Release of ammonia, particulate matter and nitrogen oxides during the Covid-19 quarantine: what is the role of livestock activities?

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***Abstract*— Several gases contribute to air pollution and most of all to the formation of secondary particulate matter ($PM_{2.5}$), which is recognized as a source of severe risk to human health. Even if huge steps forward have been done worldwide, traffic, industrial activities, and the energy sector are mostly responsible for the release of NOx and SOx, while the agricultural sector is mainly responsible for the emission of NH_3 deriving from the barn, the manure storage, management and final field application. In this study, the emission of $PM_{2.5}$, NOx and NH_3 is analyzed in the main provinces of the Lombardy region in which livestock activities are carried out, comparing emissions of 2016-2019 and those of 2020 during the lockdown determined by the spread of Covid-19 disease. The aim is to understand if and how a change in air emissions can be identified. The results show that $PM_{2.5}$ and NOx reduced, most of all in urban areas, whereas NH_3 maintained the same trend of previous years. From the statistical analysis emerges also that NH_3 has a different behavior respect to $PM_{2.5}$ and NOx, these latter being much more correlated between each other than NH_3. However, further studies should be carried out on a bigger spatial and temporal scale.**

Keywords— Air quality; ammonia; livestock; lockdown; particulate matter

I. Introduction

World Health Organization (WHO) has recognized ground-level ozone (O_3), nitrogen dioxide (NO_2) and particulate matter (PM) as the most harmful air pollutants to human health and ecosystems [1]. For this reason, a strong attention has been paid on these pollutants, with a series of measures aimed to their reduction. In particular, PM has been studied due to its adverse health effect [2], especially for what regards the long exposure to its high concentrations [3] that can cause respiratory and cardiovascular diseases. This is because particulate matter consists of fine particles that can reach lungs and affect blood circulation: the smaller are the particles, the worst is for health issues.

PM derives from primary and secondary sources; primary ones are emitted directly from sources such as road traffic and car exhaust gases. Instead, secondary PM precursors are pollutants partly transformed into particles by photochemical reactions in the atmosphere [4] among which can be included ammonia (NH_3), nitrous oxides (NOx) and sulphates (SOx). NH_3 derives almost entirely from the agricultural and livestock sector, while NOx and SOx from traffic, industrial activities and the energy sector. These pollutants can affect not only human health and animals' health [5] but also the ecosystems: air pollution in fact is responsible for environmental impacts such as eutrophication and soil acidification that finally cause biodiversity losses [6].

This environmental problem is not at all negligible, especially when considering that around 90% of the global population in 2018 was breathing polluted air [7], in particular, 6-8% of the European population was exposed to $PM_{2.5}$ exceeding limit (set by EU equal to 25 $\mu g/m^3$) and 13-19% to PM_{10} exceeding limit (set by EU equal to 50 $\mu g/m^3$) [8]. Both EU limits are less strict than the threshold fixed by WHO at 10 $\mu g/m^3$ for $PM_{2.5}$ and 20 $\mu g/m^3$ for PM_{10}, but this is not sufficient since not all EU countries are able to respect these limits every day of the year. Italy in particular can be included in this group.

Focusing on the Italian context, and especially on the Northern part of the country, it must be considered that it is an area highly industrialized, densely populated and characterized by intensive agricultural activities, and the geographical and physical characteristics of the Po valley facilitate the persistence of pollutants in the atmosphere [9]. These conditions make Po valley one of the most disadvantaged areas in Europe for air quality [10]. Moreover, among the other gases contributing to PM formation, the emission of NH_3 is expected to increase globally because of the intensification of agricultural activities by 2050 [11].

In this study, the event of the 2020 lockdown caused by the pandemic coronavirus SARS-CoV-2 is studied in respect to air emissions of Lombardy region. In particular, in this study is investigated if and how air emissions are affected by the agricultural activities in the air-polluted area of Lombardy, which is where the SARS-CoV-2 caused the most problems and where the lockdown was the most severe [12], in a period in which most of the productive activities were stopped while agricultural-related ones remained active.

