SMART COMPUTING SYSTEM TO MONITOR AND ABATE THE INDOOR CONCENTRATIONS OF NH_3, CH_4, AND PM IN PIG FARMS

LIFE-MEGA
LIFE18 ENV/IT/000200

LAYMAN REPORT

LIFE-MEGA project (LIFE18 ENV/IT/000200) has received funding from the LIFE programme of the European Union

Life-MEGA

THE PROJECT | PARTNERS

COORDINATOR

UNIVERSITY OF MILAN - DEPARTMENT OF ENVIRONMENTAL SCIENCE AND POLICY
Via Festa del Perdono 7 | 20122 Milan (IT)
Phone: +39 02 5032
eng.esp.unimi.it/ecm/home

The Department of Environmental Science and Policy (ESP) of the University of Milan (UMIL) is the coordinator of the Life-MEGA project. The research group involved is active in the field of the environmental impact of agricultural and zootechnical activities, including water, air, and soil pollution.

- Administrative and technical coordination of the project.
- Monitoring and evaluation of the abatement efficiency of the evaluated abatement systems in Italy.
- Validation of the NUVAP tool for microclimatic control.
- Socio-economic and environmental impact assessment.
- Contribution to technical reference documents and policy making.
- Dissemination and Networking activities.

PARTNERS

IRTA - INSTITUTE OF AGRIFOOD RESEARCH AND TECHNOLOGY
IRTA Torre Marimon 08140 Caldes de Montbui Barcelona
Phone: 93 467 40 40
www.irta.cat/en

IRTA is a research institute owned by the Government of Catalonia (Spain) ascribed to the Department of Climate Action, Food and Rural Agenda. Its general objectives are to promote research and technological development in the area of agri-food, to facilitate the transfer of scientific advances and to evaluate its own technological advances whilst seeking the utmost coordination and collaboration between the public and private sectors.

- Monitoring and evaluation of the abatement efficiency of the tested abatement systems in Spain.
- Animal performance and welfare monitoring and measurements.
- Environmental impact assessment in Spanish farms.
- Contribution to technical reference documents and policy making.
- Dissemination and Networking activities.

NUVAP
Administrative office: Via P. Giannone, 9 - 20154 Milano
Phone: +39 02 6203 2167
www.nuvap.com/join-nuvap-partner-program

Nuvap is the key partner for all the organisations willing to achieve a healthier indoor space via air quality management.

- Design, supply and installation of the microclimatic control units.
- Provision of an accessible and reliable cloud platform for indoor pollutant monitoring.
- Development of artificial intelligence to be integrated with the microclimatic control unit for the automatic activation of the emissions abatement systems.
- Technical support.

ROTA GUIDO
Technical and administrative offices with a production unit
Via 1° Maggio, 3 - 29017 Fiorenzuola D'arda (PC) - Phone: +39 0523 944 128
Via F.lli Bandiera, 4 - 26010 Corte De' Frati (CR) - Phone: +39 0372 93 119
www.rotaguido.it

Rota Guido has been active in the animal husbandry world for over 50 years. Its experience and its innovative technologies have always been aimed at the realization of modern and rational breeding farms, with particular attention to the animals' welfare. Planning of barns, plants, and livestock operations for cows, buffalos, and more. Rota Guido offers a wide range of breeding equipment for pigs, sheep and goats, poultry, and rabbits.

- Design, supply, and installation of the wet acid scrubbers.
- Development of the market, replicability, and transferability plan of the tested technical solutions.
- Technical support.

The Life-MEGA project is funded by the European Union within the Life Program 2018. The project actions lasted from 1st October 2019 to 30th September 2023. The Life-MEGA project intends to improve indoor air quality in pig barns by implementing two different abatement systems (dry filter and wet acid scrubber). The microclimatic control units continuously monitor and control the indoor concentration of NH_3, CH_4, PM, and VOC and are capable of automatically activating the functioning of the abating systems when pre-defined threshold limits were exceeded. As a consequence of reducing NH_3 and PM concentration within the barns an improvement in animal health and welfare was expected.

BACKGROUND

In addition to various civil, manufacturing, industrial, and transportation activities, intensive livestock farming also contributes to air pollutant emissions. Pigs are the widest livestock species reared in the European Union (EU), accounting for about 150 million heads. Italy and Spain present the highest densities of pig farms in Europe and actively contribute to the release of ammonia, particulate matter, GHG, and odours into the atmosphere. These pollutants other than affecting the surrounding environment, pose a potential health hazard to animals and operators inside the barns.

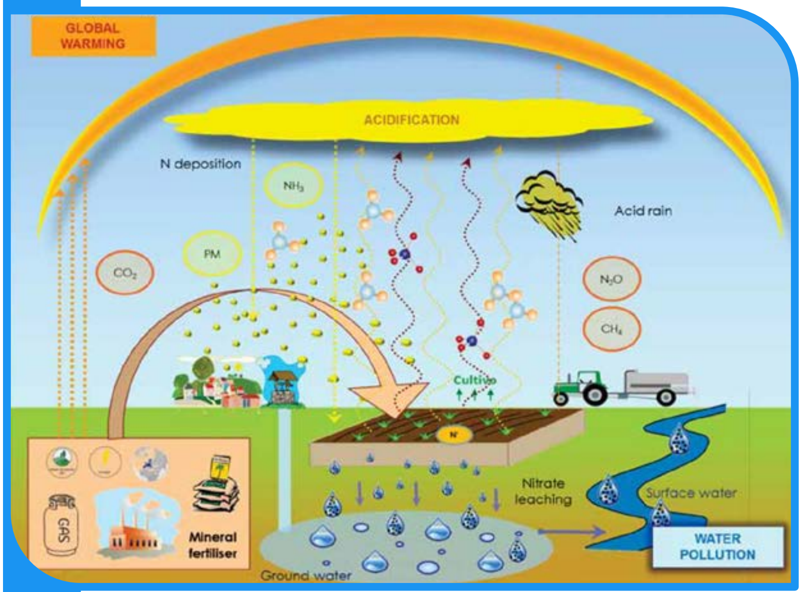

Figure 1. Effect of global warming

GHG emissions alter the Earth's energy balance between incoming solar radiation and the heat released back into space, amplifying the greenhouse effect and resulting in climate change.
Odours, besides being responsible for annoyance to nearby residents, have been defined as harmful atmospheric pollutants since they can cause airway irritation *(Conti et al., 2020)* and respiratory diseases in farmers and agricultural workers *(Maesano et al., 2019)*.

