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Describing the trend of ammonia, particulate matter and nitrogen oxides: The role of livestock activities in northern Italy during Covid-19 quarantine

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ABSTRACT

Nitrogen oxides (NOx), sulphur oxides (SOx) and ammonia (NH3) are among the main contributors to the formation of secondary particulate matter (PM2.5), which represent a severe risk to human health. Even if important improvements have been achieved worldwide, traffic, industrial activities, and the energy sector are mostly responsible for NOx and SOx release; instead, the agricultural sector is mainly responsible for NH3 emissions.

Due to the emergency of coronavirus disease, in Italy schools and universities have been locked down from late February 2020, followed in March by almost all production and industrial activities as well as road transport, except for the agricultural ones. This study aims to analyze NH3, PM2.5 and NOx emissions in principal livestock provinces in the Lombardy region (Brescia, Cremona, Lodi, and Mantua) to evaluate if and how air emissions have changed during this quarantine period respect to 2016–2019. For each province, meteorological and air quality data were collected from the database of the Regional Agency for the Protection of the Environment, considering both data stations located in the city and the countryside. In the 2020 selected period, PM2.5 reduction was higher compared to the previous years, especially in February and March. Respect to February, PM2.5 released in March in the city stations reduced by 19%–32% in 2016–2019 and by 21%–41% in 2020. Similarly, NOx data of 2020 were lower than in the 2016–2019 period (reduction in March respect to February of 22–42% for 2016–2019 and of 43–62% for 2020); in particular, this can be observed in city stations, because of the current reduction in anthropogenic emissions related to traffic and industrial activities. A different trend with no reductions was observed for NH3 emissions, as agricultural activities have not stopped during the lockdown. Air quality is affected by many variables, for which making conclusions requires a holistic perspective. Therefore, all sectors must play a role to contribute to the reduction of harmful pollutants.

1. Introduction

Air quality is a big issue in developed countries. The most developed countries and industrialized cities, characterized by important economic exchanges, traffic and highly-density populated commonly have bigger problems than others with air pollution. Several studies are available on these aspects, for example, some Chinese (Giao et al., 2020; Wang et al., 2015) and European (EEA, 2018; Izquierdo et al., 2020; Koolen and Rothenberg, 2019) cities are recognized as highly polluted.

According to the World Health Organization (WHO) (WHO, 2013), ground-level ozone (O3), nitrogen dioxide (NO2) and particulate matter (PM) are the most harmful air pollutants to human health and ecosystems. Among these, PM has been most closely studied due to its adverse health effect. PM identifies fine particles that can have both a primary and secondary origin. In the first case, they are emitted to the atmosphere directly from their sources, such as road traffic and car exhaust gases. Instead, secondary PM precursors are pollutants (e.g. NH3, NOX, and SO2) that are partly transformed into particles by photochemical reactions in the atmosphere (Koolen and Rothenberg, 2019). In more detail, air pollution has a direct effect on human health (Boldo et al., 2014), especially for what regards the long exposure to high concentrations of PM2.5 (Yang et al., 2019). This is known to cause respiratory and cardiovascular diseases (Dominici et al., 2006) since it can penetrate deeply into the lung and translocate to blood circulation (Li et al., 2018). According to EEA (2019b), in Europe, about 400,000 premature deaths per year are attributable to PM2.5 concentrations long-term exposure. Therefore, investigating how to reduce its presence in air is an important issue for society. As regards ecosystems, air pollution is known to cause...
damages to vegetation and ecosystems, such as eutrophication and soil acidification, which finally lead to biodiversity loss (EEA, 2019b). Moreover, excessive PM concentration causes undoubted problems not only in farms neighboring residents (de Rooi et al., 2017), but also in livestock buildings and on workers’ and animals’ health (Conti et al., 2020).

On a global scale, the benchmark limit for PM$_{10}$ set at 20 μg/m$^3$ and PM$_{2.5}$ set at 10 μg/m$^3$ by the WHO is often not respected (EEA, 2019a). It is estimated that around 90% of the global population in 2018 was breathing polluted air (WHO, 2018), in particular, 6–8% of the European population was exposed to PM$_{2.5}$ exceeding limit and 13–19% to PM$_{10}$ exceeding limit (EEA, 2019a). The European Union set the yearly limit for PM$_{10}$ to 50 μg/m$^3$ and PM$_{2.5}$ to 25 μg/m$^3$ (Directive, 2008/50/EC), but although it is less restrictive than the one by WHO, some countries are not able yet to respect it every day of the year; among these, Italy is an example (Kiesewetter et al., 2015). To date, in Lombardy, one of the most productive Italian regions, the measured annual average concentrations of PM$_{2.5}$ range between 10 and 31 μg/m$^3$ and those of PM$_{10}$ from about 20 to 38 μg/m$^3$ (Fattorini and Regoli, 2020). In 2017, among all the Lombardy provincial chief towns, only in Lecco, Sondrio, and Varese the annual average concentrations were lower than the limit value. Instead, Milan, Brescia, Cremona and Mantua were the cities that most exceeded the PM$_{2.5}$ annual limit value (PIA, 2018).

