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Analysis of lockdown for CoViD-19 impact on NO_2 in London, Milan and Paris: What lesson can be learnt?

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ABSTRACT

Nitrogen dioxide (NO_2) can have harmful effects on human health and can act as a precursor for the formation of other air pollutants in urban environment such as secondary $PM_{2.5}$ and ozone. The lockdown measures for CoViD-19 allowed to simulate on a large scale the massive and prolonged reduction of road traffic (the main source for NO_2 in urban environment). This work aims to selectively assess the maximum impact that total traffic blocking measures can have on NO_2. For this reason, three megacities (London, Milan and Paris) were chosen which had similar characteristics in terms of climatic conditions, population, policies of urban traffic management and lockdown measures. 52 air quality control units have been used to compare data measured in lockdown and in the same periods of previous years, highlighting a significant decrease in NO_2 concentration due to traffic (London: 71.1 % - 80.8 %; Milan: 8.6 % - 42.4 %; Paris: 65.7 % - 79.8 %). In 2020 the contribution of traffic in London, Milan and Paris dropped to 3.3 ± 1.3 $\mu g\ m^{-3}$, 6.1 ± 0.8 $\mu g\ m^{-3}$, and 13.4 ± 1.5 $\mu g\ m^{-3}$, respectively. Despite the significant reduction in the NO_2 concentration, in UT stations average NO_2 concentrations higher than 40 $\mu g\ m^{-3}$ were registered for several days. In order to reduce the pollution, the limitation of road traffic could be not enough, but a vision also aimed at rethink the vehicles and their polluting effects should be developed.

1. Introduction

In March 2020, the World Health Organization declared a pandemic state (WHO, 2020) and, in many countries a total lockdown was imposed (Collivignarelli et al., 2020b; Lau et al., 2020). The heavy restrictions on movements imposed to limit SARS-CoV-2 contagion have made it possible to significantly reduce the impact of CoViD-19 on national health systems by limiting the otherwise exponential number of victims (Lau et al., 2020; Remuzzi and Remuzzi, 2020; Saez et al., 2020; Sjödin et al., 2020; Tobías, 2020). However, these measures allowed to simulate situations only hypothesized or tested on a small scale till now but never realized on a large scale, such as the massive and prolonged reduction of vehicular traffic in urban environments.

The effects of road traffic on air quality in large cities have been studied for years and the main pollutants emitted by vehicles are: particulate matter with a diameter lower than 10 μm (PM_{10}) (Heydari et al., 2020; Ionescu et al., 2013; Pant and Harrison, 2013; Thorpe and Harrison, 2008), black carbon (Ali et al., 2020; Invernizzi et al., 2011), CO_2 (Zheng et al., 2020) and nitrogen dioxide (NO_2) (Agudelo-Castañeda et al., 2020; Degrauewe et al., 2019). In the literature there are many works on the quantification and modelling of the dispersion of pollutants from their sources. Some of thesefocused on the spaciotemporal heterogeneity of the emissions (Zhang et al., 2019, 2020).

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Several studies highlighted also that high concentration of these pollutants for prolonged periods, particularly NO_2, can have harmful effects on human health (Bahrami Asl et al., 2018; Curtis et al., 2006; Strak et al., 2017; Zhao et al., 2020). For instance, according to Khaniabadi et al. (2017), the exposure to high levels of NO_2-containing air or proximity to a busy road increases the likelihood of lung cancers among ex-smokers and non-smokers. Moreover, NO_2 can act as a precursor for the formation of other air pollutants such as secondary $PM_{2.5}$ (Chen et al., 2017) and, in the presence of solar irradiation, of ozone (O_3) (Escudero et al., 2019). While other traffic pollutants (e.g. PM_{10}) may also have a different type of origin (e.g. domestic heating, industrial sector, etc.) (EEA, 2012), the emission of NO_2 in major European cities is almost exclusively attributable to road transport (Degrauewe et al., 2019).