Finally, NH_3 causes a series of cascading negative effects that **i)** damage ecosystem biodiversity due to acidification and nitrogen enrichment **ii)** affect both pig health and productivity and **iii)** play a significant role in the formation of secondary particulate aerosols ($PM_{2.5}$) and secondary nitrous oxide (N_2O) (*Figure 1*).
Many mitigation strategies can be applied to limit these gaseous emissions, such as nutritional strategies, the use of manure treatment systems, and the application of air cleaning technologies that are all reported in the Best Available Techniques (BAT) reference document for the intensive rearing of poultry or pigs *(Santonja et al., 2017)*.

References

- Conti, C., Guarino, M., & Bacenetti, J. (2020). Measurements techniques and models to assess odor annoyance: A review. Environment International, 134, 105261.

- Maesano, C. N., Caillaud, D., Youssouf, H., Banerjee, S., Prud'Homme, J., Audi, C., ... & Annesi-Maesano, I. (2019). Indoor exposure to particulate matter and volatile organic com pounds in dwellings and workplaces and respiratory health in French farmers. Multidisciplinary Respiratory Medicine, 14(1), 1-12.

- 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. EUR 28674 EN, 11, 898.

PROJECT OBJECTIVES

The Life-MEGA project aims to monitor and improve, thanks to the application of two air treatment technologies, the indoor air quality of four pig barns, two located in Lombardy and two in Catalonia, areas with a high vocation for pig farming. Life-MEGA project intends to implement in pig houses a microclimatic control unit able to continuously monitor the environmental parameters such as temperature and humidity, other than the concentration of NH_3, CH_4, PM, and VOCs with the possibility of activating two different abatement systems to control indoor airborne pollutants. The two technologies tested were:

i) A prototype of the wet acid scrubber, washing and recirculating air inside the barns, developed by Rota Guido partner;
ii) A commercial dry filter already used in other industrial contexts, such as bakeries. These two systems were respectively installed in two Italian fattening farms and two Spanish weaning farms.

In particular, in *Figure 2* the project objectives are illustrated. Life-MEGA intends to:

1) Develop and assess the wet acid scrubber prototype aimed at improving the indoor air quality.
2) Demonstrate the usefulness of the dry filter for cleaning the air inside pig barns.
3) Develop an online monitoring control unit able to activate the abatement systems, to maintain the concentration of NH_3, and PM below a threshold value.
4) Evaluate animal welfare and performance.
5) Evaluate, using a Life Cycle Assessment (LCA) approach, the environmental performance of the proposed solutions.
6) Evaluate the socio-economic impact of the abatement systems.
7) Transfer the results to the largest numbers of farmers and actors in the pig sector.
8) Contribute to the implementation of the UNECE Code of Good Practice for reducing emissions from agriculture promoting low-emission animal housing systems.

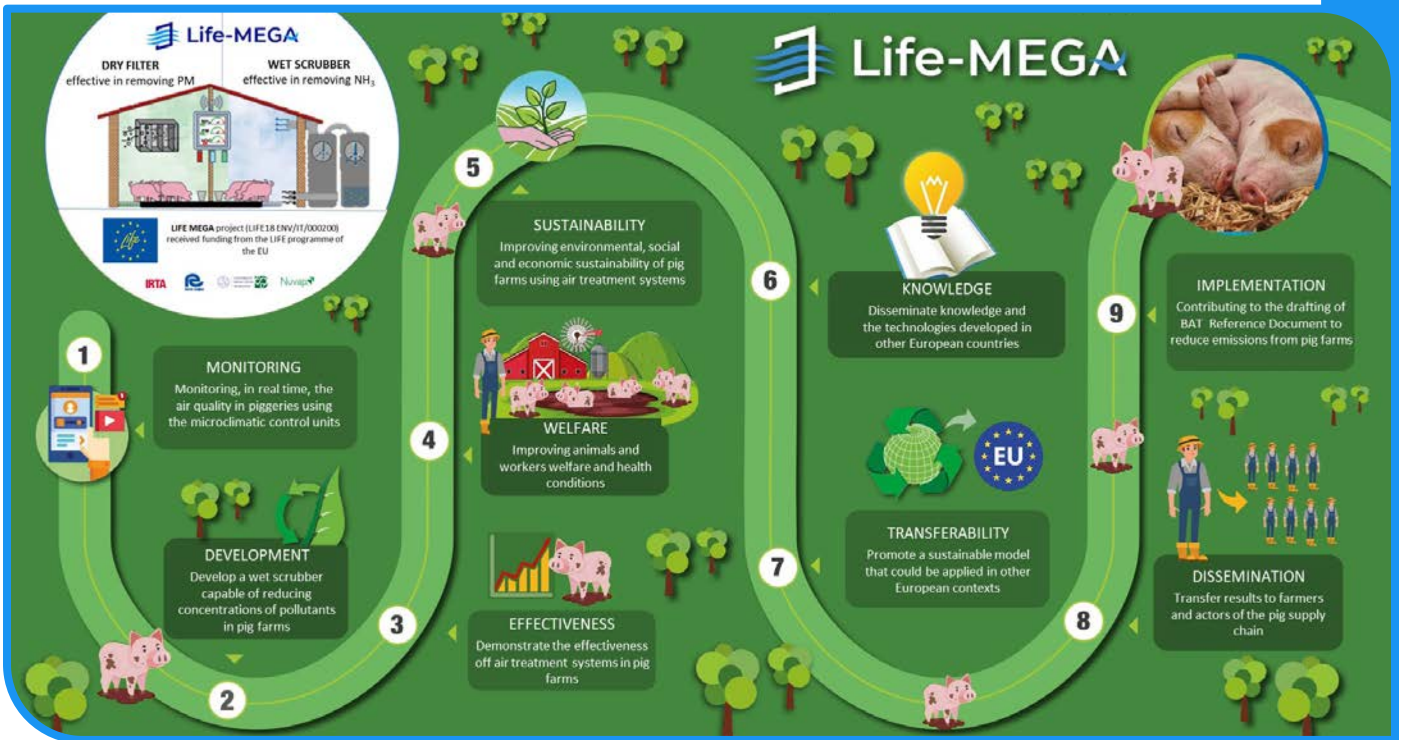

Figure 2. The project objectives

PROJECT ACTIONS

Project activities were carried out in Italy and Spain, areas with high pig stocking density. The impact and side effects of intensive pig farming play a key role in the environment, human health, and economy.

The use of mitigation strategies, such as air cleaning systems, is fundamental to reducing gas emissions in the environment and consequently providing environmental, animal, and operator welfare benefits.

Life-MEGA project tested two abatement technologies (a wet acid scrubber and a dry filter) for treating air inside pig farms that were respectively installed in two Italian and Spanish farms. The indoor pollutants concentration was monitored in real-time by a microclimatic control unit able to automatically activate the functioning of the abatement systems. In each farm, these technologies were installed in three different rooms as reported in *Figure 3*.

