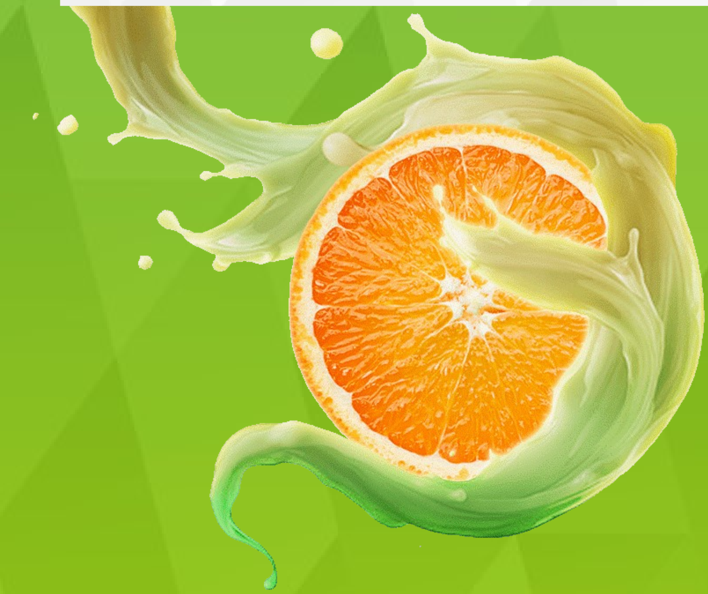
Proceedings

12th International Conference on Life Cycle Assessment of Food

TOWARDS SUSTAINABLE AGRI - FOOD SYSTEMS

13-16 OCTOBER 2020
VIRTUAL FROM BERLIN, GERMANY



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Proceedings

12th International Conference

on Life Cycle Assessment of Food

LCAFood2020

13-16 October 2020, Berlin Virtually, Germany

Editors: Ulrike Eberle, Sergiy Smetana, Ulrike Bos

Technical editors*: Dusan Ristic, Sayed Mahdi Hossaini

* - authors' formatting of papers and abstracts is preserved

Please cite this publication as:
Eberle, U., Smetana, S., Bos, U. (Eds.), 2020. 12th International Conference on Life Cycle Assessment of Food (LCAFood2020), 13-16 October 2020, Berlin Virtually, Germany. DIL, Quakenbrück, Germany.

Please cite a paper or an abstract in this publication as:
Eberle, U. & Wenzig, J., 2020. Measuring the contribution of agri-food products and services to the UN Sustainable Development Goals, in: Eberle, U., Smetana, S., Bos, U. (Eds.), 2020. 12th International Conference on Life Cycle Assessment of Food (LCAFood2020), 13-16 October 2020, Berlin Virtually, Germany. DIL, Quakenbrück, Germany., p. 500-505.

ISBN 978-3-00-067604-8

9 783000 676048

Abstract code: ID 310

Life cycle assessment of pig production in Italy considering a wet scrubber ammonia abatement system

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Abstract

Ammonia (NH_3) is the most common pollutant in the pig's environment. This study aims to provide an initial assessment of the environmental impact of a farm producing heavy pigs where a wet acid scrubber for NH_3 abatement was installed. The Life Cycle Assessment approach was applied. 1 kg of live weight was selected as Functional Unit. Two alternative scenarios were considered. In the baseline scenario (BS) the air was not treated, while in alternative one (AS) a wet acid scrubber was adopted. Using the characterization factors reported by the midpoint ILCD method 12 different impact categories were evaluated. The outcomes of this study highlighted how the best solution depends from the selected impact category. Indeed, the AS was the best one for "particulate matter formation", "acidification", "terrestrial eutrophication" and "marine eutrophication", the categories influenced by NH_3 emissions, and the worst for the other ones due to the higher energy and resource consumption related to the construction, maintenance, and operation of the scrubber.