For these reasons, attempts have been made to limit the access of private vehicles in large urban areas in favour of public transport, through various measures such as the creation of low emission zones (LEZs) or the introduction of tolls for entering in the city centre (Gehrsitz, 2017; Jiang et al., 2017; Mussone, 2017; Trivellato et al., 2019). However, in large cities, road traffic is still the main polluting source for NO_2 (Degrauewe et al., 2019).

Several researches relating to the impact of the lockdown in major cities are available in the literature (Collivignarelli et al., 2020a; Hashim et al., 2021; Mahato et al., 2020; Nakada and Urban, 2020; Tobías et al., 2020). They clearly demonstrated a significant improvement in air quality in the period of greatest limitations, but they were mainly focused on the effect of the combined reduction of all NO_2 sources. However, the total lockdown gives also the unique opportunity to evaluate the effect on air quality of the prolonged limitation of vehicular traffic, specifically.

This work aims to selectively assess the maximum impact that total traffic blocking measures can have on NO_2. For this reason, three "megacities" (London, Milan and Paris) were chosen which had similar characteristics in terms of climatic conditions, population, policies of urban traffic management and lockdown measures. 25 urban traffic (UT) air quality stations (where pollution level was influenced mainly by traffic emissions) and 27 urban background (UB) air quality stations (where pollution level was influenced by the integrated contribution of all sources) have been used to collect data measured during the lockdown and in the same periods of 2019, 2018 and 2017. Since weather conditions have a great influence on air quality, the temperature, rainfall and wind speed were also studied and discussed. The results made it possible to formulate proposals and future perspective for a better management of the urban environment to reduce traffic pollution.

2. Methods

2.1. Cities and periods studied

The study involved three European "megacities": (i) London, (ii) Milan and (iii) Paris. In order to obtain reliable results, it was decided to consider the cities as a whole beyond the municipal borders and not just a limited portion of them (Fig. 1). Ğreater Londonänd the entire territory of the "Metropolitan City of Milan" were considered. Finally, for Paris the "Départements" of Paris, Val-de-Marne, Seine-Saint-Denis and Hauts-de-Seine were considered. The aim was to develop the study on different cities that presented similar conditions to evaluate the repeatability of the results. According to recent data, they had similar population presenting over 8,500,000 (London) (ONS, 2020), 3,250,000 (Milan) (CMM, 2020) and 6,500,000 (Paris) inhabitants (INSEE, 2016). These three cities were also selected due to their similar: (i) policies of urban traffic management, with LEZs divided into different bands that impose increasingly restrictive requirements on vehicles approaching the central area (MoM, 2020; MoP, 2020; TfL, 2020), and (ii) climatic conditions, with temperate/mesothermal characteristics according to Köppen climate classification (Köppen, 1936). Moreover, these cities were subjected to similar lockdown measures.

Table 1
Total lockdown periods considered for each city.

City	Period		Reference
	Start	End	
London	26.03.2020	12.05.2020	Gov.UK (2020)
Milan	11.03.2020	03.05.2020	DPCM (2020)
Paris	17.03.2020	10.05.2020	Legifrance (2020a,b,c,d)

For each of the cities, different periods were considered depending on the entry into force of the restrictive rules that imposed a total lockdown. Table 1 shows the total lockdown periods considered in the study.

2.2. Data collection and processing

2.2.1. Movements and traffic data

Data on movements in London, Milan and Paris have been collected from Google COVID-19 Community Mobility Reports (Google LLC, 2020). In the selected periods, data on movements associated with public transport, retail and recreation (e.g. restaurants, shopping centres, museums, and cinemas), and workplaces have been studied. As reported by Google (Google LLC, 2020), for a given day of the week, the reference was the median value measured over the five-week period from the 3rd January 2020to the 6th February 2020.

Moreover, information on mobility trends related to CoViD-19 for London, Milan and Paris have been collected from Apple © reports (Apple, 2020) that assumed the 13 January 2020 as reference.

2.2.2. Meteorological data

Data on temperature, rainfall, and wind speed for London, Milan and Paris have been collected by the U.S. National Oceanic and Atmospheric Administration (NOAA-NCEI, 2020). For each city, one meteorological control unit located within the boundaries of the area, have been selected (Fig. 1). The daily averages (24 h) monitored during the lockdown were compared with those of the same period of 2019, 2018, and 2016. For rainfall values, the comparison was also made on the total contribution in the periods considered.

