PLF air quality abatement systems to improve animal welfare in piggeries: A case study

C. Conti[1,*] and M. Guarino[1]
[1]*Department of Environmental Science and Policy, University of Milan, Via G. Celoria 10, 20133 Milan, Italy*
[*]Corresponding author: Cecilia Conti, cecilia.conti@unimi.it

Abstract

Air inside pig barns is characterized by high concentration of ammonia (NH_3) and particulate matter (PM). The high number of pigs reared into large scale farms contributes to the deterioration of air quality inside the barns, posing a health risk to animals and workers. The same airborne pollutants then are emitted outside, causing pollution in the surrounding environment. The LIFE-MEGA project implemented in heavy pig houses a control unit equipped with an artificial intelligence firmware able to continuously monitor the concentration of NH_3 and PM inside the barns and activate the operation of two different abatement technologies (dry filter and wet scrubber) for air quality control. Thanks to a reduction of airborne pollutants concentration, positive effects on animal health and welfare were observed.

Keywords: air quality, scrubber, AI microclimatic tool, pig farm

Introduction

Pigs are the widest livestock species reared in the European Union (EU), accounting for about 150 million heads. In Europe, Italy occupies an outstanding position, ranking within the top ten countries with 8.7 million heads (Eurostat, 2018). The highest pig population density is concentrated in the Lombardy region where about 50% of them are produced (ISMEA, 2022).

Gaseous pollution, generated by pig farms, is originated from animals and the management of pig slurry. Pollutants such as ammonia (NH_3), particulate matter (PM), greenhouse gases (GHG), and odors lead to many environmental problems, affecting the atmosphere, the neighbourhood and the health of both pigs and workers (Conti et al., 2021). As a result of the health and environmental risks associated to air pollution, international and national Authorities imposed stricter environmental regulations concerning NH_3 emissions into the atmosphere, such as the Ambient Air Quality Directive (EC, 2008) and the National Emission Ceilings (NEC) Directive (EU, 2016).

Intensive livestock farming systems are so called to cooperate to reduce emissions into air, soil and water. For intensive pig farming, the principal mitigation measures are contained in an official document that specifies the current scientific knowledge and best techniques to prevent and reduce pollution "Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs" (Santonja et al., 2017). The application of such engineering principles and precision techniques for monitoring and managing production processes is widely accepted as a way to make livestock systems more environmentally sustainable (Tullo et al., 2019). This is recognized as a Precision Livestock Farming (PLF) approach, since with the real time and continuous monitoring of livestock environments it is possible to improve knowledge on the farming system and support the farmer in the process of decision-making, finally leading to improved farm environments and improved health and welfare for the farmed animals (Lovarelli et al., 2020).

If many studies are available on understanding how to reduce emissions to the environment, controlling the indoor air quality of a livestock building can still be a challenge. Poor indoor air quality can affect the health, productivity, and welfare of pigs, besides being a health risk to farmworkers. Among pollutants, NH_3 and PM are the most recognized because of their prevalence and distinctive effects. Exposure to high concentration of NH_3 can cause irritation and damage cells of the respiratory tract. In this context, pigs may present behavioural alterations such as a reduction in feed intake and pig activity, higher tail biting, leading to performance losses (Drummond et al., 1980). Regarding PM, controlling its concentration in the pig house is fundamental, as it represents a route to spread potentially hazardous agents like bacteria and virus, thus increasing susceptibility to respiratory diseases (Zhao et al., 2014). The monitoring of indoor air pollutants concentration in livestock farms is therefore essential. However, and especially in naturally ventilated buildings, the monitoring of air quality is still a problem quite complex to solve due to the tools to adopt, to the dirtiness of the environment and to the complexity of the management.