Life-MEGA project evaluated the abatement efficiency of the air cleaning systems using the validated monitoring control units. As a consequence of improved indoor air quality an increased animal welfare and health status was expected and this aspect was evaluated by applying the Welfare Quality protocol.

Finally, also the environmental and socio-economic impacts of the air cleaning systems were considered. The LCA approach was used to assess the environmental performance of the tested solutions, whereas S-LCA and Net Present Value and Pay-Back Time were applied for the socio-economic aspects.

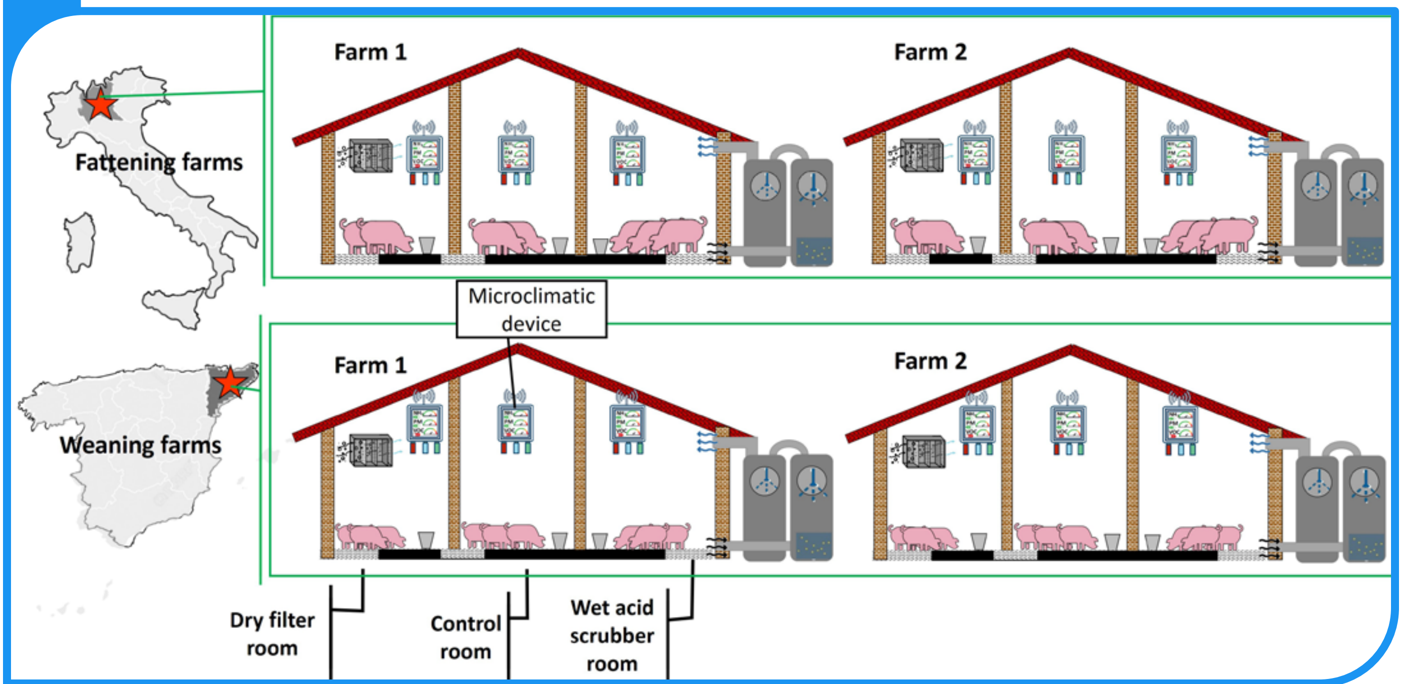

Figure 3. Scheme of the installations in the pig farms

WHAT HAS BEEN MONITORED AND EVALUATED IN THE PROJECT?

The main objective of Life-MEGA is to implement an innovative system to monitor and abate emissions of NH_3, CH_4, PM, and VOCs in pig barns.
The environmental benefits of using air cleaning systems (wet and dry) have been evaluated quantitatively based on valid and scientifically tested methodologies.

The Department of Environmental Science and Policy of the University of Milan (project coordinator) in cooperation with project partners such as Rota Guido Srl, Nuvap, and the Institute of Agrifood Research and Technology (IRTA) developed two different emission abatement technologies that were tested in conjunction with an online microclimatic tool. The activities were implemented in four different host farms located in Lombardy region, Italy, and Catalonia region, Spain.

During the project, validation and monitoring protocols were developed to compare the air treatment technique with usual farming practices. The use of these monitoring procedures on all farms involved in the project resulted in comparable data and reliable information.

DESCRIPTION OF THE TECHNOLOGIES

1) Wet acid scrubber prototype

The two prototypes of wet acid scrubber were manufactured and subsequently installed by Rota Guido Srl in Italian and Spanish pig farms. The prototype features two air treatment towers (one for abatement of ammonia and one for dust/odour), each with a capacity of 250 liters. The first tower, connected to the air inlet, was filled with water to capture dust and odours, while the second tower was with a citric acid solution (15%) to capture NH_3. The intensive contact between the air and sprayed liquids enables soluble pollutants to pass from the gas to the liquid phase. Thus, the air gets withdrawn from the pigsty, it gets washed thanks to the passage through the two towers, and it is finally returned to the barn *(Figure 4)*.

Figure 4. Wet acid scrubber prototype

2) Dry filter system

The dry filter was a commercial product provided by the company Tecnosida Srl. The system consists of cell or bag filters and cartridge filters that thanks to their robustness, low-pressure drops, high efficiency, and low cost are suitable for use in any air filtration context.
The operating principle of the dry filter is based on the interposition of serial filtering panels with different retention capacities. This arrangement, in addition to ensuring a remarkable separation capacity, allows filters to retain large amounts of dust. The air is then returned to the barn by a blower *(Figure 5)*.