2.2.3. Air quality data

Data of NO_2 concentration were obtained from the local air quality agency (AIRPARIF, 2020; ARPA Lombardia, 2020; UK AIR, 2020). All urban traffic (UT) and urban backgrounds (UB) air quality control units located in London (10), Milan (15), and Paris (27) were selected and used for obtaining hourly data in total lockdown and in the same periods of 2019, 2018 and 2017 (Fig. 1).

The daily averages (24 h) of the NO_2 pollutant concentration for each city have been calculated and the percentage change of the mean concentrations throughout the periods was examined. The European legislation requires that the NO_2 annual average concentration of 40 $\mu g\ m^{-3}$ is not exceeded (EP, 2008). This value was chosen as a reference to better understand the effect of the lockdown. Days in which the average exceeded 40 $\mu g\ m^{-3}$ were counted and this value was compared with that recorded in the same period of previous years. Moreover, for each city, the ratio between the average daily measurement of NO_2 in the UT and UB

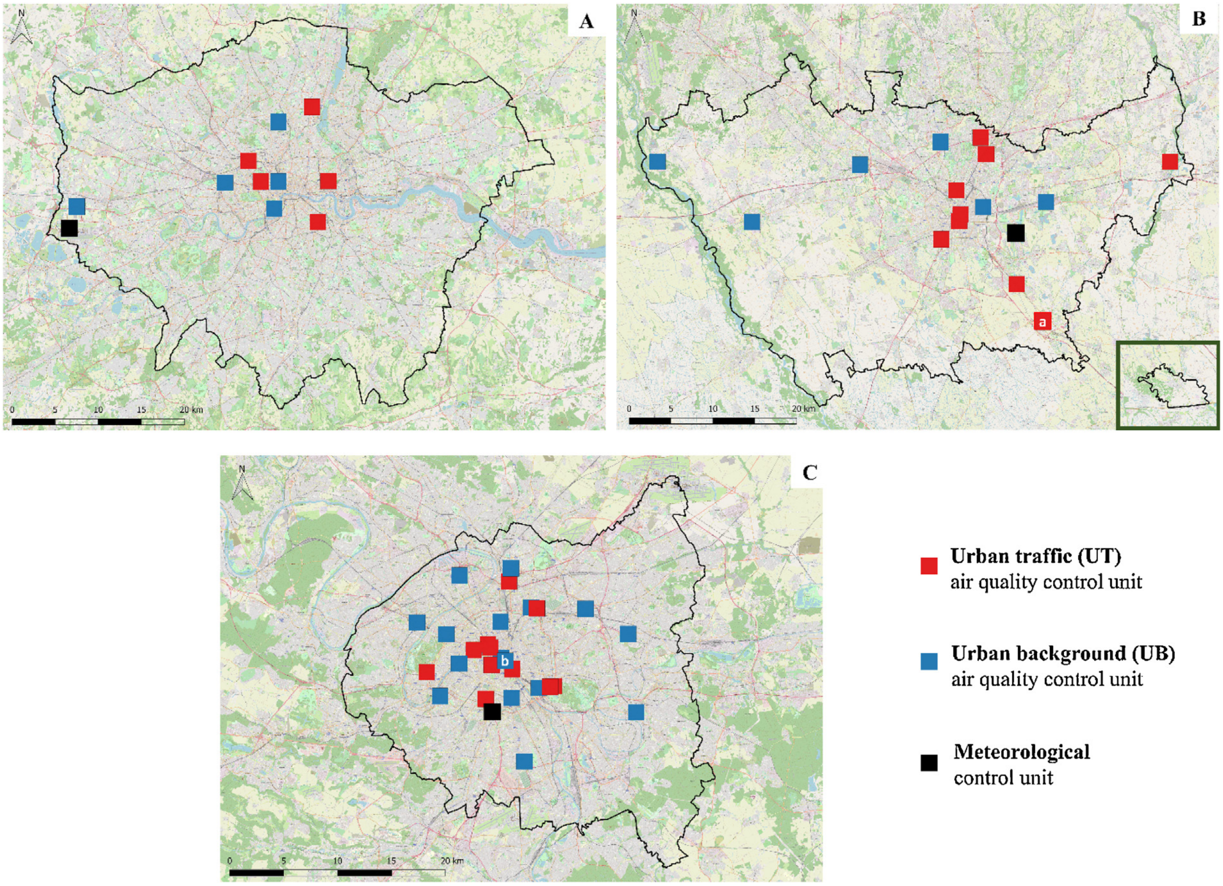

Fig. 1. Area of the study in London (**A**), Milan (**B**) and Paris (**C**). a: only data from 2017 to 2018 were available; b: The station located in Igor Stravinsky square was moved to the Nelson Mandela gardens at the end of 2019, remaining classified as UB. The figure has been realized with QGIS (2020) while the layer of the map is to be attributed to © OpenStreetMap contributors (OpenStreetMap, 2020). Map data copyrighted © OpenStreetMap contributors and available from https://www.openstreetmap.org.

stations has been calculated (Eq. 1) and compared with that of the previous years (2019, 2018, and 2017).

$$ratio\, NO_{2\,UT}\, NO_{2\,UB}^{-1} = \frac{(\sum_{i=1}^{n} NO_{2,i\,UT})\, n^{-1}}{(\sum_{i=1}^{m} NO_{2,i\,UB})\, m^{-1}} \quad (1)$$

Where $NO_{2,i\,UT}$ and $NO_{2,i\,UB}$ represent the daily measures of NO_2 in UT and UB control units, respectively. “n” and “m” are the numbers of daily data measured in UT and UB stations, respectively. Moreover, the concentrations measured by the UT control units and UB control units during lockdown were used to calculate the change in the traffic contribution, as reported in Eq. 2.