II. MATERIALS AND METHODS

A. Background

In Northern Italy, from end of February 2020, almost all industrial activities started being closed and traffic steeply reduced. This did not occur for agricultural activities, which continued. For this reason, air emissions caused by agricultural activities (mainly NH_3, which is emitted for about 97% from this sector) [13] did not change notably respect to the same period of the previous years, whereas emissions from other sectors probably did. In particular, agricultural NH_3 emissions derive most of all from manure management and fertilizers application [14] that commonly take place during spring and autumn and are influenced by temperature, wind speed, and rainfall, other than by livestock housing, storage, and field spreading practices [15-16]. Therefore, they are generally subject to intrinsic variability.

B. Monitored area

In Lombardy are reared about 1,543,639 cattle and 3,984,633 pigs [17], most of all in the 4 provinces of Lodi, Mantua, Brescia and Cremona. This makes this area intensive for livestock activities, and a source of pressure on the surrounding environment.

From the ARPA website [18], weather data and air quality data about $PM_{2.5}$, NH_3 and NOx in these provinces were downloaded. In more details, in every province, several data stations were selected and divided as follows: one average data in the city and one average data in the countryside, with the aim of identifying possible differences in air pollutants in city areas or in countryside areas. In total, 14 data stations were analyzed for each period. The period investigated was January, February, and March of the years 2016-2020. Data of years 2016-2019 were averaged to reduce the annual seasonality and were compared with 2020. These months were chosen since Covid-19 started spreading in the Lombardy region from January and almost all production activities were locked down from the end of February, except for the agricultural ones.

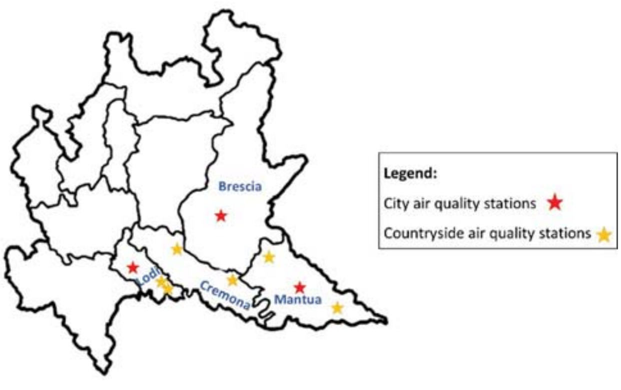


Fig. I. Map of Lombardy region with the position of the monitored air quality data stations in city and countryside areas.

The meteorological data used were air temperature (T, °C), relative humidity (RH, %), wind speed (W, m/s), and rainfall (R, mm). The air quality data used were ammonia (NH_3, μg/m³), nitrous oxides (NOx, μg/m³), and secondary particulate matter ($PM_{2.5}$, μg/m³).

C. Statistical analysis

SAS Software 9.4 was used for the data analysis. Descriptive statistics were carried out to evaluate the variables present in the dataset. Then, multivariate statistics were done, including correlation matrixes and Principal Components Analysis (PCA) to identify relationships among variables and General Linear Model (GLM) to test the resulting model of NH_3 emission in city areas for the whole studied period.

III. RESULTS

For all main weather parameters evaluated in this study, results of the descriptive statistics are reported in Table 1 as average values of the four provinces. Not all variables highlight statistically significant differences among the selected areas and in the 2 periods 2016-2019 vs 2020.

TABLE I. MEAN AND STANDARD DEVIATION OF THE MAIN WEATHER PARAMETERS.

Parameters	***Period***	**January**	**February**	**March**
		Mean ±SD	***Mean ±SD***	***Mean ±SD***
W (m/s)	2016-2019	1.26±0.3	1.47±0.4	1.58±0.3
RH (%)		75.72±8.4	80.2±8.2	67.99±7.8
T (°C)		3.18±0.8	6.1±0.8	10.15±2.0
R (mm)		0.53±0.9	2.48±3.6	1.25±1.6
W (m/s)	2020	1.29±0.3	1.69±0.8	1.75±0.7
RH (%)		90.91±7.6	71.1±20.5	73.21±14.6
T (°C)		4.19±1.9	8.32±1.6	9.86±2.7
R (mm)		0.68±2.3	0.08±0.2	1.61±3.2

Regarding air pollutants, average values were calculated with data from Brescia, Cremona, Lodi, and Mantua stations for each pollutant (NOx, NH_3, and $PM_{2.5}$) and each period (2016-2019 and 2020), and were finally distinguished into "city" stations and "countryside" stations. Table 2 shows these results.