Figure 5. Dry filter system that was installed in the Italian pig farm

3) Microclimatic control units

The indoor air quality of the three rooms was continuously monitored by a microclimatic control unit developed by Nuvap's partner.
To resist harsh environments, such as piggeries, Nuvap tools needed to undergo a waterproofing process, be encapsulated in metal cases, and be equipped with particular sensors, able to withstand the a forementioned environmental constraints.
The Nuvap tool was designed with two main hardware blocks *(Figure 6)*:

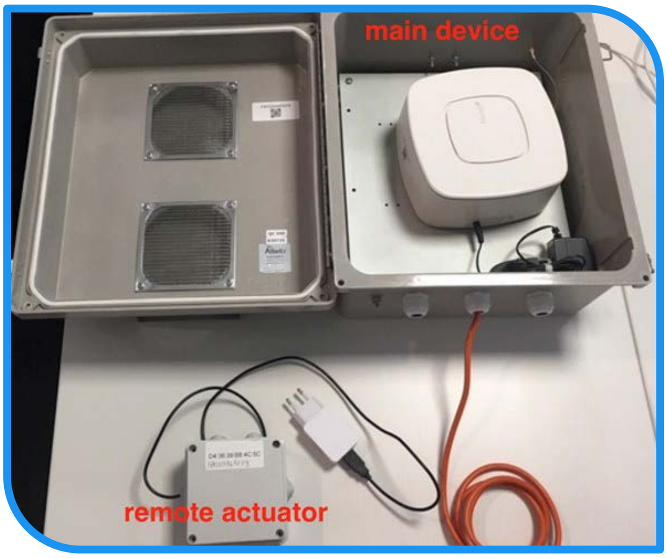

Figure 6. Scheme of Nuvap tool hardware blocks

1) A microclimatic control unit (indicated as the 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 of a communication element (BLTE) and an actuation element (relay) is used to activate the functioning of the air treatment technologies.

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 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 processing and analytic purposes.

To manage the remote actuation of the abatement technologies a new firmware was deployed. 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. 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 0.3 mg/m^3 for NH_3 and PM, respectively.

THE PIG FARMS INVOLVED

The activities were carried out in 4 pig farms, 2 located in Lombardy (fattening) and 2 in Catalonia (weaning), with typical characteristics of the Italian and Spain context, to allow a prompt diffusion of the results in the sector.

The first Italian farm was located in Tavazzano con Villavesco (LO), while the second farm was located in Corteolona e Genzone (PV). They present a yearly production of 10,000 and 13,000 fattening pigs (170 kg live weight), respectively. The pig farms are naturally ventilated, with different housing, feeding, and removal of waste systems.

Animals located on the first farm were housed on concrete floor with slatted floor in outdoor runs and the slurry was removed with a flushing system. The animals were fed twice a day with swill. The trial was conducted in three rooms with a capacity of around 550 pigs each.

Animals located in the second farm were housed on a fully slatted floor and slurry was collected under the flooring surface in a pit equipped with the vacuum system.
Pigs were fed twice a day with swill. The trial was conducted in three rooms with a capacity of around 430 pigs each.

The first farm in Catalonia was a weaning farm with a total capacity of 9600 piglets, 400 piglets per room, located in Santa Eulàlia (Osona). The second farm was located in Oristà (Osona) and its capacity was 2500 sows and 7800 piglets, 200 piglets per room. The two farms have at least 3 identical barns with forced ventilation (two fans each). The speed of the fans is regulated according to the temperature and humidity inside the barns.

MATERIAL and METHODS

For each farm - one located in Italy and one in Spain - three rooms with the same characteristics (i.e. number and category of animals, management, etc.) were simultaneously monitored via the NUVAP tools: a control room, a room equipped with a dry filter module, and a room equipped with a wet acid scrubber prototype. Data collected by the NUVAP tools were then compared with data recorded through additional instruments (e.g. Haz Dust EPAM 5000, Dräger X-AM 5000) during the monitoring campaigns and according to defined protocols.

Instead in Spain, ammonia and relative humidity were measured with a Reiken Keiki GX-6000 sensor and a hygrometer TESTO 440, respectively. Three samples were taken for each of the rooms (wet acid scrubber room, dry filter room, and control room).
Emissions outside the barns have been performed in triplicate in each of the air outlets (fan windows). Airflow has been measured with a TS AirFlow, Model TA410. The filling level of the wet acid scrubber and pH of the solutions of each of the towers, as well as power consumption, were also measured. Liquid samples of each tower were taken to analyse ammonia content in the laboratory.

In Spain, GHG emission sampling has been performed weekly throughout the entire period (6 piglets' batches in each farm). Gas samples were taken inside the rooms, and CH_4, CO_2, and N_2O analysis was performed in the laboratory with a gas-chromatograph GC (Agilent 7820° with an FID and ECD detector).

1) Instruments used during monitoring campaigns

In Italy, PM and NH_3 concentrations in the wet, dry, and control rooms were measured using Haz Dust EPAM 5000 and Draeger X-am 5000 instruments, respectively.

Haz Dust EPAM 5000 combines the traditional gravimetric technique with "near-forward light scattering" in one portable, compact, and lightweight device.

Dräger X-am 5000 is a portable gas detection instrument for the continuous monitoring of the concentration of several gases in the ambient air within the working area and in explosion-hazard areas. The NH_3 sensor has a measuring range from 0 to 300 ppm.

In Spain, a Reiken Keiki GX-6000 sensor was used to measure NH_3 in the different rooms. The particulate matter $PM_{2.5}$ and PM_{10} were sampled using SKC UNIVERSAL 224 – PCMTX8 bombs and BGI cyclones with glass fibers filter, with an aspiration time of 1 hour. Concretely, the $PM_{2.5}$ was measured with a BGI4L cyclone, with a 2.2 L/min flow, and the PM_{10} was measured with a GK2.69, with a flow of 1.6 L/min.

The data collected were used to:

- Validate the NUVAP microclimatic control units, comparing the data obtained with the data recorded by the NUVAP.
- Evaluate the performances of the dry filter and wet acid scrubber.

2) The VERA test protocols

The VERA protocol was used to test the wet acid scrubber NH_3 removal efficiency. In the VERA protocol, the abatement efficacy was estimated using the acid trap system. The traps consisted of two Dreschel traps each containing 300 ml of 1% boric acid solution, that capture ammonia. The inlet and outlet tubes of the wet acid scrubber were connected with two different acid traps *(Figure 7)*. Then the amounts of ammonia fixed by the boric acid solution were titrated with sulfuric acid and, finally, compared to evaluate the NH_3 removal efficiency.