$$NO_2\, urban \quad traffic = \int_1^n NO_{2,\,UT}(x)dx - \int_1^n NO_{2,\,UB}(x)dx \quad (2)$$

Where “1-n” represents the period considered. Finally, results were compared with NO_2 measured in the same periods of previous three years.

3. Results

3.1. Movements and traffic

As expected, according to data provided by Google LCC (2020), during the total lockdown, movement to entertainment venues (e.g. cinemas, museums and restaurants), workplaces and transit through public transport hubs dropped. In London they were reduced by 80.2 ± 0.9 %, 70.5 ± 2.5 %, and 76.8 ± 0.8 %, respectively. Similar data were recorded in Milan (−87.5 ± 1.6 %, −70.8 ± 2.1 %, and −84.2 ± 1.0 %, respectively) and Paris (−84.5 ± 1.2 %, −72.2 ± 2.9 %, and −79.9 ± 1.1 %, respectively) (Fig. 2).

This had an impact on road traffic, which in urban environments was significantly reduced. To verify the almost total absence of traffic in these cities, and therefore to motivate the research conducted, the data provided by Apple © (Apple, 2020) on the mobility trends of people during lockdown were also studied. According to data based on changes to requests for directions on Apple © Maps, during lockdown the reduction in driving activity was massive in all three cities: −66.1 ± 1.4 % in London, −83.2 ± 1.0 % in Milan and −82.5 ± 1.3 % in Paris.

3.2. Meteorological conditions

Considering that meteorological events generally have a strong influence on the concentrations of air pollutants (Baklanov et al., 2016; Borge et al., 2019; Zhao et al., 2019), meteorological data collected in cities have been studied (Table 2).

Regarding London, an overall equivalence of the average temperature and wind speed in the periods studied was found. Total rainfall during lockdown in 2020 (39.1 mm) is similar than that of the same period of 2019 (45.5 mm), while it was more abundant in 2018 (110.5 mm) and significantly reduced in 2017 (9.4 mm). The analysis of the Milan data in the lockdown phase showed climatic conditions very similar to those of previous years except for