TABLE II. MEAN AND STANDARD DEVIATION OF THE MAIN AIR POLLUTANTS.

Parameters	***Period***	**January**	**February**	**March**
		Mean ±SD	***Mean ±SD***	***Mean ±SD***
NOx country	2016-2019	77.5±14.9	57.2±11.2	36.9±4.3
NOx city		115.1±21.1	78.6±20.1	53.8±11.8
NH_3 country		28.0±8.1	31.4±10.2	36.5±6.7
NH_3 city		8.7±2.1	11.3±4.6	14.2±3.5
$PM_{2.5}$ country		43.1±14.2	33.4±7.1	26.8±4.8
$PM_{2.5}$ city		43.1±13.0	36.1±7.9	26.9±6.0
NOx country	2020	83.9±27.1	46.1±15.2	22.0±7.7
NOx city		127.2±34.2	72.1±22.3	31.9±13.4
NH_3 country		33.1±11.3	57.4±24.2	36.8±19.8
NH_3 city		6.4±2.6	13.9±7.8	10.9±7.8
$PM_{2.5}$ country		45.4±12.5	30.7±12.8	23.5±8.2
$PM_{2.5}$ city		47.3±16.3	30.1±13.9	24.0±8.6

NOx and $PM_{2.5}$ are in all cases statistically higher in January and follow a common reduction trend in February and March, depending on the needs of residential and industrial heating systems. Moreover, the emission of NOx and $PM_{2.5}$ are higher in January 2020 than in the same month of the previous years, although standard deviations are quite wide. NOx records the highest values in January (the coldest month) in the city, with 115.1 μg/m^3 in 2016-2019 and 126.0 μg/m^3 in 2020. In the countryside stations, these values are lower, being equal to 76.4 μg/m^3 in 2016-2019 and 83.5 μg/m^3 in 2020.

In 2020, and in particular, in February and March, the reduction in NOx and $PM_{2.5}$ emissions is bigger than in the previous period and is even bigger in the city stations than in those in the countryside, where are mostly located the livestock and agricultural activities. Regarding $PM_{2.5}$, its formation depends on the combined presence in air of several gases. Not completely significant differences can be highlighted in January 2016-2019 compared with January 2020, while stronger reductions occurred from February 2020, probably, as consequence of the beginning of the lockdown.

Differently, the emission of NH_3 did not reduce in 2020 respect to the same period of 2016-2019. The reason is that to agricultural activities no restriction was imposed during the lockdown. Therefore, agricultural activities, and in particular slurry spreading, took place (similarly to previous years) in the analyzed period. Values of NH_3 in the countryside are similar between 2016-2019 and 2020 in January (28.0±8.1 and 33.1±11.3 μg/m^3 in 2016-2019 and 2020, respectively) and March (36.5±6.6 and 36.8±19.8 μg/m^3 in 2016-2019 and 2020, respectively) but they are higher in February 2020 respect to the previous years, probably because of the lack of possible slurry spreading events in the previous autumn (rainy period).

Two Pearson's correlation matrixes are reported in Table 3 and Table 4, respectively for the analyzed periods of 2016-2019 and 2020. The statistical analyses were carried out separately between 2016-2019 and 2020 in order to better focus on emissions during the lockdown of 2020.

TABLE III. PEARSON'S CORRELATIONS FOR THE PERIOD 2016-2019.

Parameter	NOx city	NH_3 country	NH_3 city	$PM_{2.5}$ country	$PM_{2.5}$ city	Wind speed	Rel. Humidity	Temperature	Rainfall
NOx country	1.0	0.3	0.1	0.8	0.8	0.1	0.7	-0.4	0.0
NOx city		0.3	0.0	0.7	0.7	0.1	0.6	-0.4	-0.0
NH_3 country			0.9	0.4	0.4	0.5	0.5	0.6	-0.1
NH_3 city				0.3	0.3	0.5	0.4	0.7	-0.0
$PM_{2.5}$ country					1.0	0.1	0.7	-0.1	0.0
$PM_{2.5}$ city						0.1	0.8	-0.2	0.0
Wind speed							0.6	0.6	0.3
Rel. Humidity								0.2	0.4
Temperat.									0.1

Notes: Wind = wind speed; RH = relative humidity; T = temperature; Rain = rainfall events.

