. Manag.* **2014**, *140*, 26–32. [CrossRef] [PubMed]
37. Wang, Y.-C.; Han, M.-F.; Jia, T.-P.; Hu, X.-R.; Zhu, H.-Q.; Tong, Z.; Lin, Y.-T.; Wang, C.; Liu, D.-Z.; Peng, Y.-Z. Emissions, measurement, and control of odor in livestock farms: A review. *Sci. Total Environ.* **2021**, *776*, 145735. [CrossRef] [PubMed]
38. De Vries, J.W.; Melse, R.W. Comparing environmental impact of air scrubbers for ammonia abatement at pig houses: A life cycle assessment. *Biosyst. Eng.* **2017**, *161*, 53–61. [CrossRef]