Keywords: *Life Cycle Assessment, livestock activities, pig, ammonia, emission.*

Introduction

Air inside pig barns is characterized by either high concentration of ammonia (NH_3) and particulate matter (PM) that can pose a direct hazard to animals and workers health, or odors (VOCs). The same poor-quality air is released into the environment, causing odor nuisance and atmospheric pollution in the surrounding rural and urban areas (Schauberger et al. 2018). It is well known that the agricultural sector is mainly responsible for NH_3 emissions, arising principally from manure management and from fertilizers application (EEA, 2018). Released into the environment, NH_3 causes soil acidification, nutrient-N enrichment of ecosystems, and terrestrial eutrophication. Furthermore, NH_3 is a chemically active gas able in the atmosphere to react with sulfuric and nitric acids to form secondary inorganic PM ($PM_{2.5}$) (Schauberger et al. 2018). $PM_{2.5}$ is a threat to human health, several epidemiological studies show a causal link between PM exposure and cardiovascular and respiratory system damages (Carugno et al. 2016). According to Kiesewetter et al. (2015) in the Po valley it leads to a reduction in life expectancy of about 36 months. Po Valley is one of the European regions with the highest levels of PM due to the concurrent high density of anthropogenic sources and its orographic and meteorological characteristics unfavorable for pollutant dispersion (Carugno et al. 2016). In particular, Lombardy region is located in the middle of the Po basin and it presents the highest Italian pig population density, accounting for more than 4 million heads (ISMEA, 2019). Different strategies are available to reduce NH_3 emissions from pig housing: feeding strategies, slurry storage, treatment and application techniques, and air cleaning systems (Ti et al. 2019).

The LIFE-MEGA project (LIFE18 ENV/IT/000200) aims to reduce NH_3 and PM emissions from piggeries, with a benefit for human health in rural and urban air quality. The project aims to develop and test in pig houses, located in the Lombardy region, two different abatement systems (dry and wet scrubber). The dry scrubber is a technology already used in other industrial contexts (e.g. baking), whereas the wet scrubber will be a prototype using citric acid. This study reports the preliminary results achieved in Italy in terms of environmental impact reduction using the wet acid scrubber.

Material and methods

The aim of the present study was to provide an initial assessment of the environmental impact of an Italian farm producing heavy pigs where a wet acid scrubber for air treatment was installed. The functional unit selected was 1 kg of pig live weight (LW) at the farm gate. Two alternative scenarios were considered: the baseline scenario (BS) representing the situation as it is, and the alternative scenario (AS) where the wet acid scrubber prototype (with 60% NH_3 removal efficiency) was adopted. Regarding the system boundary, a "cradle to farm gate" approach was applied, including all inputs (e.g. machinery, fuel, lubricant, organic and mineral fertilizers, pesticides, water, off farm feed) and outputs (emissions to air, soil and water) as reported in Fig. 1.

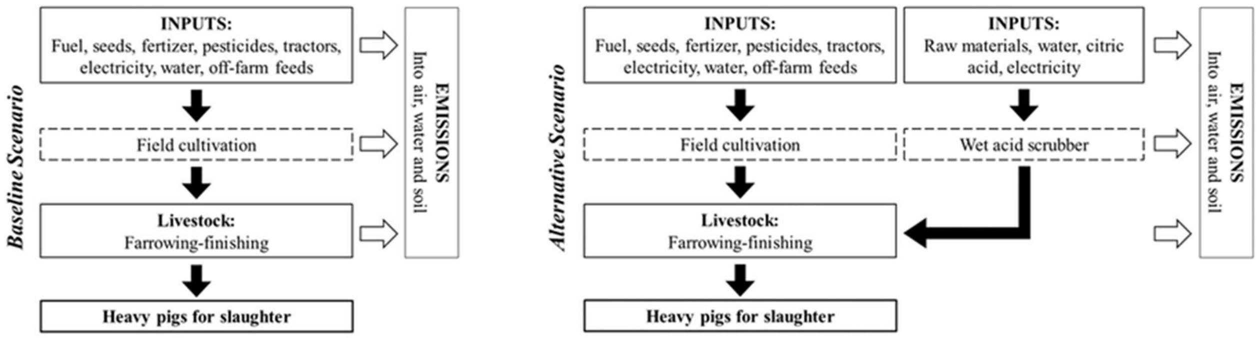

Figure 1. System boundaries for Baseline and Alternative scenarios

The case farm was an intensive farrowing to finishing farm, producing heavy pigs for traditional dry-cured hams, located in the province of Brescia (Italy). A farrow-to-finish system comprises all phases of pig production, from the farrowing phase to produce piglets till the growing-finishing one where pigs are raised till market weight (for dry-cured ham PDO disciplinary, minimum 160 kg LW at slaughter). The agricultural area of the farm was 100 ha, entirely used for maize grain production. Primary data were collected during surveys on farm carried out by experts by asking for information about: herd management, field production, feeding, and slurry management. Data related to the wet acid scrubber prototype were provided by the construction company. Table 1 report the main inventory data about herd traits and performances.

