Health, air pollution and animal agriculture

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Introduction

Although animal agriculture is critical to the subsistence of smallholders in some poor countries, the global detrimental impact of animal farming is now both well documented and overwhelming. Animal farming is a primary cause of deforestation (De Sy et al., 2015), biodiversity loss (Machovina et al., 2015), antibioresistance (O'Neill, 2015) and infectious diseases emergence and amplification (Rohr et al., 2019). Moreover, it contributes significantly to water pollution, water scarcity and climate change (Godfray et al., 2018; Poore & Nemecek, 2018; Springmann et al., 2017). Additionally, the exploitation of farmed animals, especially in its widespread intensive forms, raises various moral issues. In this paper, we discuss another impact of animal farming, that on air pollution and in turn on human health. While this impact is also potentially considerable, we stress that it has been largely overlooked by regulators as well as by researchers, and in particular by economists.

Pathways and Health Impacts

Air pollution is a major environmental health issue, and the necessity to reduce this pollution is well recognized both in academia and policy making. However, emissions of pollutants in agriculture have remained relatively stagnant over decades. In the EU, the decrease in particulate matter (PM)

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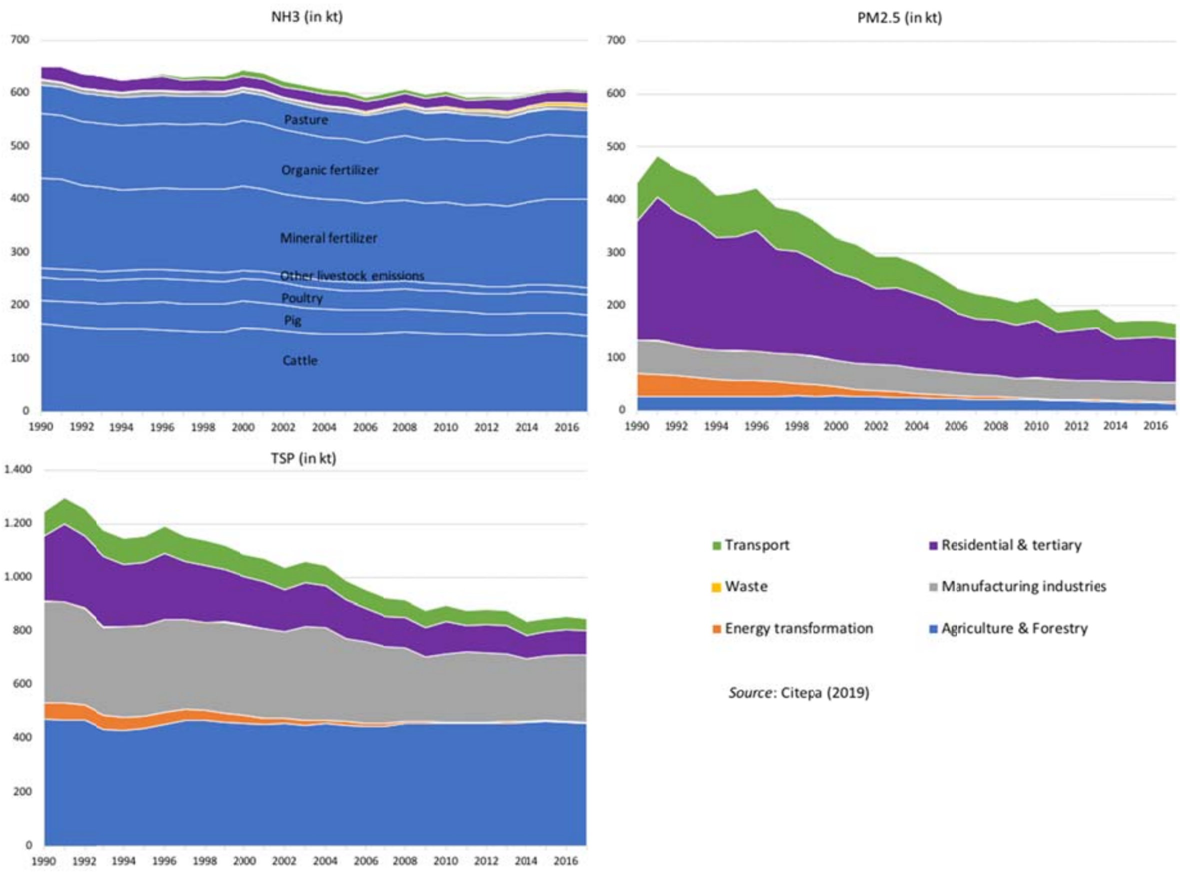
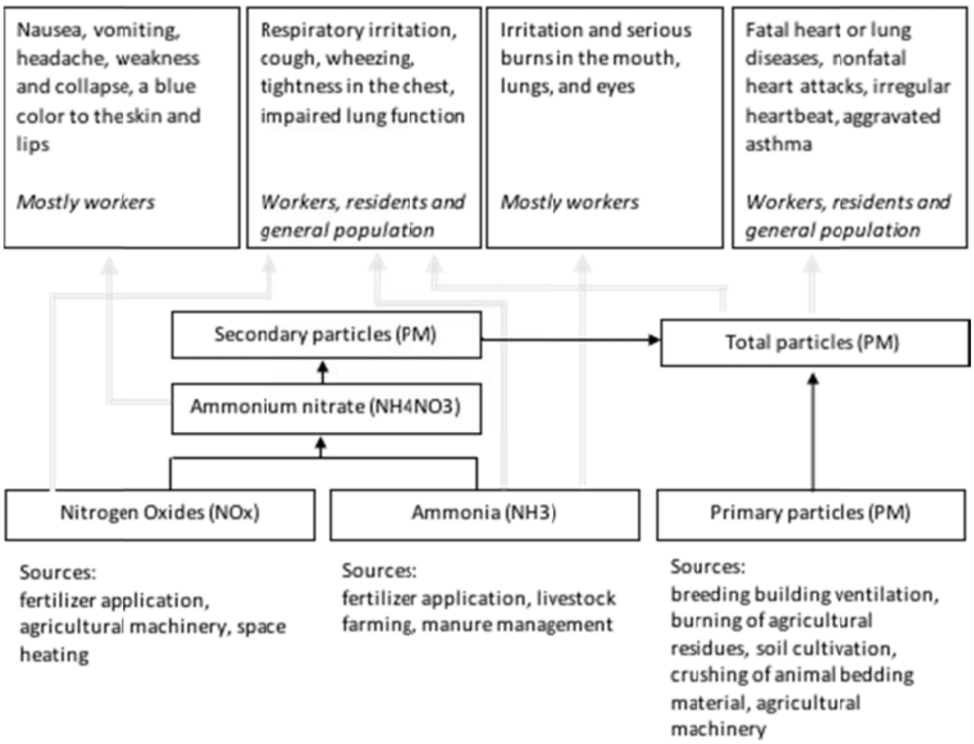
emissions is mainly due to reductions in other sectors such as transport, energy production and energy use in industries (EEA, 2018). These sectors also significantly reduced emissions of their main pollutants; nitrogen oxides (NOx) emissions in transport decreased by 59% and sulfur oxides (SOx) emissions in energy production decreased by 93% since 1990 (EEA, 2019a; EEA, 2019b). In agriculture, one