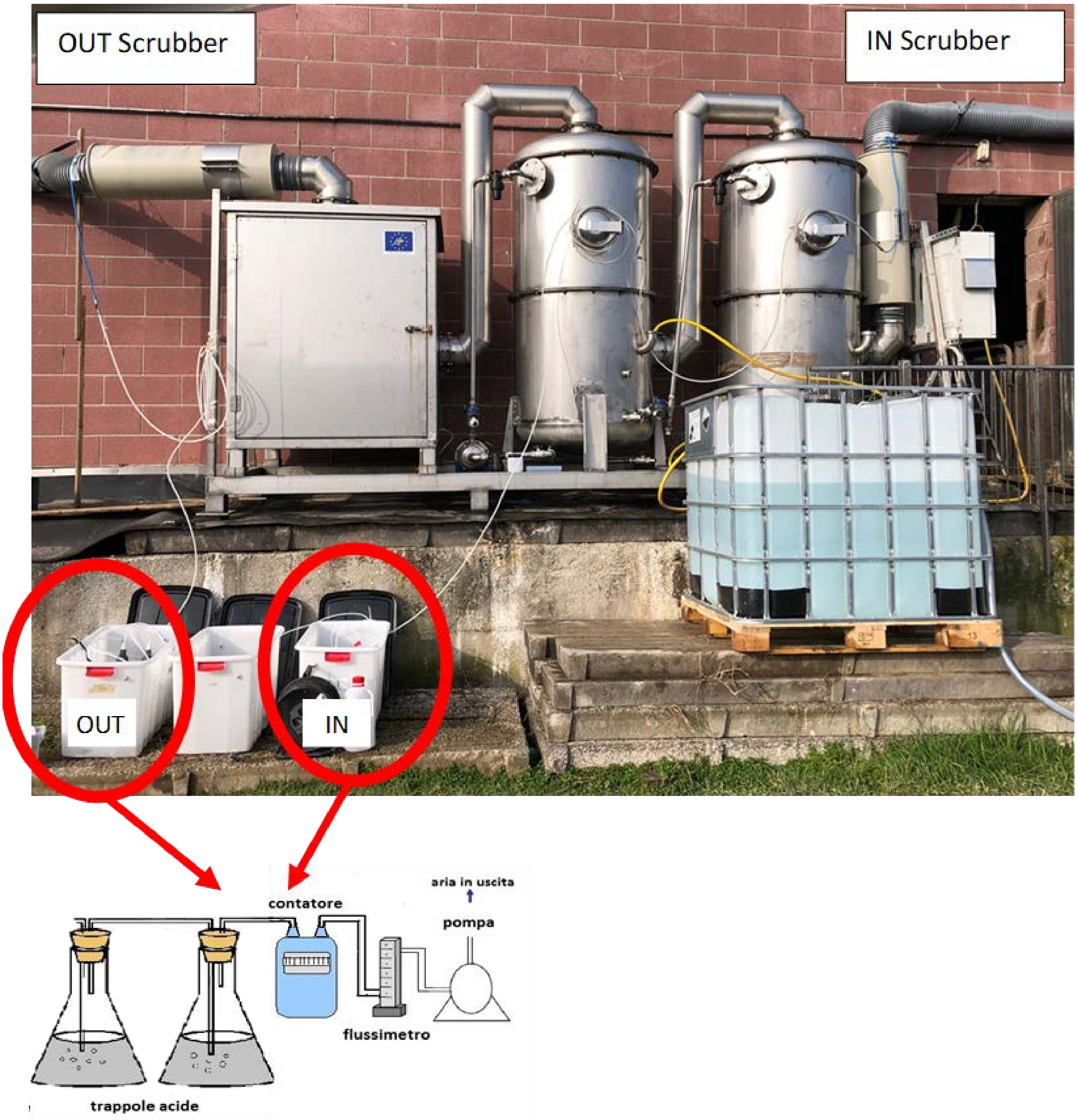

Figure 7. The acid trap system connected to the wet acid scrubber

3) Olfactometry analysis

Odours were monitored through olfactometric measurements with a panel of experts, according to EN 13725. Air samples were collected from the inlet and outlet of the wet acid scrubber. Average odour concentrations were then compared to determine the odour abatement efficiency of the wet system. Regarding the dry filter, as it was not possible to collect air samples from the inlet and outlet the average odour concentration measured during the olfactometric analysis was compared to those obtained from the control room.

Finally, to compare results among the three rooms, air samples collected from the wet acid scrubber outlet were compared with average odour concentrations evaluated in the other two rooms.

4) Welfare Quality® protocol

The effect of the two different innovative approaches on animal welfare was evaluated using an adaptation of the Welfare Quality® protocol.

In fact, in intensive pig production conditions, environmental factors such as air quality do have a direct effect on different welfare dimensions. Welfare was evaluated by the observation of specific indicators mostly based on behavioural observations and pathology parameters, that are schematically reported in *Figure 8* (fattening farm) and *Figure 9* (weaning farm).

Saliva samples were also collected to evaluate cortisol levels as a stress indicator.

Data were collected in each room 2-3 days after pigs reached the fattening barn, at mid-cycle, and 2-3 days before going to the slaughterhouse.