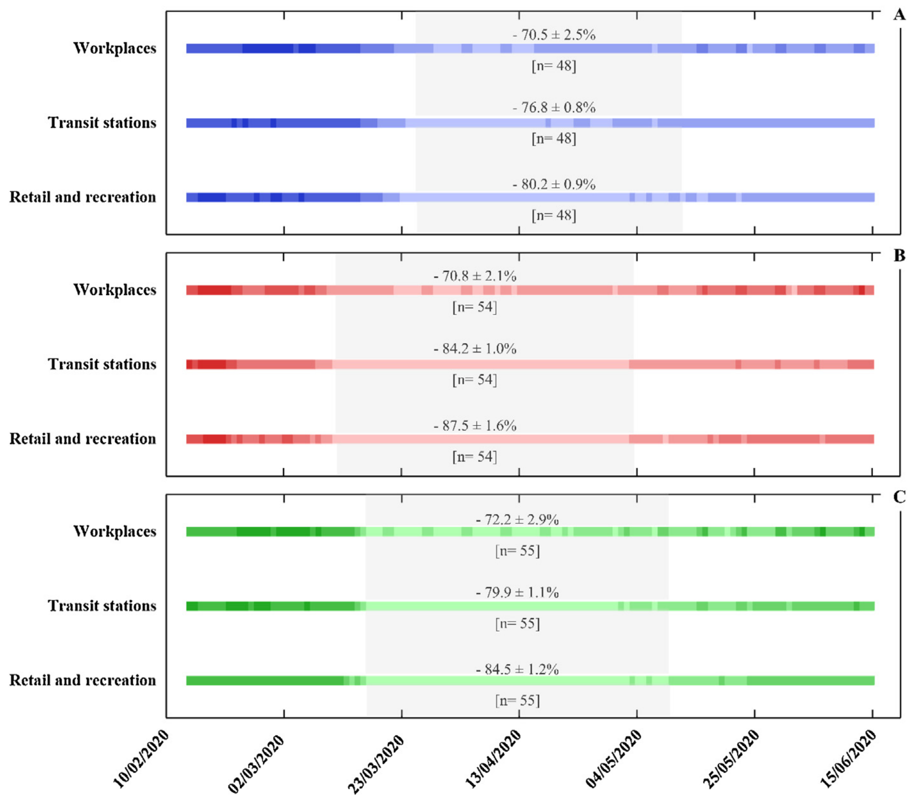

Fig. 2. Data on movements associated with workplaces, public transport, and retail and recreation in London (**A**), Milan (**B**) and Paris (**C**) from the 15th of February 2020 to the 15th of June 2020 (Google LLC, 2020). For each city, the period of total lockdown selected in the study is highlighted in grey. Lighter staining represents residual activity while more intense staining is associated with more significant activity than baseline values. n: number of data.

Table 2
Temperature, rainfall and wind speed measured during lockdown and in the same periods of 2019, 2018, and 2017. n: number of data.

		2020	2019	2018	2017
LONDON *(from 26 March to 12 May)*					
Temperature [°C]	Average	11.3 ± 0.9 [n = 48]	10.3 ± 0.8 [n = 48]	11.4 ± 1.1 [n = 48]	11.1 ± 0.6 [n = 48]
Rainfall [mm]	Average	0.2 ± 0.1 [n = 48]	2.3 ± 1.0 [n = 48]	0.9 ± 0.7 [n = 48]	0.8 ± 0.8 [n = 48]
	Total	39.1 [n = 48]	45.5 [n = 48]	110.5 [n = 48]	9.4 [n = 48]
Wind speed [m s^{-1}]	Average	3.1 ± 0.3 [n = 48]	3.4 ± 0.3 [n = 48]	2.9 ± 0.4 [n = 48]	3.1 ± 0.3 [n = 48]
MILAN *(from 11 March to 03 May)*					
Temperature [°C]	Average	13.3 ± 1.0 [n = 54]	13.0 ± 0.7 [n = 54]	13.2 ± 1.2 [n = 54]	14.0 ± 0.6 [n = 54]
Rainfall [mm]	Average	0.6 ± 0.5 [n = 54]	1.9 ± 1.3 [n = 54]	4.6 ± 2.6 [n = 54]	2.5 ± 1.9 [n = 54]
	Total	35.1 [n = 54]	102.1 [n = 54]	250.7 [n = 54]	136.9 [n = 54]
Wind speed [m s^{-1}]	Average	1.8 ± 0.2 [n = 54]	2.2 ± 0.3 [n = 54]	1.9 ± 0.1 [n = 54]	1.9 ± 1.9 [n = 54]
PARIS *(from 17 March to 10 May)*					
Temperature [°C]	Average	13.7 ± 1.1 [n = 55]	11.6 ± 0.9 [n = 55]	12.5 ± 1.4 [n = 55]	11.8 ± 0.6 [n = 55]
Rainfall [mm]	Average	1.2 ± 1.3 [n = 55]	1.0 ± 0.6 [n = 55]	1.5 ± 0.8 [n = 55]	1.3 ± 0.9 [n = 55]
	Total	67.3 [n = 55]	56.6 [n = 55]	83.8 [n = 55]	73.9 [n = 55]
Wind speed [m s^{-1}]	Average	2.6 ± 0.3 [n = 55]	2.6 ± 0.2 [n = 55]	2.7 ± 0.2 [n = 55]	2.6 ± 0.9 [n = 55]