of the main pollutants is ammonia (NH3) from livestock (poultry, pig, cattle) as well as pastures and fertilizing activities, largely used for animal feed (Figure 1). However, ammonia emissions have experienced only a moderate reduction over the last thirty years. This is particularly true for France, where NH3 emissions decreased only by 8%, compared to 23% in the EU (EEA, 2019a). Moreover, French agriculture is now the country's sector largest emitter of total suspended particles (TSP), though emissions of fine particles (PM2.5), considered the most harmful for human health, have remained comparatively low (Figure 1).

Fig. 1: France emissions for NH3, PM2.5 and TSP by sector



Agricultural activities emit a wide range of air pollutants with serious negative impacts on human health. Figure 2 presents in a simplified way the pathways and health impacts of the major pollutants. We distinguish between three populations whose health is impacted by air pollution: workers, local residents (i.e., those living in the surrounding area of farming) and the general population. In France, 94% of anthropogenic emissions of NH3, 6% of the total of NOx and 20 % of the total of particles with 10 µm or less in diameter are due to agriculture (Citepa, 2019).[2] This sector contributes not only to such primary emission of particles but also to secondary particles. In fact, atmospheric particles include a primary fraction emitted directly into the atmosphere and a secondary fraction formed by chemical reactions. Ammonium nitrate from agriculture is a major compound of secondary particles measured in ambient air (other compounds include sulfate ammonium, carbon and organic matter) formed from NH3 (coming almost exclusively from the agricultural sector) and NOx (coming mainly from road traffic and industry). Chronic and/or over-exposition to those pollutants generate adverse health impacts mainly related to the circulatory and respiratory system.