The aim of this study is to show the results of a pig farm monitored in Northern Italy, where different technologies were installed to monitor and treat air inside the building. In particular, this study lies in the LIFE-MEGA project, financed by the LIFE Programme of the EU, aimed at improving the indoor air quality in piggeries. A dry filter and a wet scrubber prototype with a citric acid solution were installed in an Italian fattening farm, naturally ventilated. The indoor airborne pollutants concentration was monitored in real-time with a microclimatic control unit, that was able to activate the operation of the scrubbers when predetermined thresholds limits were exceeded (NH_3: 10ppm; PM: 0.3 mg/m^3). As a consequence of reducing NH_3 and PM concentrations within the barns an improvement of animal's health and welfare was expected. Indeed, an improved indoor air quality leads to a reduction of the insurgence of respiratory diseases and increases animals' welfare, that is defined as the state of an individual with regards to its attempts to cope with the environment.

Materials and methods

Farm system

The studied farm is located in Pavia province (Lombardy region, Northern Italy). It is an intensive farrowing to finishing farm, which means that it produces piglets and raises them to market weight. In this case, heavy pigs for PDO dry-cured ham consortia are produced.

The trial was conducted during the fattening phase (from 80 to 160 kg of live weight) in a naturally ventilated building divided in three rooms with the capacity of 430 pigs each. Animals were fed twice a day with liquid feed (morning and late afternoon). The slurry was collected under the flooring surface in a pit equipped with the vacuum system.

Abatement technologies managed by AI microclimatic control units

A fattening building of the farm was equipped with two different abatement technologies for the treatment of air inside the piggery. The removal efficiency of these two technologies was then compared. In particular, a dry and a wet acid scrubber were installed in the building as reported in Figure 1. The air cleaning systems were installed in two different rooms separated by a buffer zone, that was used as control. Each room was equipped with a microclimatic control unit to monitor indoor air quality and was divided from the others by a wall.

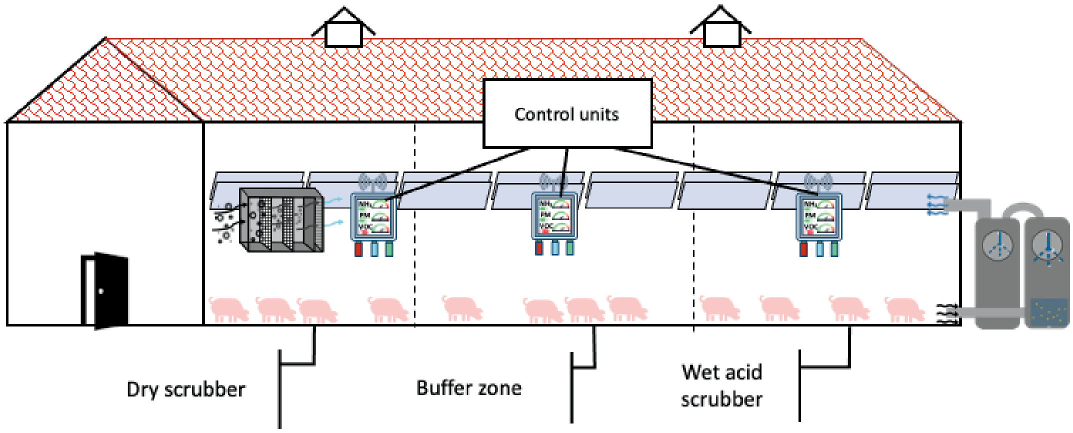

Figure 1: Scheme of the monitored building.

The dry filter was a commercial system provided by a company specialized in air treatment technologies. The air is conveyed through a series of filters that retain dust of different particle sizes. The clean air is then returned to the barn by a blower. This system was installed in the middle of the barn, hanging from the ceiling 4 meters above the ground in order to ensure maximum filtering efficiency while avoiding contact with the animals.

The wet scrubber was a prototype realized by a company partner of the LIFE-MEGA project. The scrubber uses a citric acid solution to remove NH_3, dust and odorous compounds from the gas stream. Respect to sulphuric acid, commonly used in air scrubber systems, citric acid presents the advantage of being safer to handle and harmless for pigs and workers. The prototype presents two tanks of 250 L capacity each, the first one filled with water, the second one with a citric acid solution (15% of citric acid). 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 barn. This latter aspect differs from what normally happens in forced ventilation system, where treated air is released outside the piggeries, to reduce pollutants emissions in the surrounded environment.