For this series of reasons, some researchers (Wang et al., 2020a; Wu et al., 2020) have started believing that the global spread of Covid-19 has reinforced in areas characterized by bad air quality.

Focusing on Italy, the Po valley – in the Northern part of the country, where also Lombardy region is located - is a highly industrialized and densely populated area characterized by a large concentration of intensive livestock farms (Arvani et al., 2014). These characteristics are also causing pollution, and in addition to them, also geographical and physical characteristics of the Po valley facilitate the persistence of pollutants (Fattore et al., 2011). In particular, they make Po valley one of the most disadvantaged areas in Europe for air quality. First of all, this area is characterized by the presence of the mountain chains of Alps and Apennines on three sides, which affects the pedo-climatic variables, reduces the air exchanges and negatively affects the local air quality. Secondly, the area is poorly ventilated favoring the stagnation of pollutants and consequently contribute to the accumulation of PM (Carugno et al., 2016). Lombardy is located in the middle of the Po valley and it is Italy’s leading industrial and agricultural area (Lovarelli et al., 2020), whose emissions (methane, ammonia, dinitrogen monoxide, etc.) worsen the air quality issue (Rebolledo et al., 2013). To confirm this, Lombardy ranks among the most air polluted areas of Europe (Carugno et al., 2016). Several studies highlighted that the unfavorable geographical context, climate characteristics, and intense anthropogenic activities, such as industry and agriculture, of the Po valley promote a high level of air pollution (Arvani et al., 2014; Diemoz et al., 2019; Thunis et al., 2009). For example, Giannakis et al. (2019) found that the highest PM$_{2.5}$ concentration from the agricultural sector in Europe is present in northern Balkan countries and Northern Italy. Similarly, Thunis et al. (2019) identified as “hotspots” regions for PM emissions the Po valley and Eastern Europe. In addition, by 2050, global ammonia (NH$_3$) emissions are estimated to further increase because of agricultural intensification (Rebolledo et al., 2013). Emissions of NH$_3$ are an important aspect to evaluate, in fact it was estimated that 640 kg of PM$_{10}$ can be formed per ton of NH$_3$ emitted and that 880 kg PM$_{10}$ are formed per ton of nitrogen oxides (NOx) emitted (De Leeuw, 2002).

With the 2020 quarantine caused by the pandemic coronavirus, in Italy, many production and industrial activities have started being locked down from March, except for agricultural ones. The main evidence of this is related to the reduction in traffic: respect to the first part of February 2020, the beginning of March 2020 points out a reduction of about 90% of car traffic and about 50% of heavy vehicles (Buganza et al., 2020). Consequently, it is interesting to identify if and how air emissions are affected by agricultural activities in a polluted area such as Northern Italy, and in particular Lombardy, the Italian region most affected by Covid-19 (Fattorini and Regoli, 2020) and where the lockdown was the most severe (Bontempi, 2020), in a period in which most of the productive activities have been stopped while agricultural-related ones have remained active.

This study aims to analyze the main air emissions related to livestock activities in the cities and provinces of Lombardy that are mostly dedicated to livestock productions. This is carried out to evaluate if and how air emissions have changed in the quarantine period. In particular, from the comparison between the data about air emissions in data stations located in the main cities and those located in small cities or countryside stations, where livestock is the main activity, it is expected to identify a reduction in emissions due to the strong limitation of the industrial sector and transport, but a low reduction of those emissions related to agricultural activities.

1.1. Background

With the lockdown of work activities as a consequence of Covid-19, it can be expected that:

(i) anthropogenic emissions caused by industries, energy-related industries, and traffic deeply reduce,
(ii) emissions caused by agricultural activities should maintain a usual trend.