Fig. 2: Air pollution from (animal) agriculture: Pathways and health impacts

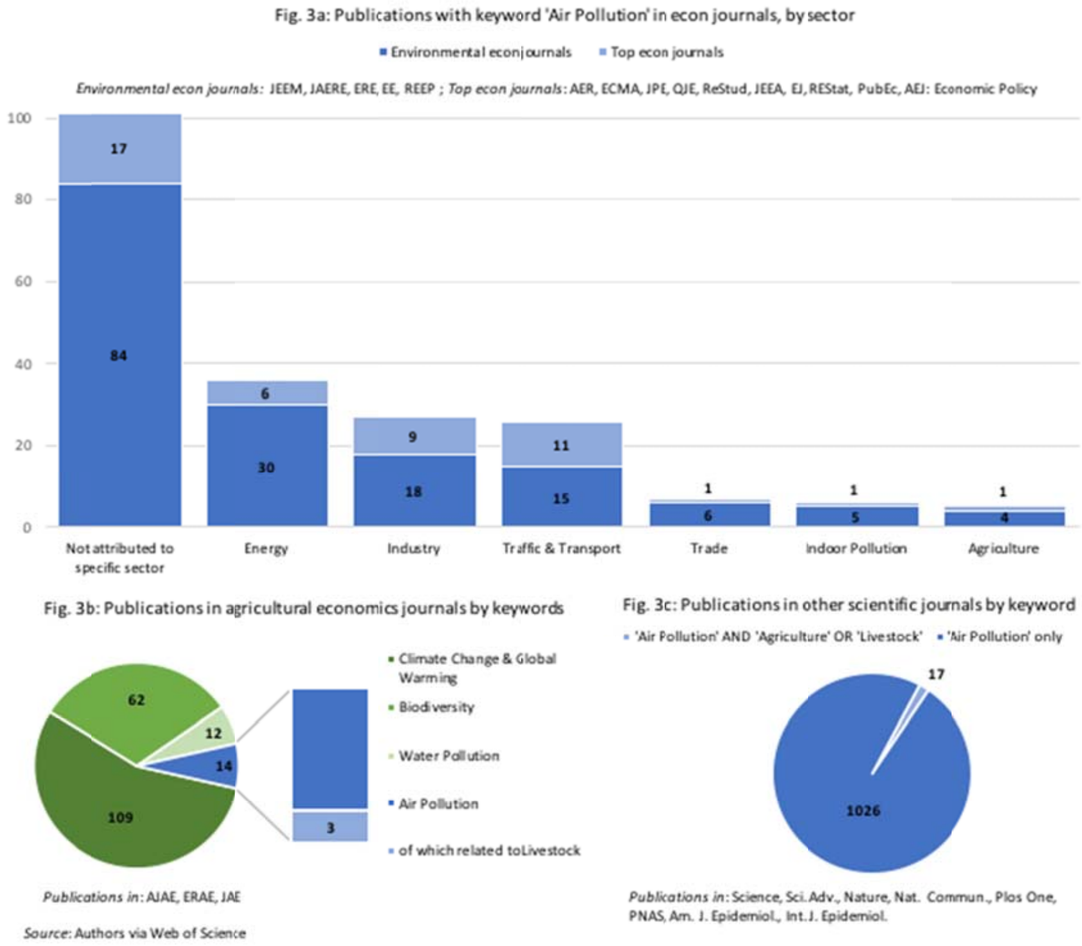


Literature Review

A literature search on Web of Science indeed indicates that there exist few publications related to air pollution from agriculture in top generalist or public economics journals as well as in environmental economics journals, compared to air pollution from other sectors such as energy or transport (Figure 3a). Moreover, from the only five studies found, two are related to forest fire pollution, and none are related to livestock. In agricultural economics journals, a lot more attention has been paid to