AI microclimatic control units

The indoor air quality of the three rooms was continuously monitored by a microclimatic control unit developed by Nuvap project partner. Nuvap's technology is protected by international patents, relating to the exclusive combined and constant monitoring of polluting agents. For the LIFE-MEGA project purposes, a tool able to resist in harsh environment, such as piggeries, was developed. In fact, due to the characteristics of indoor air quality in piggeries - namely high levels of NH_3, dust and VOCs - the Nuvap tools needed to undergo a waterproofing process, to be encapsulated in metal cases, and to be equipped with particular sensors, able to withstand the aforementioned environmental constraints. In particular, to prevent saturation of the sensors, a series of tests were carried out to find the most feasible ones. Regarding NH_3 sensor, NT-NH_3-PL100 revision 5 was chosen. Regarding PM, a new firmware version was deployed and installed remotely on each device.

The Nuvap tool was designed with two main hardware blocks (Figure 2):

1. A microclimatic control unit (indicated as main device), which incorporates the air quality sensors and the communication elements (2G/4G mobile remote connectivity, BLTE for local connectivity);

2. A remote actuator composed by a communication element (BLTE) and an actuation element (relay) used to activate the functioning of the air treatment technologies.

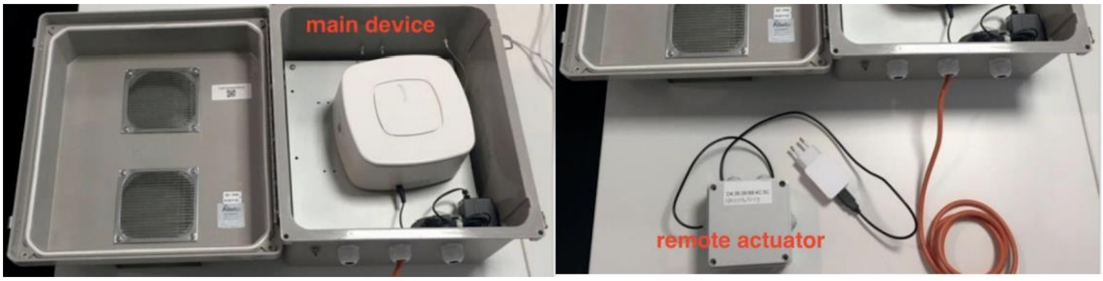

Figure 2: Scheme of Nuvap tool hardware blocks.

The tools were fixed in each room at a height of 2 meters in order to be close enough to pigs (source of pollutions), yet not too close for the animals to reach them. Furthermore, in order to allow optimal detection of indoor pollutants, the tools were positioned reasonably far away from any source of air flow.

Each control unit was equipped with several sensors, one for each parameter monitored (e.g., NH_3, PM, T, RH, etc). The unit continuously records real-time airborne pollutants concentrations and microclimatic environmental parameters. Approximately every 15 minutes an aggregate data for each parameter is transmitted to the Cloud platform, where data are easily and timely accessible for the remote control of the functioning, and for the processing and analytic purposes.

In order to manage the remote actuation of the abatement technologies a new firmware was deployed, characterised by: i) a communication system between the main device and the remote actuator and ii) an actuation algorithm based on artificial intelligence (AI).

Depending on the NH_3 and PM concentrations detected by the microclimatic control unit, a signal to open or close the contact on the remote actuator is sent. The actuation element was electrically connected to the abatement technologies, in this way it could control their functioning by opening (switch off) and closing (switch on) the contact. In particular, the air treatment systems were switched on when NH_3 and/or PM sensors detect three continuous measurements exceeding predefined threshold values, equal to 10 ppm and to 0.3 mg/m^3 for NH_3 and PM, respectively. These values were established during a workshop, organized by LIFE-MEGA partnership, after an in-depth literature research on recommended maximum exposures limits for swine and workers health (Conti and Guarino, 2021).