When the resulting correlation values are equal to or higher than 0.6 a good correlation is considered. In particular, this condition occurs between NOx and $PM_{2.5}$ ($r \geqslant 0.7$), both for city and countryside data, while different results can be observed for NH_3. NH_3 is well correlated only between NH_3 in the countryside station and NH_3 in the city station ($r = 0.9$). Relative humidity and temperature have good correlations with $PM_{2.5}$, NOx and NH_3, while wind speed and rainfall show small correlations.

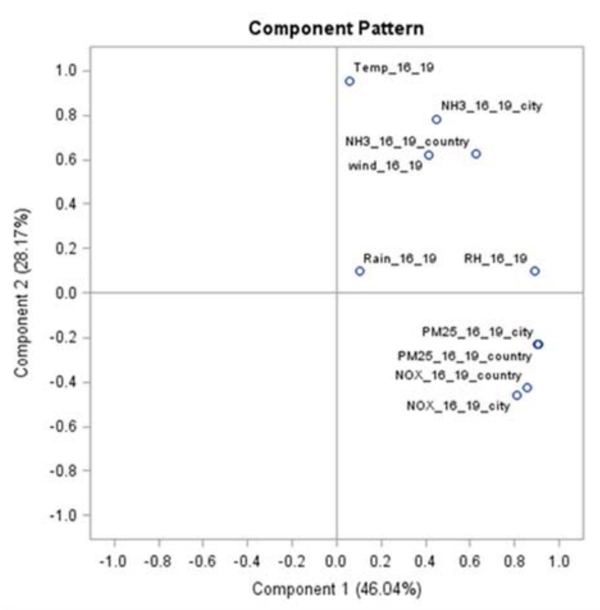
In 2020, the correlations are similar respect to air pollutants, while for weather variables, temperature and relative humidity were well correlated, but wind speed and rainfall not.

TABLE IV. PEARSON'S CORRELATIONS FOR THE PERIOD 2020.

Parameter	NOx city	NH_3 country	NH_3 city	$PM_{2.5}$ country	$PM_{2.5}$ city	Wind speed	Rel. Humidity	Temperature	Rainfall
NOx country	1.0	0.1	-0.0	0.8	0.8	-0.1	0.7	-0.3	-0.1
NOx city		0.2	-0.1	0.8	0.8	-0.1	0.6	-0.3	-0.1
NH_3 country			0.9	0.3	0.3	0.1	0.2	0.6	-0.1
NH_3 city				0.2	0.2	0.0	0.2	0.6	-0.0
$PM_{2.5}$ country					1.0	-0.0	0.8	0.0	-0.1
$PM_{2.5}$ city						-0.1	0.8	-0.0	-0.1
Wind speed							0.2	0.5	0.1
Rel. Humidity								0.1	0.2
Temperat.									-0.0

Notes: Wind = wind speed; RH = relative humidity; T = temperature; Rain = rainfall events.

Fig. 1 reports the graphs that relate Component 1 and Component 2 of PCA for years 2016-2019 and the year 2020, respectively. These components together explain >60% of the variability.



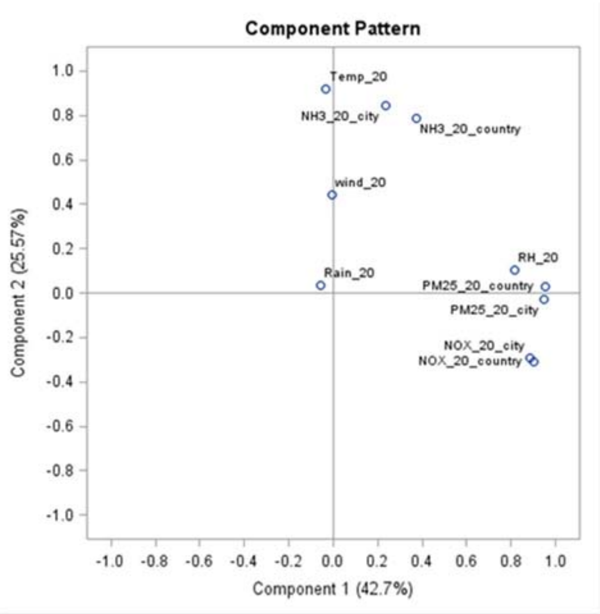


Fig. II. Results of PCA. On the top: period 2016-2019; on the bottom: period 2020.