[2] Although less significant, agricultural emissions also include volatile organic compounds (VOC) from metabolic processes of vegetation, manures, burning of agricultural residues, and agricultural machinery.

global warming and biodiversity issues than to air pollution (Figure 3b). In some of the top journals of natural and epidemiological sciences, publications on air pollution are rarely related to agriculture or livestock (Figure 3c).[3]



Henceforth, we identify outcomes and limitations from three strains of literature that do investigate livestock-related air pollution impacts: i) health and epidemiological studies on the exposure to intensive animal farms, ii) air quality simulation models in atmospheric chemistry, and iii) life cycle assessments of livestock production systems. While health studies mainly consider workers and local residents, simulation models and life cycle assessments account for impacts on the general population.

Health and epidemiological studies on farm workers and regional communities

Livestock production has been linked to adverse health effects on workers. The literature reports high levels of contamination with organic dust in farms (Viegas et al., 2018). Livestock farm dust contamination contains high concentrations of fine PM associated with obstructive pulmonary

[3] The search strategy is provided in detail in the supplementary appendix.

disorders, nasal symptoms, hypersensitivity pneumonitis, and interstitial lung disease (Nordgren & Bailey, 2016; Cambra-López et al., 2010; Oppliger et al., 2008). Chronic respiratory disorders such as asthma and ODTS (organic dust toxic syndrome) are also prevalent among poultry farm workers (Viegas et al., 2013). PM can also worsen symptoms of workers caused by preexisting lung disease (Nordgren & Bailey, 2016). Evidence also suggests that ammonia exposure from animal farming causes irritation to the mucus membranes in the eyes and the respiratory system (Kristensen & Wathes, 2000). In addition, dust pollution in farming has been associated with headache, irritation of eyes, nose and throat, and drowsiness (Hartung & Schulz, 2011). Finally, livestock farm workers have significantly elevated mortality for several respiratory conditions, in particular for hypersensitivity pneumonitis (Greskevitch et al., 2008; Rautiainen & Reynolds, 2002). However, much remains unknown about respiratory disease among livestock workers. In fact evaluation analyses are often limited to a single compound while exposure includes a combination of animal products, dust, pathogens, and chemicals (Dignard & Leibler, 2019).

Individuals living in surrounding areas of intensive farms are also exposed to pollution from livestock production and investigations on such populations are discussed in recent literature reviews. Some have reported positive relationships between living close to intensive farms and asthma (mainly among children), wheezing, deficits in lung function, and higher incidence of pneumonia (Casey et al., 2015; Douglas et al., 2018; Smit et al., 2017). However, a few studies actually indicate protective associations between intensive farm exposure and respiratory health (Douglas et al., 2018) and one systematic review finds no evidence of a consistent association (O'Connor et al., 2017).[4] [5]

One caveat in this literature is that the pathway between air pollution and health impacts remains unclear. For instance, the majority of studies use distance-to-farm as a measure for exposure rather than emission data, and outcomes are often based on self-reported health status, while mortality is not considered. Moreover, the fact that most of the reviewed studies are cross-sectional rather than longitudinal limits the ability to make strong causal inferences. Finally, the empirical validity in some of the publications may be questioned since important confounders are not controlled for. Air pollution is not fully exogenous and likely to be systematically related to the socioeconomic status of the household. For instance, wealthy households are less likely to live next to a polluting farm. Hence, the non-random assignment of pollution prevents causal inferences. In particular, O'Connor

[4] Casey et al. (2015) review 33 publications, 7 of which consider respiratory health impacts. 5 of these are also among the 7 residential studies on respiratory health reviewed by O'Connor et al. (2017). Douglas et al. (2018) review 17 publications on health effects for residents, covering most of the studies considered by the aforementioned authors.

[5] The previously mentioned reviews apply a vote-counting approach, which has been shown to be problematic as the probability of finding a real effect decreases with the number of studies included (Hedges & Olkin, 2014). A preferred method would consist of a meta-analysis corrected for publication bias (Andrews & Kasy, 2019).

et al. (2017) note that there is a high risk of bias among the studies they reviewed, and they cannot establish a consistent dose-response relationship between exposure and respiratory diseases.