Animal welfare data

The evaluation of animal welfare was based on the Welfare Quality® protocol. The protocol was fine-tuned and adapted to the present project, by selecting the indicators that fit to the objectives of evaluating the effect of the environmental factors studied (basically air quality) on animal welfare. Welfare was evaluated by the observation of specific indicators mostly based on behavioral observations and pathology parameters, that are schematically reported in Figure 3.

Data were collected in each room 2-3 days after pigs reached the fattening barn and 2-3 days before going to the slaughterhouse. In total, 4 stables in each room for three fattening cycles were monitored. Only during the last two cycles the abatement systems were properly managed by the AI microclimatic tool.

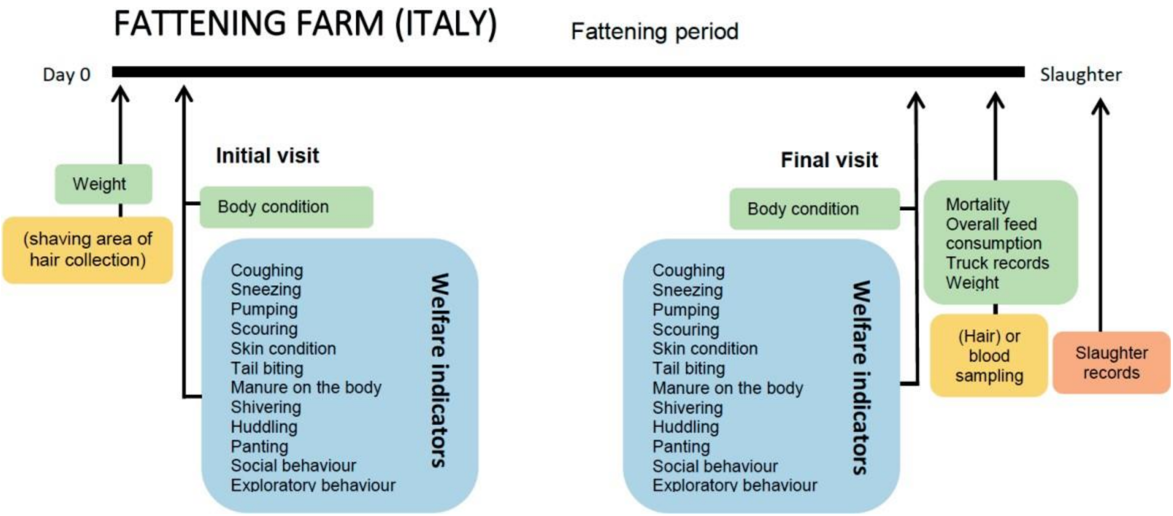

Figure 3: Scheme of data collected during animal welfare evaluations.

After data collection, a descriptive and visual analysis of the data was performed. In particular, descriptive statistics (i.e., average and standard deviations) were calculated both for each monitored fattening period and for each room.

Results and discussion

NH_3 and PM removal efficiency managed by AI microclimatic control units

During the three monitored fattening periods (each of around 3 months), that lasted throughout 2022, the dry filter was activated on average by the AI 67% of the time, whereas the wet scrubber for about 45%. During the first cycle some connection problems were encountered and their operation time was not calculated.

According to preliminary results, the dry filter was effective during cold season in reducing PM concentration with an average abatement efficiency of 60% but not in removing NH_3. Conversely, the wet scrubber prototype was effective in removing NH_3 but not PM, presenting an average NH_3 removal efficiency of 66% during cold season and 43% during warm one. In general, higher abatement efficiencies were obtained during cold months when, due to natural ventilation, windows are kept mostly closed. Instead, during hot-warm season, pollutants are more diluted due to complete windows opening. Moreover, these differences in the abatement efficiency can be mainly due to the different operational function of the scrubbers.