In Italy, agriculture is known to be responsible for more than 90% of NH$_3$ emissions (EEA, 2019c), in particular in Lombardy region they account for around 97% of all NH$_3$ emissions, corresponding to yearly 94,000 tons (INEMAR, 2020). Therefore, it can be assumed NH$_3$ did not vary in this analyzed quarantine period, except for possible different meteorological aspects. In particular, NH$_3$ emissions from the agricultural sector derive mainly from manure management and the application of fertilizers (Oenema et al., 2012), among which the superficial slurry spreading. Slurry spreading is generally carried out previous to soil preparation for crops sowing. Because this operation occurs seasonally every year and because agricultural activities have not been stopped during quarantine, emissions of NH$_3$ should not be subject to variations caused by the quarantine, instead of by the meteorological trend. In fact, NH$_3$ is a volatile gas whose amount is influenced by temperature, wind speed, and rainfall, other than by livestock housing, storage, and field spreading practices (Anderson et al., 2003; Welch et al., 2005). Given the dependence of agricultural field operations from weather conditions and given the European regulation for organic fertilizers spreading (Nitrate Directive) (Directive 91/676/EEC), the slurry is commonly spread between the end of winter and early spring before soil tillage and summer crops’ sowing, as well as in autumn after the harvest of summer crops and before sowing of winter crops. To this, the Directive norms also organic nitrogen application (Directive 91/676/EEC, 1991). In particular, this Directive obliges to avoid the slurry spreading in the months in which no crop requirements for nutrients occur, and consequently in which runoff and leaching occur the most. Moreover, it is also forbidden to spread slurry when rainfall occurs or is expected to occur in the following days. For these reasons, NH$_3$ emissions can differ on a seasonal and a daily basis. One additional aspect related to NH$_3$ is that it plays an important role in atmospheric chemical reactions that bring to the formation of secondary PM$_{10}$ and PM$_{2.5}$ (Koolen and Rothenberg, 2019). However, it should be considered that the quantity of secondary particulate matter that is formed in the atmosphere starting from the latter is variable in time and space and depends on non-linear processes and meteorology (Marongiu et al., 2020). PM can be classified as primary or secondary according to its origin and it can be both organic and/or inorganic in nature (Cambrá-López et al., 2010). In the atmosphere, NH$_3$ reacts with atmospheric nitric and sulfuric acids to form particulate sulfate (SO$_4^{2-}$), nitrate (NO$_3^-$) and ammonium (NH$_4^+$) compounds, which constitute the major
fraction of secondary inorganic PM$_{2.5}$ (Behera et al., 2013; Wang et al., 2020a). With the reduction in the release of NOx and sulphur oxides (SOx) from industrial activities, energy-related industries and traffic, PM$_{2.5}$ reduces only partially (EIA, 2018). It can be assumed that if NH$_3$ is not subject to changes during the Covid-19 quarantine (Marongiu et al., 2020). PM$_{2.5}$ may also reduce only partially, because the decrease in pollutant emissions caused by transport and industrial activities are not sufficient to avoid the chemical reaction (Wu et al., 2016).

Regarding the agricultural sector, the main sources of PM emissions are buildings housing livestock, in particular those in which are carried out the feed operations, which account for 80–90% of total PM emissions from the agriculture sector. Pig and poultry livestock farms are the main sources of PM (EIA, 2019b) from the agricultural sector. Other than the just mentioned sources, particulate matter emissions from pig houses arise also from skin particles, faeces, and bedding, while emissions from poultry housing from feathers and manure (EIA, 2019b). Together with these categories, cattle farming brings to relevant NH$_3$ and PM emissions, mainly from feed operations (Brown et al., 2018), feedlots (McGinn et al., 2016), barn, and storage tanks. In Lombardy, in 2017, PM$_{2.5}$ and PM$_{10}$ emissions deriving from agriculture accounted for 4% and 6%, respectively (INEMAR, 2020).

2. Materials and methods

2.1. Monitored area

Lombardy houses 38% of the farms specialized in cattle milk production (ISMEA, 2019a), 10% of the farms specialized in cattle meat production (ISMEA, 2019b), and 11% of the pig farms for heavy pig production (ISMEA, 2019c), reaching a total number of reared animals together represent about 77.5% of the total Lombardy livestock production (ISMEA, 2019a), 10% of the farms specialized in cattle milk production (ISMEA, 2019b), and 6%, respectively (INEMAR, 2020).

NH$_3$ volatilization worsens also when optimal meteorological conditions occur (e.g., mild temperatures, low wind speed, and no rainfall) (Brentrup et al., 2000).

2.2. Data collection

Meteorological data and air quality data were collected from the database of the regional agency for environmental protection (ARPA, 2020). Data of ARPA (ARPA, 2020) were downloaded from different ground-based stations per province. The period investigated was January, February, and March of the years 2016–2019 and 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 have been locked down from February, except for agricultural ones.