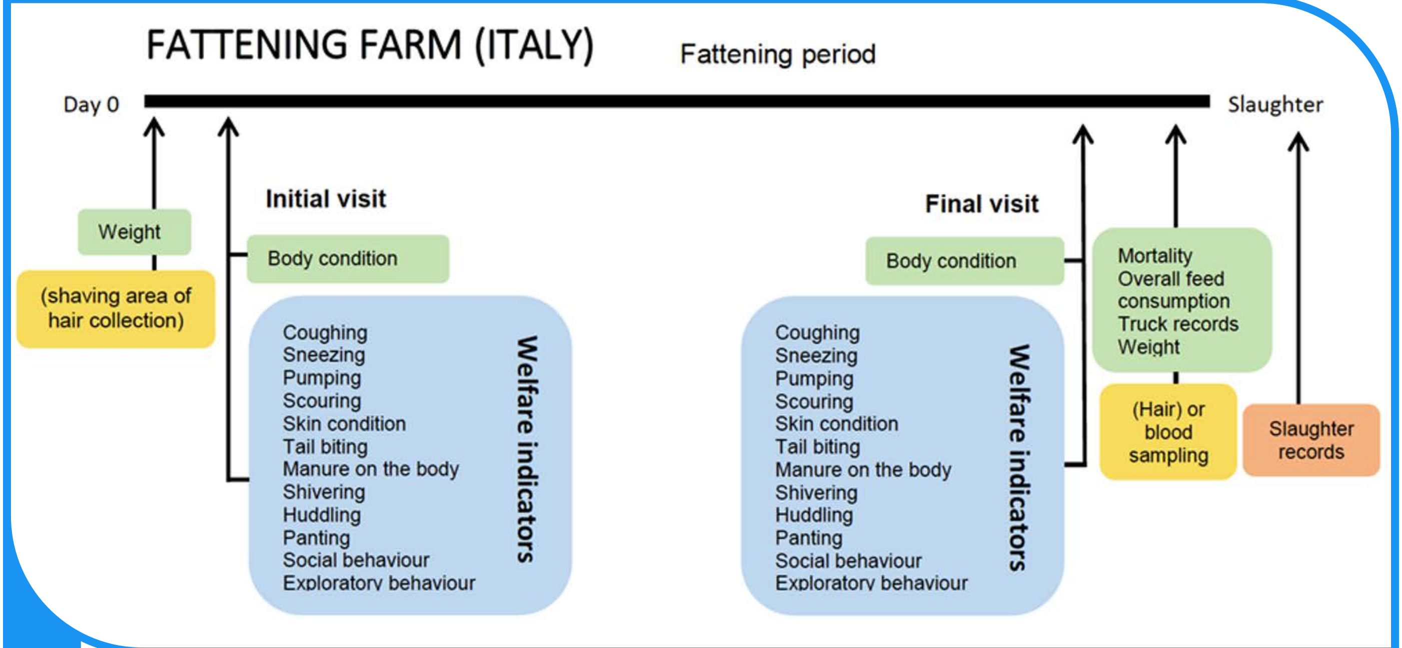

Figure 8. Scheme of data collected during animal welfare evaluations

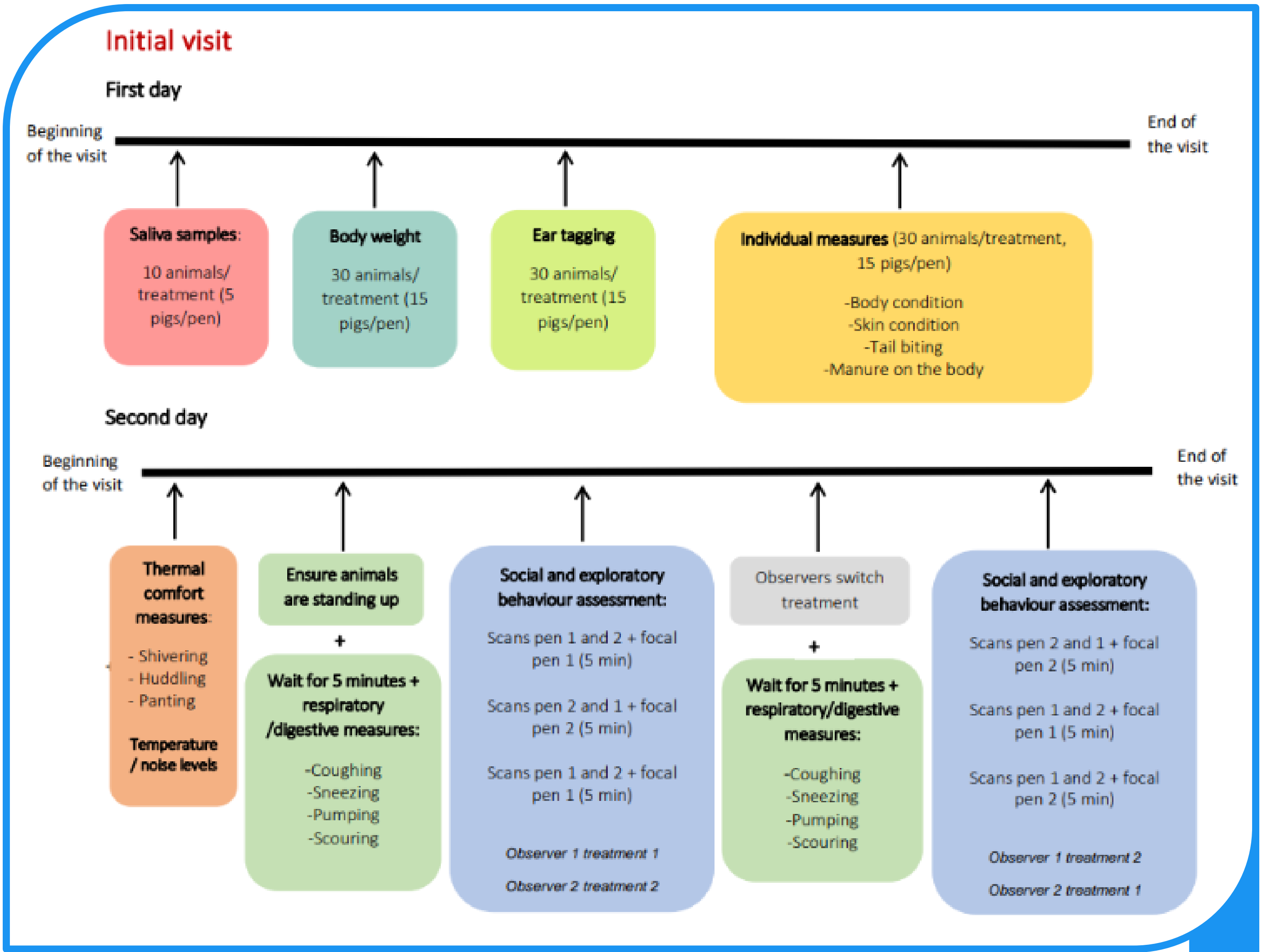

Figure 9. Scheme of data collection during animal welfare evaluations at the Spanish weaning farms

5) LCA and socio-economic analysis

LCA study was performed to compare a Baseline scenario (current pig production system) to an Alternative scenario (pig production envisaging the introduction of air cleaning technologies). The difference between the baseline and the alternative scenarios was due to the adoption in the latter of different methods of air treatment of the pig housing facilities.

This environmental assessment was completed with a detailed economic feasibility study. Finally, a social study considered and examined, through questionnaires, farmers' perceptions of the main constraints and benefits of the use of these two abatement systems in their farming operations.

Removal efficiencies of the two air abatement systems

▪ NH_3 and PM results

In Italy, considering all the fattening cycles monitored, the highest NH_3 removal efficiency obtained using the wet acid scrubber was >90%. Applying the dry filter system, the maximum NH_3 abatement efficiency was 22%. Regarding PM_{10}, the wet acid scrubber was capable of abating to 49%, whereas the dry filter till 51%. Results are shown in *Table 1*.

Table 1. *Removal efficiency (%) of the two air abatement systems in Italy*

Removal efficiency	Wet acid scrubber		Dry filter	
	NH_3	PM_{10}	NH_3	PM_{10}
Maximum	>90	49	22	51
Average	61	45	21	44

In Spain, the piglet batch that performed better presented an NH_3 removal efficiency of 79% with the wet acid scrubber and 48% with the dry filter. PM_{10} reduction was also remarkable, see *Table 2*. Despite other batches presenting much lower removal efficiencies, the average N recovered in the acidic tank was between 32- 52 g N/d.