In Table 1 are reported NH_3 and PM average concentrations detected by the Nuvap tools in the three rooms during the second and the third fatting cycle, that took place from February till April 2022 (identified as cold season) and from May to July 2022 (warm season), respectively.

The innovation of the LIFE-MEGA project relies on the introduction of existing techniques (dry and wet scrubber) in naturally ventilated buildings. Thus, the obtained removal efficiencies could be considered a promising result. Wet scrubbers are commonly used in forced ventilation barns to treat exhaust air abating outdoor emissions with a removal efficiency up to 99% (Van der Heyden et al., 2015), so their internal application represents a novelty in the agricultural context.

Table 1: NH_3 and PM average concentrations in the three rooms detected during the second and the third fattening cycle.

Airborne pollutant	Season	Wet scrubber	Dry filter	Control
NH_3 (ppm)	Cold	0.96	8.45	9.55
	Warm	0.58	4.60	4.11
PM (µg/m³)	Cold	34.28	35.27	26.80
	Warm	11.40	17.20	10.95

Animal welfare

Overall, only slight differences were observed among the three monitored rooms in respect to the animal welfare assessment. In general, the pigs responded almost always well to all indicators of the followed welfare protocol, therefore not many differences among the treatments and control could be registered.

Regarding thermal comfort parameters (shivering, panting, huddling), no difference was observed among the 3 rooms, as all the animals scored as 0.

Among the respiratory parameters (Figure 4), coughing resulted slightly better in the treated rooms, especially during the last batched observed (Batch 4), even if no significant difference could be highlighted. As expected, during Batch 2 when the abatement systems were not properly connected to the AI tool, worse results were obtained. Instead, no improvements were registered for sneezing, as in general there were only few episodes recorded in all the rooms. Also in this case, better results were recorded during the last fattening cycle monitored. Finally, pumping was always equal to 0 in all rooms.

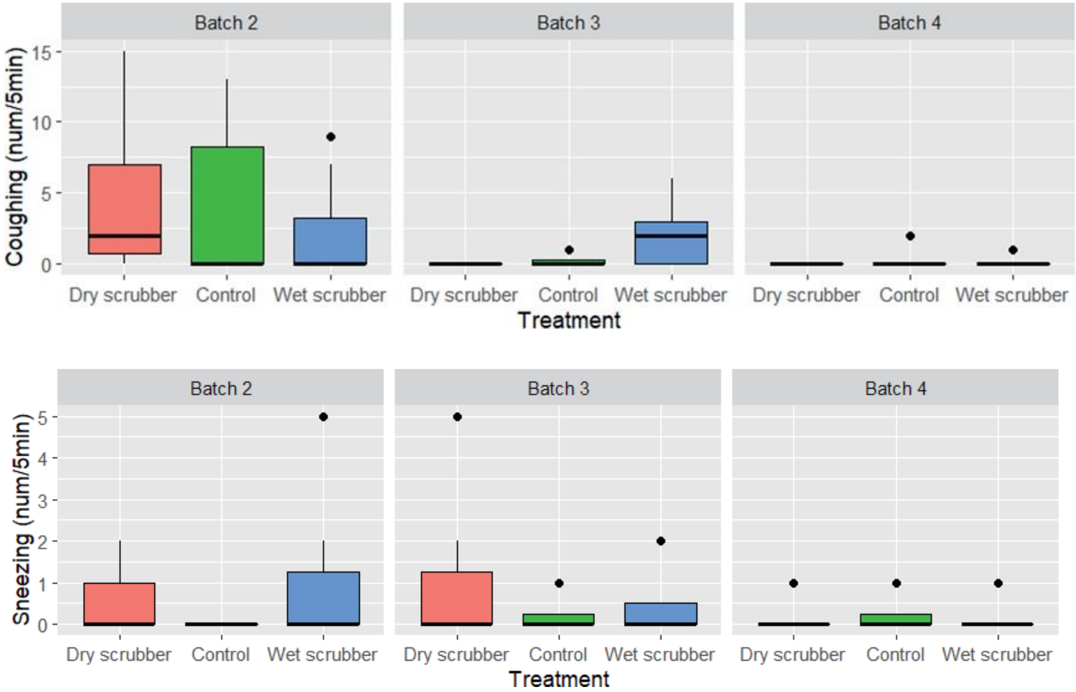

Figure 4: Average coughing (top) and sneezing (bottom) episodes in the 3 rooms during each fattening period monitored.