From these results emerges that every pollutant averaged for city and countryside stations is positioned close to each other. NOx and $PM_{2.5}$ are also very close to each other. Instead, NH_3 is positioned in the upper quarter, thus is influenced by other aspects. However, this difference is partly due to the different sources from which NOx, $PM_{2.5}$ and NH_3 are emitted.

For the period of 2016-2019, wind speed and temperature are quite close to NH_3 emission, so they influenced each other. Differently, relative humidity and especially rainfall are quite isolated. In the analysis referred to the 2020, rainfall results even more isolated, while relative humidity results close to $PM_{2.5}$ emission, and temperature and wind speed are quite far but slightly closer to NH_3, both considering the emission in the city as well as the one in the countryside. This highlights their relationship.

A final step of multivariate analysis includes the GLM. With this procedure are calculated the estimates of GLM for NH_3 emitted in 2020 in the city stations.

TABLE V. GENERAL LINEAR MODEL ESTIMATES FOR NH_3 IN THE CITY STATIONS FOR THE PERIOD JANUARY-MARCH 2020.

Parameters	Estimate	S.E.	t Value	Pr > |t|
Intercept	-0.43	4.82	-0.09	0.93
NOx country	0.09	0.05	1.76	0.09
NOx city	-0.10	0.04	-2.73	0.01
NH_3 country	0.25	0.03	9.05	<.00
$PM_{2.5}$ country	0.03	0.17	0.17	0.86
$PM_{2.5}$ city	-0.02	0.14	-0.14	0.89
Wind speed	-2.37	0.95	-2.49	0.02
Relative Humidity	0.05	0.04	1.04	0.30
Temperature	0.42	0.27	1.54	0.13
Rainfall	0.16	0.31	0.50	0.62

This choice is motivated by the need of estimating the NH_3 emission in the city, even if it is predominantly emitted in countryside areas. From this result, the effect of NH_3 emitted in the countryside and of wind and temperature can be highlighted, as shown in Table 5.

The model significance was equal to r^2=0.83. From the results of the model there is evidence that wind contributes to reduce the emission of NH_3 in the urban areas, whereas temperature contributes to its increase. The same occurs with the emission of NH_3 in the countryside, which also contributes to the increase of the presence of this pollutant in the city areas.

As expected also thank to other literature findings [20], from this analysis emerges that the main part of NH_3 emissions can be observed in the countryside stations. NH_3 is correlated with $PM_{2.5}$ formation because it co-participates together with other pollutants such as NOx and SOx to $PM_{2.5}$ formation. Hence, PM is formed on a larger scale than the one considered in this analysis.

Focusing on Po valley, the study by [20] showed that reducing by 50% the agricultural emissions of NH_3, $PM_{2.5}$ could reduce by 2.4 $\mu g/m^3$, which is not a negligible fraction. However, reducing NH_3 by 50% is not easy, especially because it is formed also from other uncontrollable weather variables, and it requires interventions in the management of livestock manure and of barn air quality, which is a direction towards which stakeholders are investing.

IV. CONCLUSIONS

As effect of the lockdown, some emissions caused by industries, energy production, and traffic deeply reduced (e.g., NOx and $PM_{2.5}$) at least in the urban areas considered, while some emissions caused by agricultural activities did not change (e.g., NH_3) because no stop occurred for agricultural activities.

In this preliminary study emerged the need of further studies focusing on agricultural emissions taking into consideration more data stations and longer periods. In fact, better monitoring locally the emission of NH_3 and introducing targeted interventions for its reduction could be a big opportunity for improving the mitigation capabilities of the agricultural sector. Indeed, in this study attention was paid most of all on NH_3, therefore data stations were selected based on this need. However, air quality is affected by a big series of other factors, such as other pollutants, weather conditions and regional air exchanges, traffic, energy sector and industrial activities. In any case, if NH_3 released from the agricultural activities reduced, also a fraction of $PM_{2.5}$ would reduce.

In order to improve air quality of every country, a combined role of all productive sectors is fundamental.

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