Table 1. Herd traits and performances

Zootechnical data	Unit	
Heavy pigs produced	no./year	10,050
Slaughter LW	kg	167
Sows	no.	730
Giving births/sow	no./year	2.32
Piglet weaned/sow	no./year	21
Average LW per reproduction sow	kg	200
Average LW per piglet	kg	23
Average LW per fatteners – 1st phase	kg	40
Average LW per fatteners – 2nd phase	Kg	103
Mortality	%	3

As concern secondary data, CH_4 and N_2O emissions were estimated according the IPCC guidelines (IPCC, 2019), whereas EEA guidelines (EEA, 2019) were used for NH_3 ones. Finally, background data concerning the production of the different inputs (e.g. seeds, pesticides, fertilizers, diesel, tractors and implements) were retrieved from the Ecoinvent Database v.3 (Weidema et al., 2013).

Twelve environmental impacts were evaluated: Climate Change (CC), Ozone Depletion (OD), Human toxicity, non-cancer effects (HTnoc), Human toxicity, cancer effects (HTc), Particulate matter (PM), Photochemical ozone formation (POF), Acidification (TA), Terrestrial eutrophication (TE). Freshwater eutrophication (FE), Marine eutrophication (ME), Freshwater ecotoxicity (FEx) and Mineral, fossil & renewable resource depletion (MFRD).

Results and discussion

Table 2 shows the environmental impacts of 1 kg of pig LW for the two scenarios analyzed. Besides the absolute values for the different impact categories it is reported also the variation between BS and AS calculated as: (Impact of AS – Impact of BS)/Impact of BS.

Table 2. Absolute environmental impacts for the baseline (BS) and alternative (AS) scenario

Impact category	BS	AS	Δ (%)
CC	3.55 kg CO_2 eq	3.65 kg CO_2 eq	+ 2.91
OD	3.12 kg CFC^{-11} eq · 10^{-7}	3.32 kg CFC^{-11} eq · 10^{-7}	+ 6.53
HTnoc	7.08 CTUh · 10^{-7}	7.29 CTUh · 10^{-7}	+ 3.00
HTc	1.9 CTUh · 10^{-8}	2.24 CTUh · 10^{-8}	+ 17.68
PM	3.28 kg $PM_{2.5}$ eq · 10^{-3}	3.20 kg $PM_{2.5}$ eq · 10^{-3}	-2.39
POF.	1.08 kg NMVOC eq · 10^{-2}	1.13 kg NMVOC eq · 10^{-2}	+ 4.66
TA	0.12 molc H+ eq	0.11 molc H+ eq	-8.53
TE	0.51 molc N eq	0.46 molc N eq	-9.34
FE	4.49 kg P eq · 10^{-4}	4.65 kg P eq · 10^{-4}	+ 3.46
ME	1.93 kg N eq · 10^{-2}	1.92 kg N eq · 10^{-2}	-0.21
FEx	23.74 CTUe	23.95 CTUe	+ 0.89
MFRD	2.42 kg Sb eq · 10^{-5}	4.88 kg Sb eq · 10^{-5}	+ 101.8

For 8 of the 12 evaluated impact categories, AS shows higher impact respect to BS, due to the impact associated with the wet acid scrubber construction and maintenance. The best solution depends on the selected impact category. Indeed, the AS was the best the impact categories influenced by NH_3 emissions (PM, TA, TE, and ME), for which a reduction of 2% (PM), 8% (TA), 9% (TE), and 0.2% (ME) was observed. The climate change impact was 3.55 kg CO_2 eq/kg LW and 3.65 kg CO_2 eq/kg LW for BS and AS, respectively, aligning with Bava et al. (2017) and González-García et al. (2015) results. The scrubber affects positively the impact categories influenced by the ammonia emissions while increase the impact of the other impact categories and, in particular, of MFRD.
Fig. 2 reports the hotspot processes of the farm for both scenarios.