Simulation-based air quality models

Air quality models are used to estimate ambient concentration levels of primary and secondary pollutants by sector, based on emission rates, meteorological conditions, and chemical processes in the atmosphere (EPA, 2016). In contrast to the epidemiological literature, these simulations are not restricted to local impacts, but account for the capability of particles to travel long distances and impact larger populations.

In the atmospheric chemistry literature, publications mainly rely on "full-form" models, which capture the complexities of such environmental processes by including detailed representations of each mechanism. In economics, usually reduced complexity versions of these models are applied in the form of integrated assessment models (IAM). They approximate estimates from full-scale models without explicitly representing all chemical and physical processes that impact pollutant fate and transport (Baker et al., 2020). Moreover, IAMs estimate the health damages as well as their economic cost, by integrating outcomes from epidemiological concentration-response functions and economic non-market valuation for morbidity and mortality in peer-reviewed literature (National Research Council, 2010).

Several recent publications relying on such air quality models identify agriculture to be one of the largest contributing sectors to premature mortality from PM2.5 concentration today, driven by ammonia emissions (Brandt et al., 2013; Lelieveld et al., 2015; Tschofen et al., 2019). Global simulations with full-scale models indicate that agriculture is the largest contributing sector to PM2.5 in eastern USA, Russia, East Asia and Europe.[6] Simulations show that a 50% decrease in agricultural ammonia emissions would reduce annual PM2.5 concentration levels by 11, 8 and 5% over Europe, North America and East Asia respectively (Lelieveld et al., 2015; Pozzer et al., 2017). As for economic investigations, IAM-based simulations show that, largely due to animal farming, agriculture has become the biggest contributor to PM2.5 damages in the US, with the sector's cost outweighing its value added to the economy (Tschofen et al., 2019). A prior assessment considering not only mortality but also morbidity indicates that the agricultural sector is the second largest contributor to health cost in Europe (Brandt et al., 2013).[7] Finally, Giannakis et al. (2019) compare health benefits of complying with the 2020 ammonia ceiling set by the EU with the cost of

[6] Lelieveld et al. (2015) estimate that in many European countries agriculture's contribution to PM2.5 concentration is 40% or higher.

[7] The study uses emissions from the year 2000 for the European level. The authors also estimate that in 2008 the Danish agricultural sector was the largest contributor to this country's health cost.

abatement options to reach this goal.[8] They estimate an annual economic benefit of 14,837 M€ from avoided premature mortality, compared to abatement cost ranging between 80 and 3,738 M€ per year depending on the option, suggesting that more ambitious commitments could be set with relatively low cost.[9]

Though the models applied in such investigations are highly sophisticated and able to account for complex atmospheric chemistry processes, the fact that they are simulations remains an important limitation. For instance, the produced concentration levels depend on the reliability of emissions data. While point sources are usually dependable due to mandated monitoring, ground-level sources may be problematic because they are more rarely measured and often estimated (Tschofen et al., 2019). Moreover, most of the reviewed models do not disentangle livestock-related emissions from other polluting agricultural activities. Finally, there is currently still a lack of knowledge regarding how toxicity of particles from different sources varies. For instance, agricultural emissions forming mostly inorganic particles may be much less harmful than carbonaceous particles emitted by other sectors (Lelieveld et al., 2015).[10]