Table 2. *Removal efficiency (%) of the two air abatement systems in Spain*

Removal efficiency	Wet acid scrubber		Dry filter	
	NH_3	PM_{10}	NH_3	PM_{10}
Maximum	79	100	48	100
Minimum	23	77	28	67
Average	49	92	37	89

▪ GHG results

In Spain, the wet acid scrubber removal efficiency for CO_2 and N_2O presented small figures, 5%, and 13%, respectively, whereas for CH_4 no abatement was observed. On the contrary, the dry filter performed better with average removal efficiencies of 28%, 42%, and 27%, for CO_2, CH_4, and N_2O, respectively. Results are shown in *Table 3*.

Table 3. *Removal efficiency (%) of the two air abatement systems in Spain*

Removal efficiency	Wet acid scrubber			Dry filter		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Maximum	13	-	23	48	62	33
Minimum	9	-	2	10	15	17
Average	5	-	13	28	42	27

▪ Odour results

In *Table 4* the average odor concentrations (ouE m^{-3}), measured by olfactometric analysis in the dry filter, wet acid scrubber, and control rooms, are shown.

Table 4. *Average odour concentration (ouE m^{-3})*

	Dry Filter	Control	IN wet acid scrubber	OUT wet acid scrubber
Average	3,417	5,047	3,851	2,585

Generally, the dry filter room registered the lowest values compared to the control room. Compared to the wet acid scrubber (OUT) the dry filter room showed higher concentrations of odour.
In Italy, considering all the fattening cycles monitored, the highest odour removal efficiency obtained using the wet acid scrubber was 90%, whereas applying the dry filter system was 80%. In *Table 5*, are reported maximum and average abatement efficiencies for the two air treatment systems.

Table 5. *Odour removal efficiency (%) of the two air abatement systems in Italy*

Removal efficiency	Wet acid scrubber	Dry filter
Maximum	90	80
Average	36	34.5

Animal welfare results

In Italy overall, only slight differences were observed among the three monitored rooms (dry filter, wet acid scrubber, and control) concerning 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. Only for respiratory parameters and behavioral observations were slight differences seen among the three rooms. In particular, among the respiratory parameters, coughing resulted slightly better in the treated rooms, even if no significant difference could be highlighted.

Regarding behavioural observations, 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. Cortisol levels were found to increase over time in the control room, whereas, in the dry filter room, there was no increase, indicating similar levels of stress in the first and final samples. For the wet acid scrubber treatment, the increase over time was also lower as compared to the control group.

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 greater uniformity implies greater gains at the slaughterhouse because fewer animals (those that did not reach 160 kg) are discarded.

In Spain, similar results as those reported in the fattening farm were found. From the two treatments, dry filter was the one having a more pronounced significant effect on welfare parameters.
Basically, the dry filter presented a positive effect on the reduction of manure on the body, ear lesions, and negative social behaviour like aggressions over time. In contrast, no effect of the treatments was found for tail lesions, which is at present an iceberg indicator for welfare, since the pressure to stop tail docking in the EU has increased. This lack of difference between treatments could be associated with the fact that the individuals in the study were tail-docked, and tail-biting events are normally less relevant. For that reason, the positive effect of the dry filter in reducing ear lesions becomes more relevant, since the incidence of ear lesions in docked pigs has been found to be higher than in undocked pigs. For the wet acid scrubber, these positive effects were not significant, although a tendency for a reduced cortisol level in one of the batches was found. For the other indicators evaluated, such as body weight and average gain, the effect of the batch was more pronounced than those of treatment (this is the variability between initial weights in the animals probably masked the effect of treatment).

In conclusion, the treatments, especially the dry filter, presented a positive impact on some of the welfare indicators (manure on the body, ear lesions, social behaviour). However, the impacts in other indicators, like the ones more related to performance, were not significant, probably due to the high variability of the different batches evaluated. More studies would be required to gain further knowledge.

Life cycle assessment of the studied solutions for NH_3, GHG, PM, and VOCs reduction

Data from the project were used to implement a life cycle assessment (LCA) to evaluate the environmental impact of these two abatement technologies. From LCA study, both tested technologies showed their potential to reduce emissions in the pig housing stage, which affected all those categories affected by air pollutant emissions, such as particulate matter formation, acidification, and eutrophication.
At the same time, various trade-offs have been observed between the categories that are affected

by the emission abatement and those that are instead more linked to energy and resource use. In fact, both air treatment systems need consumables for their operation, and these involve an additional impact on the system compared to the base scenario. When considering the balance between emissions avoided and trade-offs generated, the dry filter was found to be the best solution.

In detail, in Italian farms, the dry filter has more positive environmental performances than the wet acid scrubber for three reasons:

1) The impact categories positively influenced in the dry filter scenario are always more than those in the wet acid scrubber scenario. In fact, the latter has led to reductions in impact only for two categories, namely particulate matter formation potential and terrestrial eutrophication, while the dry filter has led to improvements, albeit small, also for other categories including climate change, acidification, marine eutrophication, and terrestrial ecotoxicity.

2) For the two categories improved also by the wet acid scrubber, the dry filter has, in any case, achieved higher mitigations: for PM formation a maximum of -25% and -18% in farms A and B against -14% and -10% in the wet acid scrubber scenario; and for terrestrial eutrophication a maximum of -24% and -16% in farms A and B versus -18% and -12% in the wet acid scrubber scenario.

3) The impact categories are not influenced by the emissions abatement given by the machinery. For these, in fact, in the wet acid scrubber scenario, there are non-negligible increases in the impact, which in the worst case (Farm A, maximum emissions reduction scenario) are even greater than 50% for ozone depletion, ionizing radiation, fossil resource use and even greater of 100% for mineral and metal resource use. In the case of the dry filter, however, these increases are very limited, always less than 5% across categories, farms, and efficiencies scenarios.

Instead in the Spanish alternative scenarios, wet acid scrubber was more efficient reducing ammonia emissions compared to the dry filter, which was related to an improvement in different impact categories.
Particulate matter and terrestrial eutrophication reduced the impact by 9.66% and 1.80% considering the maximum emissions abatement scenario. Also, marine eutrophication, but to a lesser extent (0.16%). Ammonia emissions reduction had also an impact on cancer human toxicity, acidification, and freshwater ecotoxicity, but this was overwritten by the increase in impact to these categories coming from the consumables used for the wet acid scrubber operation, and specifically citric acid consumption. Similar results are achieved considering the median emissions abatement scenario.

While reducing impact for the abovementioned categories, both wet acid scrubber and dry filter add impact over the baseline scenario for all remaining categories. This is because the implementation of these technologies involves extra energy (electricity), infrastructure, and, in the case of wet acid scrubber, also consumables (citric acid and water). This added impact was greater in the case of wet acid scrubber than in the dry filter.