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/m$^3$), nitrous oxides (NOx, μg/m$^3$), and secondary particulate matter (PM$_{2.5}$, μg/m$^3$). SO$_x$ were not included since these data were not available on the ARPA website. Particulate matter on the order of 10 μm (PM$_{10}$) was investigated only in an initial phase because it is caused by multiple sectors (transport, heating systems, energy sector, etc.) therefore its formation is not only due to agricultural activities and attributing its effect to one single sector may be misleading (Ansari and Pandis, 1998). Instead, since with PM$_{10}$ are intended particles with a diameter equal or less than 10 μm, PM$_{10}$ includes the smaller PM$_{2.5}$, and their trends can be compared. Moreover, because secondary PM$_{2.5}$ is partially formed from NH$_3$ released from livestock activities and the effect of PM$_{2.5}$ on health and ecosystem is damaging (Wang et al., 2020b), in this study PM$_{2.5}$ was analyzed in more detail instead of PM$_{10}$.

Fig. 1 summarizes the research framework and air quality detection and meteorological stations referred to every province analyzed. In every province (i.e. Brescia, Cremona, Lodi, and Mantua), the stations with the availability of the pollutants NH$_3$, NOx, and PM$_{2.5}$ were used, except for Brescia where no detection stations for NH$_3$ emissions were available. All of them were distinguished in stations in the city and the countryside, to investigate the effect of pollutants in the city where most people live, traffic jams may occur and industrial activities are carried out, respect to the countryside, in which the main activities are related to livestock farms. Therefore, with “city” authors refer to those data stations located in a densely populated settlement whose members work primarily on non-agricultural tasks, whereas with “countryside” those located in a rural area mainly used for farming activities (field cultivation and livestock). As mentioned, together with pollutants, the meteorological data (temperature, relative humidity, wind speed, and rainfall) were collected by the same stations for the identified periods. In total, 14 data stations were analyzed for each of the 2 periods (January–March 2016–2019 vs January–March 2020). The final dataset was made of about 6000 data for every emission and meteorological variable. Statistical analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC, USA) statistics software. The mean and standard deviation of weather parameters for the two periods considered were calculated. Descriptive statistics were calculated using a means procedure in SAS. Principal Components Analysis (PCA), Factor Analysis (FA), and a general linear model (GLM) were used to identify relationships among variables and test the resulting model.

3. Results and discussion

For what concerns the analysis of the meteorological aspects, Table 1 reports the average data of the 4 provinces for mean, standard deviation (SD) and minimum and maximum values for temperature (T), relative humidity (RH), wind speed (W) and rainfall (R) in the period of January–March for 2016–2019 and 2020. From the results, it emerges that the weather conditions show reduced differences in the selected years 2016–2019 vs 2020. No events of strong wind speed or heavy rainfall were highlighted for these periods. Moreover, no differences can be observed between city and countryside stations in regard to average weather parameters, since in Italy, especially in the Po valley, agricultural areas are closed to cities due to population density.

To support the fact that PM$_{10}$ and PM$_{2.5}$ maintain a similar trend over time, Fig. 2 reports the average daily trend of PM$_{10}$ and PM$_{2.5}$ in the city of Brescia for the period January–March 2019, to which are associated the wind speed and rainfall events of the same period. In particular, it is possible to notice that air pollutants generally reduce when wind and rainfall events occur. Although not reported, a similar trend was observed also for the other 3 provinces considered (Cremona, Lodi, and Mantua) (available in Supplementary Material).

Analyzing these data, the average presence of PM$_{2.5}$ in air changes as a consequence of meteorological variables; PM$_{2.5}$ in the air after rainfall events is on average 28.14 (±9.97) μg/m$^3$, whereas if no rainfall occurred this value was equal to 37.07 (±14.76) μg/m$^3$. Similarly, although the wind speed is generally low (<1.6 m/s or <6 km/h), when higher wind speed occurred, PM$_{2.5}$ for the studied period of January–March was on average 17.17 (±4.62) μg/m$^3$, while with low wind speeds it was equal to 40.36 (±13.87) μg/m$^3$.

In order to analyze the trend of emissions in the two periods
considered, the air quality stations were grouped as follows: all data stations were split between stations located in the city ("city") and the countryside ("country"). Average values were calculated with data from Brescia, Cremona, Lodi, and Mantua data stations for each pollutant. Hence, for each pollutant (NOx, NH3, and PM2.5) and each period (2016–2019 and 2020) are available average data for "city" and "country" stations. Fig. 3 reports these results.