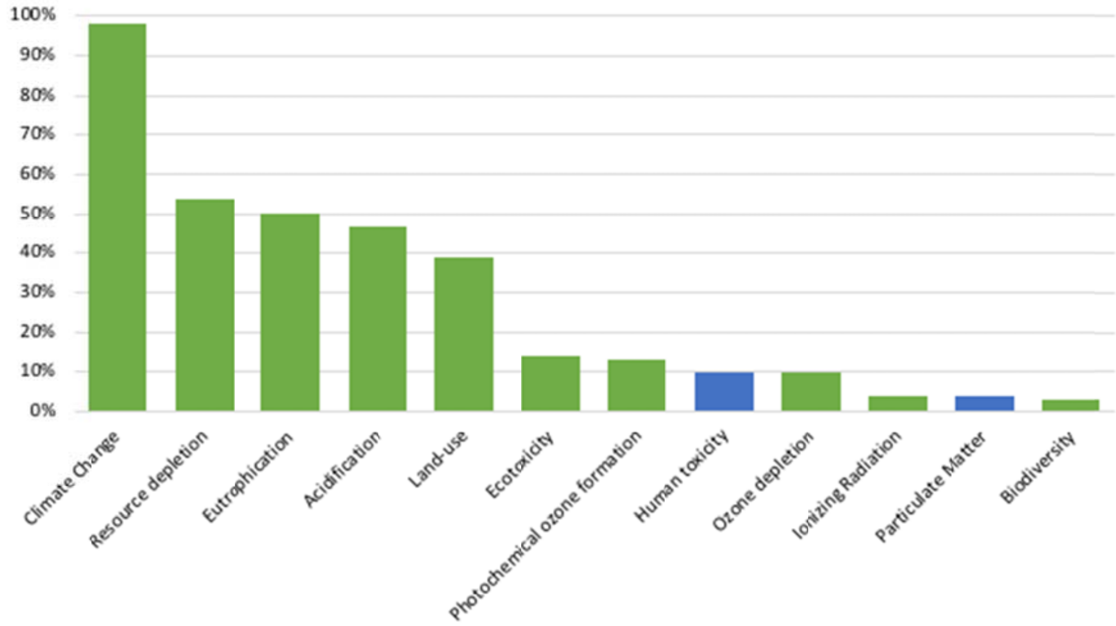
Life cycle assessments of livestock production systems

Life cycle assessment (LCA) is a tool based on a precise methodology, used to evaluate all environmental impacts of a functional unit of a product (such as one kg of a certain meat) across all stages of the life cycle of this product. In agriculture, the analyzed cycle is usually limited to "cradle to gate", meaning the use and disposal phases are omitted (Dumont et al., 2016). Although in theory particulate matter formation can be assessed among these environmental impacts (again by using atmospheric models and epidemiological studies), much more attention is given to other impact areas in practice. The array of literature reviews on livestock LCA published in recent years mainly summarises impacts on global warming, land use, energy use, eutrophication and acidification, while rarely mentioning air pollution impacts on human health (DeVries et al., 2010; DeVries et al., 2015; McAuliffe et al., 2016; McAuliffe et al., 2017; Zervas et al., 2016). McClelland et al. (2018) confirm this in a systematic literature review, in which they compare the amount of different types of impact categories investigated across 173 livestock LCAs (Figure 4). They show that PM formation is one of the least assessed topics, discussed in only 4% of reviewed studies. Impacts on human toxicity are

[8] They estimate cost and benefits for 16 member states who exceeded the 2020 ceiling in 2016. Abatement options include low nitrogen feed, low-emission housing, covered manure storage and urea fertilizer application.
[9] For France, the estimated annual benefit was 848.78 M€ with cost ranging between 12.5 and 569.48 M€.
[10] Most of the cited studies account for this uncertainty in a sensitivity analysis.

also seldomly included (in 10% of studies), whereas 98% of publications consider climate change impacts.[11]

Fig. 4: Share of LCA publications by impact category in McCelland et al. (2018)



The systematic review includes 173 published LCAs on livestock production between 2000-2016.
One publication may address multiple impact categories.

Source: McCelland et al. (2018)

This underrepresentation of health impacts from particles pollution in LCA may be related to methodology and data availability issues. In a recent LCA on US beef production, Asem-Hiablie et al. (2019) exclude impacts on particulate matter formation "due to lack of industry data, complexity in characterization, and resulting unavailability of standard LCA procedures". Indeed, the latest methodology report of Agribalyse, one of the most popular databases used in LCA, explains that particle emissions from farm activity are not considered, because data availability is currently too limited in France and Europe in order to correctly take them into account (Koch et al., 2016). Moreover, Notarnicola et al. (2017) claim that LCAs do not capture the real toxicity of a product, as there is no causality between a mass of a substance (as measured in LCA) and its toxic effect.