The dry filter showed less efficiency in the removal of ammonia, but it also added less impact to the overall results for each indicator (<1% contribution to all indicators). Moreover, results obtained showed a reduction in methane emission in the dry filter scenario, which had an effect in considerably reducing the potential impact to climate change.

In conclusion, air treatment systems are both environmentally interesting technologies and can bring benefits, especially in areas where eutrophication and particulate matter formation are locally relevant issues.
At the same time, these alone do not solve the problem of the environmental impact of pig farming, which requires various interventions at different levels of the supply chain.

DISSEMINATION

An important aspect of the project activities was the dissemination and transfer of the results obtained. The main communication media used were:

- Website
- Social media (Instagram, Facebook, LinkedIn, Twitter, and YouTube channel)
- Newsletters
- Dissemination events, such as workshops and conferences
- Videos
- Scientific and technical publications
- Brochures and leaflets
- Poster and oral presentations at national and international conferences
- Participation in sector fairs and agricultural exhibitions

Figure 10. Kick-off meeting

Figure 11. General steering committee meeting

TRANSFER AND FUTURE PERSPECTIVES

The actual prevalence of air scrubbing in pig farms in the EU is currently unknown. In north-continental countries, such as Belgium, Denmark, Germany, and the Netherlands, the implementation is quite widespread and even mandatory in some specific contexts (*Van der Heyden et al., 2015*), and it is estimated that the implementation rate affects about 35% of the total number of pigs housed. In the other Member States, on the other hand, although some of them play an important role in the sector, among which Italy and Spain stand out, the adoption of these technologies is practically zero.

Moreover, according to Eurostat, the majority of pigs and sows in the European Union, i.e. between 70% and 80%, are reared on farms with more than 1,000 animals, reflecting intensive farming practices.

For both environmental and economic reasons, it is reasonable to assume that it is precisely large farms that could be affected by the future introduction of air treatment technologies. As a result, there are huge transfer opportunities for the tested technologies that can affect up to thousands of pig farms and millions of pig heads, leading to significant and widespread reductions in air pollutant emissions across the EU, and thus to improvements in air quality.

A single fattening pig, according to estimates by the European Environment Agency, is responsible for an average annual emission of about 2 kg of NH_3 and between 0.1 and 0.2 kg of PM_{10} from the housing phase alone (i.e. excluding manure storage, treatment, and field application). Starting from this data and combining it with the pig population in the EU, it is easy to estimate how emission abatements in the order of those obtained by the project could heavily affect the overall emissions of these pollutants if the technologies were implemented on a large scale (*Costantini et al., 2020*).

The environmental performance achieved in this project could be improved in the future thanks to optimizations in operations that allow for a better balance between ammonia and particulate emissions abatement and consumables use (i.e., electricity, and acid solution for the wet acid scrubber). However, the energy consumption of the two systems, which to some extent represents a trade-off with the environmental benefit of reducing emissions, will have less and less impact in the long term, as the EU aims to steadily increase the share of renewable energy in the energy mix at the same pace.

As far as GHG are concerned, no direct emission reduction effects of the wet acid scrubber were found, but the reduction of ammonia emissions has a positive effect on indirect N_2O emissions, which can occur after ammonia soil re-deposition. The dry filter, on the other hand, showed interesting reductions of CH_4 in the experimental field tests carried out on piglets in Spain. Even if the chemical-physical principle of this result is not completely clear, it is certainly an issue that deserves further investigation in order to support its installation on farms.

As shown by the economic analyses carried out, the relatively high implementation and running costs currently represent the main obstacle to the widespread application of air treatment technology in pig farms in the EU, especially for the wet acid scrubber.
However, its diffusion in north-continental countries proves that this technique is economically viable in intensive livestock systems. The stainless steel prototype tested in the project should be redesigned in a plastic material, such as PVC. In this way, the investment for its installation could be reduced. Furthermore, during the project, thanks to a choice experiment carried out among consumers of dry-cured ham in Italy, a certain propensity to pay for products coming from farming

practices that limit pollutant emissions emerged (*Mazzocchi et al., 2022*).
All actors in the supply chain should then focus on effective communication strategies regarding environmental commitment to obtain a premium price that will at least partially recover the costs incurred by the farmers for the implementation of scrubbers.

For the wet acid scrubber, the reuse of the effluent solution as fertilizer is also a factor that can influence the decision of farmers towards the implementation of this technology.
Future research should focus on agronomic and environmental assessments regarding scrubber discharge solution use as fertilizer in the open field, which has remained outside the scope of the present project.

Last but not least, it should be noted that the indirect environmental cost for society linked to the emission of ammonia and particulates is estimated to be on average 17 €/kg and 26.6 €/kg of kg emitted by ammonia and particulates < 10 μm respectively (*De Bruyn et al., 2018*).

In conclusion, the opportunities are there for technology transfer and scrubbers' ever-increasing implementation, which would ultimately have environmental and economic benefits within farms and far beyond.

References

- Costantini, M., Bacenetti, J., Coppola, G., Orsi, L., Ganzaroli, A., & Guarino, M. (2020). Improvement of human health and environmental costs in the European Union by air scrubbers in intensive pig farming. Journal of Cleaner Production, 275, 124007.

- De Bruyn S., M. Bijleveld, L. de Graaff, E. Schep, A. Schroten, R. Vergeer, S. Ahdour. Environmental Prices Handbook – EU28 Version. Publication Code: 18.7N54.125. CE Delft, Delft (2018)

- European Environmental Agency, 2019. EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019, 3, B - Manure management.

- Mazzocchi C., Orsi L., Zilia F., Costantini M., Bacenetti J., 2022. Consumer awareness of sustainable supply chains: A choice experiment on Parma ham PDO, Science of The Total Environment, Volume 836, 155602.

- Van der Heyden, C., Demeyer, P., Volke, E.I.P., 2015. Mitigating emissions from pig and poultry housing facilities through air scrubbers and biofilters: state-of-the-art and perspectives. Biosyst. Eng. 134, 74-93.

Life-MEGA project

SMART COMPUTING SYSTEM TO MONITOR AND ABATE THE INDOOR CONCENTRATIONS OF NH_3, CH_4, AND PM IN PIG FARMS

Life Program 2018, Life-MEGA LIFE18 ENV/IT/000200

DURATION: 01/10/2019 – 30/09/2023

PROJECT COST: 1,729,272 €

EU CONTRIBUTION: 918,909 € (53.14%)

Contacts:

lifemega.unimi.it - lifemega@unimi.it

LIFE-MEGA project (LIFE18 ENV/IT/000200) has received
funding from the LIFE programme of the European Union