From these results emerges that emissions of NOx and PM2.5 are in all cases higher in January and follow a common reduction trend in February and March, which is common in all periods analyzed. Moreover, the emission of NOx and PM2.5 were 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), with an average of the city stations equal to 115.1 μg/m³ in 2016–2019 and to 126.0 μg/m³ in 2020. In the countryside stations, these values were equal to 76.4 μg/m³ in 2016–2019 and 83.5 μg/m³ in

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**Table 1**
Mean, standard deviation (SD), minimum and maximum values for daily weather parameters in the weather stations of the Lombardy region during the evaluated periods.

| Year     | Parameter | January | February | March    |
|----------|-----------|---------|----------|----------|
|          |           | mean (SD) | Min-Max | mean (SD) | Min-Max | mean (SD) | Min-Max |
| 2016–2019| W (m/s)   | 1.26 (0.3) | 0.79–2.04 | 1.47 (0.45) | 0.94–3.35 | 1.58 (0.28) | 1.23–2.24 |
|          | RH (%)    | 75.72 (8.4) | 60.99–95.6 | 80.2 (8.25) | 64.23–98.63 | 67.99 (7.8) | 55.63–85.48 |
|          | T (°C)    | 3.18 (0.84) | 1.58–5.32 | 6.1 (0.82) | 4.5–8.91 | 10.15 (2.04) | 6.3–14.25 |
|          | R (mm)    | 0.53 (0.89) | 0–3.99 | 2.48 (3.56) | 0.01–18.65 | 1.25 (1.59) | 0–5.06 |
| 2020     | W (m/s)   | 1.29 (0.3) | 0.88–2.2 | 1.69 (0.76) | 0.83–3.48 | 1.75 (0.68) | 0.98–3.35 |
|          | RH (%)    | 90.91 (7.61) | 66.58–99.53 | 71.1 (20.5) | 31.73–99.63 | 73.21 (14.64) | 40.4–97.5 |
|          | T (°C)    | 4.19 (1.94) | 0.35–7.28 | 8.32 (1.64) | 5.45–11.03 | 9.86 (2.73) | 6.05–14.9 |
|          | R (mm)    | 0.68 (2.32) | 0–12.7 | 0.08 (0.18) | 0–0.85 | 1.61 (3.23) | 0–10 |

Notes: W = wind speed; RH = relative humidity; T = temperature; R = rainfall.
2020. Indeed, NOx emissions gradually decrease from January to March in both periods considered, mainly because of the lower use of heating systems with milder temperatures.

In 2020, and in particular, in February and March, the reduction in NOx and PM2.5 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. NOx in March 2020 amounted to 22.03 (±7.72) μg/m³ in countryside stations and 31.92 (±13.45) μg/m³ in city stations, whereas in the previous period 2016–2019 they amounted to 36.88 (±4.28) μg/m³ and 53.84 (±11.85) μg/m³, respectively in countryside and city stations. This highlight considerable reductions in both city and countryside stations, partially motivated by the mentioned milder temperatures (on average for January–March 2020, 7.46 °C) that allowed reducing home heating systems. Therefore, following the adoption of the Ministerial Decree (DPCM March 8, 2020), which introduced measures to limit travels, and following the reduced adoption of home heating system, NOx emissions decreased in March more than in the other months. In particular, the difference between March and February 2016–2019 ranged from 22.5% to 41.9%, while in the same period for 2020, NOx reduced by 43.3%–61.5%.

Regarding PM2.5, the emission in the cities for March ranges between 19% and 32% respect to February for the period 2016–2019 and between 21% and 41% respect to February in 2020, thus with a considerable reduction that characterized firstly the area of Lodi that was the first to be locked down (DPCM February 23, 2020). Respect to January, in some of the evaluated provinces, the reduction of PM2.5 even reached 65% in 2020, while in the previous period 2016–2019 it did not exceed 46%. In the countryside stations, the reduction of PM2.5 in March respect to February ranged between 16% and 26% in 2016–2019 and between 18% and 43% in 2020. Respect to January 2020, also in the countryside areas the PM2.5 reduction in March reached 57%. Such a reduction for PM2.5 is due to the fact that some of the pollutants co-participating to the formation of PM2.5 have reduced. As reported in Section 1.1, in fact, PM2.5 derives from a chemical reaction in which NH3, NOx, and SOx pollutants can participate. This latter aspect has been highlighted by the study of Collivignarelli et al. (2020), and even if they focused on the area of Milan, they found that PM2.5 concentrations were almost halved during the lockdown period probably due to the precursors (e.g. NOx) reduction. However, focusing on March 2020, PM2.5 was equal on average to 23.48 (±8.17) μg/m³ and 23.99 (±8.59) μg/m³, respectively in countryside and city stations, while in the period March 2016–2019, the average values were 26.8 (±4.8) μg/m³ and 26.92 (±6.04) μg/m³, respectively for countryside and city. For PM2.5, therefore, no evident differences emerge between countryside and city stations; however, some small differences emerge between 2020 and the previous years, which can be mainly due to the reduction in car traffic during the lockdown.