For scouring, manure on the body, body and tail lesions scores, no significant differences between the treatments were found during the monitored periods.

Regarding behavioural observations, average results of the last two fattening cycles are reported in Figure 5. In particular, for behaviour scans and focal observations, on average, more scan positive interactions were observed in rooms with abatement systems, even if the same difference was not observed during focal observations. This could be due to the improved air quality in the room that increases pigs' positive interactions, thus slightly improving their welfare status.

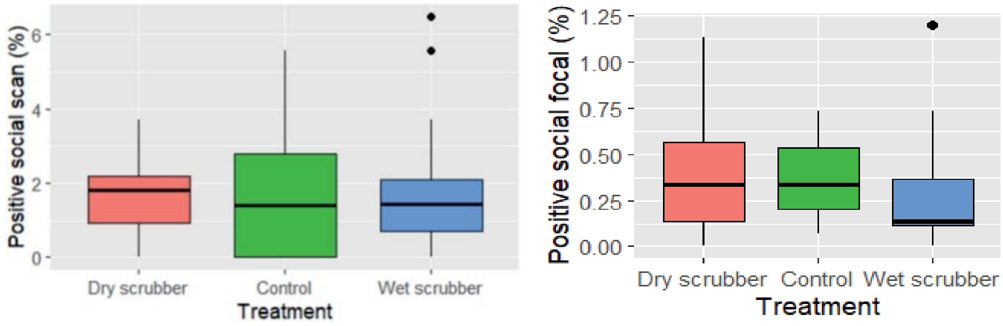

Figure 5: Average positive behaviours observations in the 3 rooms.

Regarding the percentages of ear and tail biting, also in this case the results were very similar among the treatments as very few episodes were recorded (Figure 6).

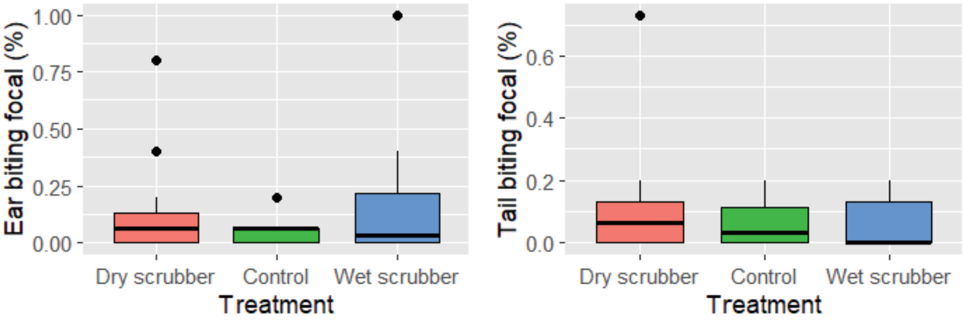

Figure 6: Average biting observations in the 3 rooms.

Similarly, also regarding the other behavioural categories, such as exploration of the pen and enrichment manipulation, any significant change was observed over time.

In the present study, no significant differences were observed among the three monitored rooms as no respiratory problems or behavioral issue are normally observed by the farmer. Moreover, it should be considered that although NH_3 and PM concentrations were reduced by the two abatement technologies, these latter did not work continuously and they resulted effective only on one air pollutants each (NH_3 for wet scrubber and PM for dry filter). Finally, the trial was conducted in a naturally ventilated building where it is more difficult to maintain controlled indoor conditions. Due to the specific context in which the trial was performed (natural ventilation) and to the air cleaning technologies used, to the authors knowledge, the results of this study are not comparable to other findings in the literature.