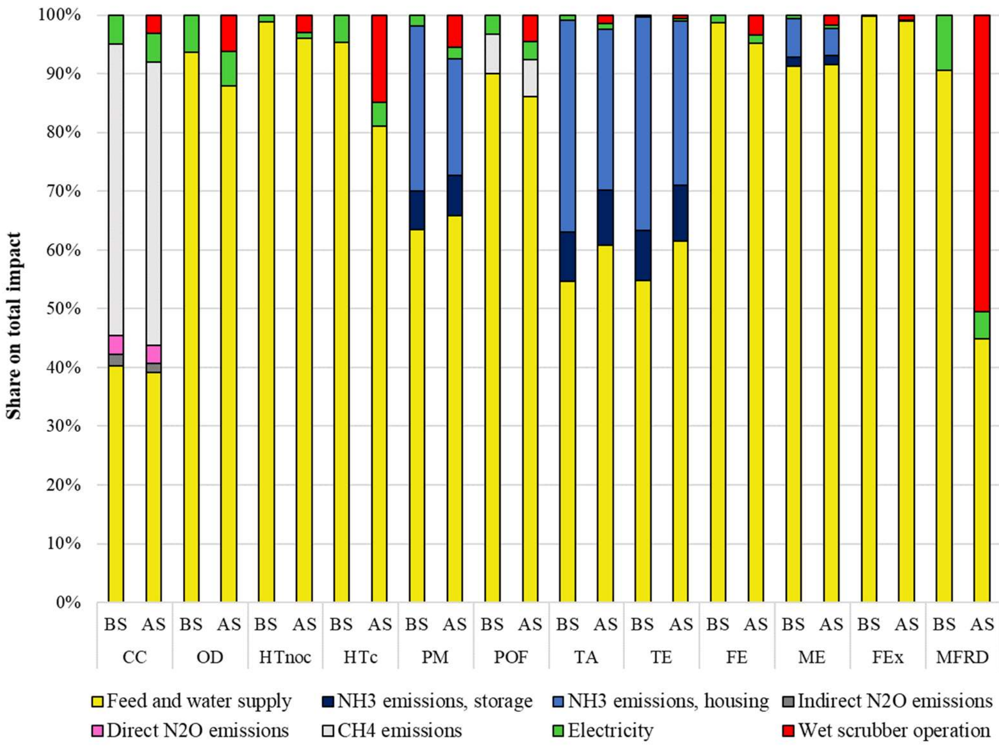

Figure 2. Environmental hotspots for BS and AS

Regardless of the scenario considered, feed production was the main hotspot in all impact categories and of heavy pig production, as also reported in other LCA studies (Bava et al. 2017; González-García et al. 2015). In the farm analyzed, only maize grain is partially produced on-farm, instead all other feed ingredients are purchased. As an example, the replacement of soybean imported from South America with protein sources locally produced certainly could affect the final impact (Bava et al. 2017). Moreover, also the use of precision feeding systems in growing and finishing phase could help in reducing the environmental impact of pig production (Andretta et al. 2018). CH_4 emissions affect significantly CC (50% and 48% in BS and AS, respectively). After feed, NH_3 emissions are the main responsible for PM, TA and TE impact share, ranging from 34% to 45% for BS and from 26% to 37% for AS. As expected, in AS NH_3-related impacts are less than in BS. Electricity is responsible for a share ranging from 0.2% to 4.9% for all the evaluated impact categories. Regarding the wet scrubber contribution to the environmental impact of 1 kg of pig LW at the farm gate, in AS it registers the highest relative contribution for MFRD (50%) and the lowest for TE (0.6%). A reduction of the scrubber impact could be achieved substituting the source of the electricity consumed (e.g., by installing a photovoltaic panel on the roof of stables). Even if not specifically foreseen in the Life MEGA project the use of renewable energy to feed the scrubber would probably improve its environmental performances.

Conclusions and perspectives

Although further evaluation is needed, these preliminary results are preliminary and provide a first quantitative indication of the environmental benefits that can be achieved by the introduction of the wet acid scrubber technology. The high livestock density present in Lombardy makes it a region susceptible to nitrates leaching, as a consequence most of the fields are recognized as Nitrate Vulnerable Zones (NVZ) in the context of the Council Directive 91/676/EEC. So, it is crucial to find effective ways to reduce the excessive nitrogen loads. As demonstrated in this work, the wet acid scrubber is an effective strategy to reduce NH_3-related impacts, although it increased the other impacts evaluated. Possible optimizations of the air treatment system should focus attention on reducing the consumption of water and acid, increasing their recycling. Moreover, the enhancement of ammonium citrate salt (produced by the reaction between NH_3 and citric acid) as nitrogen fertilizer could further reduce the environmental impacts due to the replacement of mineral fertilizer. In addition, the field application of the discharge water is another valuable strategy to reduce the use of mineral fertilizer, as demonstrated by de Vries and Melse (2017). Finally, in the next steps, the LIFE-MEGA project foresees the implementation of the scrubber with a microclimatic tool, that will activate its functioning only when fixed pollutants thresholds are exceeded, thus achieving the best indoor air quality and minimizing energy and citric acid solution consumption.

Acknowledgements
The LIFE-MEGA project (LIFE18 ENV/IT/000200) has received funding from the LIFE Programme of the European Union.

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