As emerges from Fig. 3, however, the emission of NH3 did not reduce in 2020 respect to the same period of 2016–2019. The reason is related to the fact that for agricultural activities no restriction was imposed during the quarantine. Therefore, agricultural activities, and in particular slurry spreading on the field, took place (similar to previous years) in the analyzed period.

Values of NH3 in the countryside are similar between 2016 and 2019 and 2020 in January (28.0 ± 8.1 and 33.1 ± 11.3 μg/m³ in 2016–2019 and 2020, respectively) and March (36.5 ± 6.6 and 36.8 ± 19.8 μg/m³ in 2016–2019 and 2020, respectively), which was expected; however, they were higher in February 2020 respect to the previous years, probably because of the lack of possible slurry spreading events in the previous autumn. This condition was caused by a particularly rainy period that obliged farmers to avoid the slurry spreading in autumn and introduce more spreading interventions in February 2020. In February 2020, in fact, NH3 emissions are about the double than in the 2016–2019 period (31.4 ± 10.2 μg/m³ in 2016–2019 and 57.5 ± 24.2 μg/m³ in 2020). The higher NH3 emission in the countryside is also reflected by slight increase respect to February 2016–2019 in the stations located in the cities (11.3 ± 4.6 μg/m³ in 2016–2019 and 14.0 ± 7.8 μg/m³ in 2020). Respect to the NH3 emission in the city stations occurred in March, the average values were found equal to 14.2 ± 3.5 μg/m³ in 2016–2019 and 10.9 ± 7.8 μg/m³ in 2020, thus with values considerably lower than in the countryside areas. No strong distances can be observed between city and countryside areas, but specifically for NH3 emission this difference can be relevant.

From the statistical analysis carried out with these data, a Pearson’s correlation matrix is reported in Table 2 and in Table 3, where the main relationships among the identified parameters can be highlighted for the studied periods 2016–2019 and 2020. The statistical analyses were carried out separately between 2016 and 2019 and 2020 in order to better focus on emissions during Covid-19 quarantine. The considered parameters include air quality data of NOx, NH3 and PM2.5 from city and countryside stations as well as weather data of temperature, wind speed, relative humidity, and rainfall for city and countryside stations. A good correlation has been considered for values equal to or higher than 0.6. In particular, a good correlation emerges among pollutants, especially between NOx and PM2.5 (r ≥ 0.74), both for city and countryside data. Instead, NH3 is well correlated only between NH3 in the countryside station and NH3 in the city station (r = 0.88). Relative humidity and temperature have good correlations with PM2.5, NOx and NH3 (r ≥ 0.60), while wind speed and rainfall show small correlations. Regarding 2020, the correlations are similar: NH3 is well correlated with itself (r = 0.86), while PM2.5 and NOx are well correlated with each other (r ≥ 0.76). Once more, correlations are obtained with temperature and relative humidity but not interestingly with wind speed and rainfall.

Similar information emerges also from the Principal Components Analysis (PCA) and Factor Analysis (FA). Fig. 4 reports the first graph relating Component 1 and Component 2 of PCA for years 2016–2019 and the year 2020, respectively. These components together explain >60% of the variability.

In more detail, PCA shows that every pollutant averaged for city and countryside stations is positioned close to each other. NOx and PM2.5 are also close, while NH3 is positioned in the upper quarter. For the 2016–2019 period, wind speed and temperature are quite close to NH3 emission, while relative humidity and especially rainfall are quite isolated. In 2020, rainfall is isolated, relative humidity is closed to PM2.5 emission, while temperature and wind speed are quite far but slightly closer to NH3. With FA, a clear distinction emerges between factors. In particular, 3 factors are identified that describe the components. Factor 1 can be entitled as “PM2.5, NOx and RH”, Factor 2 as “NH3, wind and temperature” and Factor 3 as “rain” for the analysis on 2016–2019. In 2020, the factors are much similar, although a small change occurred between Factor 2 that was characterized as “NH3 and temperature” and Factor 3 that was “wind and rain”. The results of FA are reported in Table 4 and
Finally, a General Linear Model (GLM) was carried out with SAS software, from which emerged interesting results. In particular, the model resulted significant, with $r^2 = 0.83$.