Even if data on animals' weight are not yet available, based on the farmer's observation and opinion a greater uniformity was observed in treated rooms. This aspect positively impressed the farmer as a greater uniformity implies grater gains at the slaughterhouse because fewer animals (those that did not reach 160 kg) are discarded.

Conclusions

Animal welfare and environment protection could not be considered as independent issues. Improving air quality is necessary, not only to reduce outdoor emissions but particularly to improve living and working conditions inside the barns. The application of only a mitigation strategy is not enough to assure the best results in terms of air quality, but other precautions such as a correct manure management and improving the nitrogen utilization in feed are fundamental. The results of this study showed that air quality in the barn could be improved satisfactorily, although further improvements can still be achieved with the enhancement of the technology, especially in the naturally ventilated barns. Regarding animal welfare, a positive aspect was that some of the indicators resulted better than in the control room, although these differences are very small probably because the building and the animals are already in a proper environment and other aspects of pigs' lives may influence the welfare response of pigs.

Acknowledgements

This project was funded by the LIFE Programme of the European Union (LIFE18 ENV/IT/000200 – LIFE MEGA).

References

Conti, C., Guarino, M. (2021) Ammonia concentration and recommended threshold values in pig farming: a review. In: *Proc. 2021 IEEE International Workshop on Metrology for Agriculture and Forestry* Trento - Bolzano, Italy, 162-166.

Conti, C., Tullo, E., Bacenetti, J., and Guarino, M. (2021) Evaluation of a wet acid scrubber and dry filter abatement technologies in pig barns by dynamic olfactometry. *Applied Sciences* 11(7), 3219.

Drummond, J.G., Curtis, S.E., Simon, J., and Norton, H.W. (1980) Effects of aerial ammonia on growth and health of young pigs. *Journal of Animal Sciences* 50:1085-1091.

EC. (2008). *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 (oj l 152, 11.6.2008, p. 1)*. https://eur-lex.europa.eu/TodayOJ/

EU. (2016). *Directive 2016/2284/ec of the european parliament and of the council of 14 december 2016 on the reduction of national emissions of certain atmospheric pollutants, amending directive 2003/35/ec and repealing directive 2001/81/ec (oj l 344, 17.12.2016, pp. 1-31)*.

Eurostat. (2018) *Agriculture, forestry and fishery statistics. Statistical book 2018 edition*. Publications Office of the European Union. https://doi.org/doi:10.2785/668439

ISMEA. (2022). *Settore suinicolo – scheda di settore*. https://www.ismeamercati.it/carni/carne-suina-salumi

Lovarelli, D., Bacenetti, J., Guarino, M. (2020) A review on dairy cattle farming: Is precision livestock farming the compromise for an environmental, economic and social sustainable production? *Journal of Cleaner Production* 262,121409

Santonja, G.G., Georgitzikis, K., Scalet, B.M., Montobbio, P., Roudier, S., and Sancho, L.D. (2017) *Best available techniques (bat) reference document for the intensive rearing of poultry or pigs*. https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC107189_IRPP_Bref_2017_published.pdf

Tullo, E., Finzi, A., and Guarino, M. (2019) Environmental impact of livestock farming and Precision Livestock Farming as a mitigation strategy. *Science of the Total Environment* 650, 2751-2760.

Van der Heyden, C., Demeyer, P., Volcke, E.I.P. (2015) Mitigating emissions from pig and poultry housing facilities through air scrubbers and biofilters: state-of-the-art and perspectives. *Biosystem Engineering* 134, 74–93.

Zhao, Y., Aarnink, A.J.A., de Jong, M.C.M., and Koerkamp, P.W.G. (2014) Airborne microorganisms from livestock production systems and their relation to dust. *Critical Reviews in Environmental Science and Technology* 44(10):1071-1128.