Discussion and conclusion

Several pollutants emitted in animal agriculture such as ammonia are considered as emerging and important risks for air quality (Anses, 2018). High polluting sectors such as transport or energy have long been regulated; however, this is not the case of the agricultural sector, which has benefited

[11] Particulate matter formation and human toxicity are considered as separate impact categories in LCA. The latter considers carcinogenic and noncarcinogenic effects from chemical products released in the environment (Koch et al. 2016).

from regulatory exemptions and low oversight. Cambra-López et al. (2010) stress for instance that no legislation is in force regarding maximum PM concentrations or emissions neither in agricultural environments nor in and from livestock houses. In the EU, the main legislative instrument to achieve the 2030 objectives of the Clean Air Programme is Directive 2016/2284/EU on the reduction of national emissions of certain atmospheric pollutants. This directive provides a range of suggestions to reduce emissions from agriculture and particularly from livestock manure, but none of them is mandatory.[12] These observations are consistent with the fact that the main pollutants emitted in animal agriculture have been less reduced than in other sectors (see Figure 1). The policy ambition appears to remain relatively low, as is the case of ammonia emissions reduction targets compared to other pollutants in France (Table 1).[13]

Table 1: Objectives of emissions reduction compared to emissions in 2005 in France

Pollutant	From 2020	From 2030
Sulfur dioxide (SO2)	-55%	-77%
Nitrogen oxides (NOx)	-50%	-69%
Organic compounds (NMVOC)	-43%	-52%
Ammonia (NH3)	-4%	-13%
Fine particles (PM2.5)	-27%	-57%

Source: MEEM (2017)

The lack of stringent regulation of agricultural air pollution may be related to different factors. The agricultural sector is well known to be powerful politically, and thus difficult to regulate in general (Bonnet et al., 2020).[14] Given that world agricultural markets are very competitive, environmental regulation may strongly disadvantage domestic farmers, complicating the implementation of stringent regulation. Since farmers are often poor or very poor, regulation thus also raises strong equity issues. Further, regulation may be perceived by the public as a threat to food security and a barrier to the provision of basic needs. Finally, and more specific to air pollution, one additional

[12] In the US, farms are exempted from complying with the three main air pollution laws, namely the Clean Air Act, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Emergency Planning and Community Right-to-Know Act (EPCRA). This under-regulation problem is a longstanding one (Ruhl, 2000), but it has apparently worsened recently (see for instance here: https://thefern.org/2019/12/a-breathtaking-lack-of-oversight-for-air-emissions-from-animal-farms/).

[13] France has received a formal notice in 2020 by the European Commission to improve its air quality legislation (see https://www.lemonde.fr/planete/article/2020/05/28/pollution-de-l-air-la-france-de-nouveau-dans-le-collimateur-de-la-commission-europeenne_6040976_3244.html). Furthermore, it appears that the constraints to register large intensive animal farm units have been made easier in France, thus indirectly increasing the risk exposure of the residents (see for instance: https://reporterre.net/Le-droit-de-l-environnement-est-detricote-au-nom-de-la-simplification).

[14] To illustrate this difficulty in another environmental domain, the agricultural sector has been and still is largely exempted from climate policy such as carbon tax or emissions trading systems (Springmann et al., 2017).

factor may be the lack of study in academia, and thus the scientific uncertainty regarding the air pollution health damage due to agriculture. A related issue is the difficulty to attribute the precise origin of an air pollutant. As an example, ammonium nitrate, an important compound of particulate matter (Figure 2) is formed from ammonia, coming almost exclusively from the animal agriculture sector, and nitrogen oxides, coming mainly from road traffic and industry.

We emphasize that modern research in economics may help fill (partially) this knowledge gap. Indeed, novel quasi-experimental approaches, such as difference-in-difference or regression discontinuity may help disentangle the origin of pollution and provide causal estimates (Dominici et al., 2014; Chabé-Ferret et al., 2017).[15] However, the only economic study focusing on causal impacts that we are aware of is Sneeringer (2009). She uses geographic shifts in the animal farming industry to measure the impact of pollution on infant health, finding that a doubling of animal production leads to a 7.4% increase in infant mortality. Hence, future research and the development and accessibility of data should be able to come up with exogenous variation in air pollution generated by agriculture in order to credibly causally assess the air pollution related health impacts. These results should in turn help better design environmental and agricultural policies.