Table 5 reports the estimates of GLM for NH$_3$ in 2020 in the city station, from which can be highlighted the effect of NH$_3$ emitted in the country and of wind and temperature.

The interesting aspect that can be gathered from this study is that among the pollutants, NH$_3$ is mostly evident in the countryside stations, therefore confirming what reported by EEA (2018) and Pozzer et al. (2017). Moreover, NOx and PM$_{2.5}$ are well correlated, but NH$_3$ highlights a specific trend, only partially correlated with PM$_{2.5}$. Since NH$_3$ also contributes with NOx and SOx to PM$_{2.5}$ formation, if NH$_3$ reduced from the agricultural activities, PM$_{2.5}$ would reduce even more, as confirmed also by Zhao et al. (2017). This would involve additional positive benefits on the environment, ecosystems, and human health. As an example, Zambrano-Monserrate et al. (2020) highlighted as positive effects of Covid-19 quarantine an improvement of air quality associated...
Table 4
Factor Analysis for the period 2016–2019.

| Parameters          | Factor1 | Factor2 | Factor3 |
|---------------------|---------|---------|---------|
| NOx 2016–19 country | 0.86    | −0.42   | −0.01   |
| NOx 2016–19 city    | 0.81    | −0.46   | −0.04   |
| NH3 2016–19 country | 0.63    | 0.63    | −0.35   |
| NH3 2016–19 city    | 0.45    | 0.78    | −0.26   |
| PM2.5 2016–19 country | 0.90   | −0.23   | −0.11   |
| PM2.5 2016–19 city  | 0.91    | −0.23   | −0.08   |
| Wind 2016–19        | 0.42    | 0.62    | 0.38    |
| RH 2016–19          | 0.89    | 0.10    | 0.33    |
| T 2016–19           | 0.06    | 0.96    | 0.00    |
| Rain 2016–19        | 0.10    | 0.10    | 0.91    |

Table 5
Factor Analysis for the period 2020.

| Parameters          | Factor1 | Factor2 | Factor3 |
|---------------------|---------|---------|---------|
| NOx 2020 country    | 0.90    | −0.31   | −0.01   |
| NOx 2020 city       | 0.89    | −0.29   | −0.02   |
| NH3 2020 country    | 0.37    | 0.78    | −0.31   |
| NH3 2020 city       | 0.24    | 0.84    | −0.32   |
| PM2.5 2020 country  | 0.95    | 0.03    | −0.03   |
| PM2.5 2020 city     | 0.95    | −0.03   | −0.03   |
| Wind 2020           | −0.01   | 0.44    | 0.69    |
| RH 2020             | 0.81    | 0.10    | 0.40    |
| T 2020              | −0.04   | 0.92    | 0.15    |
| Rain 2020           | −0.06   | 0.03    | 0.68    |

Table 6
General Linear Model results.

| Parameter     | Estimate | S.E. | t Value | Pr > |t| |
|---------------|----------|------|---------|------|---|
| Intercept     | −0.431   | 4.823| −0.090  | 0.929|   |
| NOx 2020 country | 0.087   | 0.050| 1.760   | 0.085|   |
| NOx 2020 city  | −0.966   | 0.035| −2.730  | 0.009|   |
| NH3 2020 country | 0.249   | 0.028| 9.050   | <.0001|   |
| PM2.5 2020 country | 0.028  | 0.165| 0.170   | 0.864|   |
| PM2.5 2020 city  | −0.020   | 0.141| −0.140  | 0.889|   |
| Wind 2020      | −2.371   | 0.954| −2.490  | 0.016|   |
| RH 2020        | 0.045    | 0.043| 1.040   | 0.301|   |
| T 2020         | 0.417    | 0.271| 1.540   | 0.130|   |
| Rain 2020      | 0.156    | 0.311| 0.500   | 0.618|   |

with PM2.5 and NO2 emissions reduction, improved appearance of beaches and a reduction of the environmental noise level. Moreover, also in the study of Pozzer et al. (2017), it is reported that reducing by 50% the agricultural emissions of NH3, a reduction of PM2.5 equal to 2.4 μg/m3 could be obtained in the Po valley region. In this way also global mortality and respiratory diseases due to PM2.5 could be reduced. This reduction value is important considering that Po valley basin is among the European areas at greatest risk of exceeding the threshold limits of air quality due to its geographic confinement and to the high level of industrialization and anthropization. Regarding the reduction of NOx and partial reduction of PM2.5, this effect is more evident in the cities than in the agricultural areas; therefore, their reduction can be partially attributed to the reduction in traffic and interruption of many industrial and energetic activities. As reported by Marongiu et al. (2020), during March 2020 NOx deriving from transport reduced by 60%, and NOx from energy production and industries decreased by 4% and 13%, respectively. Also, Buganza et al. (2020) and Chauhan and Singh (2020) observed a reduction in PM2.5 concentrations in the period characterized by the Covid-19 emergency. Improving these aspects of air quality is very important, as reported also by a preliminary study conducted by ARPA and Lombardy region (Buganza et al., 2020). Considering all these emissions, it is important to note that the current strong reduction in traffic and industrial activities has helped reduce PM2.5 (Wu et al., 2016), therefore a combined reduction of all air pollutants should be promoted.

Being the agricultural sector responsible for the widest part of NH3 emissions, this sector should adopt measures for its reduction, providing interventions to improve the agricultural impact on the environment (Zhao et al., 2017). Policymakers and stakeholders should promote policies, incentives and disseminate knowledge to farmers about the need of abating NH3 emissions with the already widely studied solutions: covering tanks for slurry and digestate storage instead of adopting open tanks (Bacenetti et al., 2016b; Finzi et al., 2019; Guarino et al., 2006), introducing treatment systems for slurry (anaerobic digestion, solid-liquid separation, nitro-denitro, air treatment, additives, etc.) (Dinuccio et al., 2011; Fangueiro et al., 2009; Finzi et al., 2020), removing frequently slurry and manure from the barn (Hoff et al., 2006) and spreading slurry on-field through injection techniques that permit to spread slurry into the soil through anchors and avoiding the superficial spreading with diverter plates (Hansen et al., 2003; Mattila and Joki-Tokola, 2003) that instead favor the conditions for NH3 volatilization. These just mentioned are all strategies related to manure/slurry management, however, other strategies allow reducing pollutants inside livestock houses, such as biofilters, bioscrubbers (or biotrickling filters), dry filters, water scrubbers, and wet acid scrubbers (Dumont, 2018; Van der Heyden et al., 2015). All these air cleaning systems improve the air quality that animals and farmers breathe daily, with positive effects on animal welfare and thus on-farm performance and profitability, but also assuring a healthier environment for animals and workers. Finally, it could be useful to set a benchmark limit not only for PM2.5 and nitrogen application, but also for NH3, NOx, and SOx. To date, the only limit set by the National Emission Ceilings Directive, 2016/2284/EU regards the obligation in European countries to abate NH3 emission by 6% by 2020 (Directive (EU) 2016/2284).

4. Conclusions

From this preliminary study about air quality variation during the Covid-19 quarantine period, some conclusions can be drawn, and some key aspects can be opened for discussion on the agricultural sector, but also on industrial activities, energy sector, and traffic. The achieved results allowed to confirm what was initially expected. Probably as an effect of the quarantine, some emissions caused by industries, energy production, and traffic deeply reduced (e.g., NOx and PM2.5) at least in the cities areas considered, while some emissions caused by the agricultural activities did not change (e.g., NH3) because no variations occurred for agricultural activities within the quarantine framework. However, further studies focused on agricultural emissions considering more data air quality stations are needed, also over a longer period of time. These could give the opportunity to better monitor the emission of NH3 on the territory and introduce targeted interventions for its reduction. This study may be considered as a preliminary reference to future evaluations on agricultural emissions.

From some current discussions, it could be concluded that somehow air quality has slightly improved; but this last conclusion cannot be drawn at the time being and relatively to this study. This research aimed to focus on agricultural activities, therefore data stations were selected based on this need. Moreover, air quality is affected by a big series of factors, among which other pollutants such as SOx, local weather conditions, regional air exchanges, traffic, energy-related industry and industrial activities that in this study were not evaluated. For what regards the responsibility of the agricultural sector to PM2.5 emission, the need for abating NH3 emissions is highlighted. Since agricultural NH3 emissions derive mainly by livestock housing, manure storage and manure spreading, the already studied solutions of covering tanks, introducing additives, removing and treating slurry, using air cleaning systems in barns, and improving the spreading techniques should be promoted by policymakers and stakeholders. This last point can be carried out through the promotion of policies and incentives, and disseminating knowledge to farmers who are the final decision-makers for investing in
the improvement of air quality. Moreover, much need to be done to comply with air quality regulations in order to not exceed PM limits and also implement more restrictive rules related to agricultural NH3 emissions reduction. In any case, to improve the air quality, a combined role of all productive sectors is fundamental because pollutants, and in particular PM2.5, derive from the co-presence of multiple pollutants in the air.

Authorship contribution statement

All authors have contributed equally to this work. All authors have read and approved the final manuscript.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2020.110048.

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