We therefore conclude this discussion by emphasizing the need to develop more studies on the air pollution health impact due to agriculture, especially economic ones. We believe however that limited academic research cannot justify the current under regulation. There are two main reasons for this. First, the results that we presented in the literature survey above emphasize the existence and often the possible severity of health risks to workers, residents as well as to the general population. Current scientific knowledge thus can hardly justify that the risks are nonexistent or small enough to be ignored. Second, if anything, scientific uncertainty due to sparse research and methodological difficulties should justify policy action, and not policy inaction, consistent with the precautionary principle. Hence, the best strategy should be to err on the side of safety while stimulating more research to improve knowledge. We further emphasize that introducing regulation can boost monitoring and measures of agricultural air pollution, and in turn the production of data, thus facilitating academic research. To break the current academic and regulatory inertia, it is thus

[15] Let us give a few examples. Using the congestion pricing program in Stockholm, Simeonova et al. (2018) show for instance that the significant reduction of nitrogen dioxide (NO2) and particulate matter (PM10) relative to pre congestion pricing levels lead to significant reductions in the incidence of childhood asthma in Stockholm in the months and years after the program was implemented. In that case, comparing the before and after difference in pollution for the group receiving the pricing program and its counterpart makes it possible to attribute the pollution reduction to the program. In the same vein, Schlenker & Walker (2016) use the residual exogeneous daily taxi time variation in daily airport congestion to estimate the population dose response of respiratory and heart-related outcomes to carbon monoxide (CO) exposure. Using China's Huai River Policy, which provides free or heavily subsidized coal for indoor heating during the winter to cities located in the north of the Huai River but not to those in the south, Ebenstein et al. (2017) find a 10μg/m3 increase in PM10 reduces life expectancy by 0.64 years. The findings are derived from a regression discontinuity design based on distance from the Huai River making it possible once again to attribute the pollution reduction to the policy.

urgent that policy makers begin to integrate air pollution in the regulation of animal agriculture. The main regulatory instrument in the EU is the Common Agricultural Policy (CAP). We thus close the discussion with a clear policy recommendation: Regulators must urgently integrate air pollution in the CAP, for instance as a part of the conditionality requirements, as it has already been advanced by several NGOs and policy makers.

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Supplementary Appendix: Search Strategy for Publications related to Air Pollution and Agriculture

Searches were executed on Web of Science for strings included in publication title, abstract or author-specific keywords. For Fig. 1a, the search string initially generated 287 results. The abstracts of these results were then manually reviewed to attribute each publication to a sector and excluded if they did not focus on pollution.

<u>Search String Fig. 1a</u>

TOPIC: ("Air Pollution") *AND* **PUBLICATION NAME:** ("Econometrica" OR "American Economic Review" OR "Journal of Political Economy" OR "The Quarterly Journal of Economics" OR "The Review of Economic Studies" OR "American Economic Journal: Economic Policy" OR "The Economic Journal" OR "The Review of Economics and Statistics" OR "Journal of the European Economic Association" OR "Journal of Public Economics" OR "Journal of Environmental Economics and Management" OR "Ecological Economics" OR "Journal of the Association of Environmental and Resource Economists" OR "Review of Environmental Economics and Policy")

For Fig. 1b, the number of results for the search strings “Climate Change” OR “Global Warming”, “Biodiversity”, “Water Pollution”, “Air Pollution” were compared (see below for an example). Results for the string “Air Pollution” were manually reviewed to identify publications related to livestock production.

<u>Search String Fig. 1b for “Climate Change” OR “Global Warming”</u>

TOPIC: ("Climate Change" OR "Global Warming") *AND* **PUBLICATION NAME:** ("American Journal of Agricultural Economics" OR "European Review of Agricultural Economics" OR "Journal of Agricultural Economics")

For Fig. 1c, the search string including only “Air Pollution” generated 1043 results. Within these results a refined search was executed to identify publications related to agriculture or livestock production.

<u>Search String Fig. 1c</u>

TOPIC: ("Air Pollution") *AND* **PUBLICATION NAME:** ("Science" OR "Science Advances" OR "Nature" OR "Nature Communications" OR "Plos ONE" OR "American Journal of Epidemiology" OR "International Journal of Epidemiology" OR "Proceedings of the National Academy of Sciences of the United States of America")

Refined by: TOPIC: ("Agriculture" OR "Farm" OR "Livestock")