the overall rainfall which in 2020 (35.1 mm) was less than half of that measured in 2019 (102.1 mm). On the contrary, in Paris, average temperature, average and total rainfall and average wind speed during lockdown were entirely comparable to those of the same period of previous years (2017–2019).

These results are useful for explaining the trend of the average NO_2 concentration in the urban environments considered over the various years.

3.3. *Nitrogen dioxide in urban environment*

3.3.1. *Monitoring of air quality control units*

Data from all the UT and UB control units present in the cities were used to determine the average NO_2 concentrations during the total lockdown. These values were compared with what was recorded in the same period of the previous years (2017, 2018, and 2019) (Fig. 3). The reduction of NO_2 concentration in UT and UB stations during lockdown and the comparison with previous years are detailed in Table 3.

In London, during the lockdown, the measured NO_2 concentration was 25.1 ± 2.6 μg m^{-3} and 21.8 ± 2.4 μg m^{-3} in the UT and UB control units, respectively. The reduction was significant: 53.6 % in UT control units and 39.3 % in UB control units compared to the average value of 2017–2019 (54.2 ± 2.0 μg m^{-3} in UT and 36.0 ± 1.8 μg m^{-3} in UB).If compared with previous years, these values allowed to highlight a greater percentage reduction in correspondence with the UT control units (even over 55 %) while in the UB control units it was more contained (around 40 %). In Milan, during

Table 3
Reduction of NO_2 concentration in UT and UB stations during lockdown in comparison with previous years.

	$\Delta_{2020/2017-2019}$ [μg m^{-3}] (%)	$\Delta_{2020/2019}$ [μg m^{-3}] (%)	$\Delta_{2020/2018}$ [μg m^{-3}] (%)	$\Delta_{2020/2017}$ [μg m^{-3}] (%)
LONDON *(from 26 March to 12 May)*				
UT	29 ± 2.7 (53.6)	23.8 ± 4.6 (48.7)	33.2 ± 4.5 (56.9)	30.1 ± 4.3 (54.5)
UB	14.1 ± 2.4 (39.3)	12.9 ± 4.4 (37.1)	15.2 ± 3.9 (41.0)	14.4 ± 4.1 (39.7)
MILAN *(from 11 March to 03 May)*				
UT	17.2 ± 2.6 (39.0)	13.1 ± 4.5 (32.7)	19.7 ± 4.1 (42.3)	18.8 ± 4.7 (41.1)
UB	14 ± 2.4 (40.2)	12.6 ± 4.4 (37.6)	15.2 ± 3.9 (42.2)	14.2 ± 4.1 (40.6)
PARIS *(from 17 March to 10 May)*				
UT	33.6 ± 3.2 (51.5)	31.2 ± 5.5 (49.7)	34.1 ± 5.2 (51.9)	35.4 ± 5.9 (52.8)
UB	14.9 ± 2.2 (45.0)	16.0 ± 4.1 (46.7)	14.4 ± 3.5 (44.1)	14.4 ± 4 (44.2)

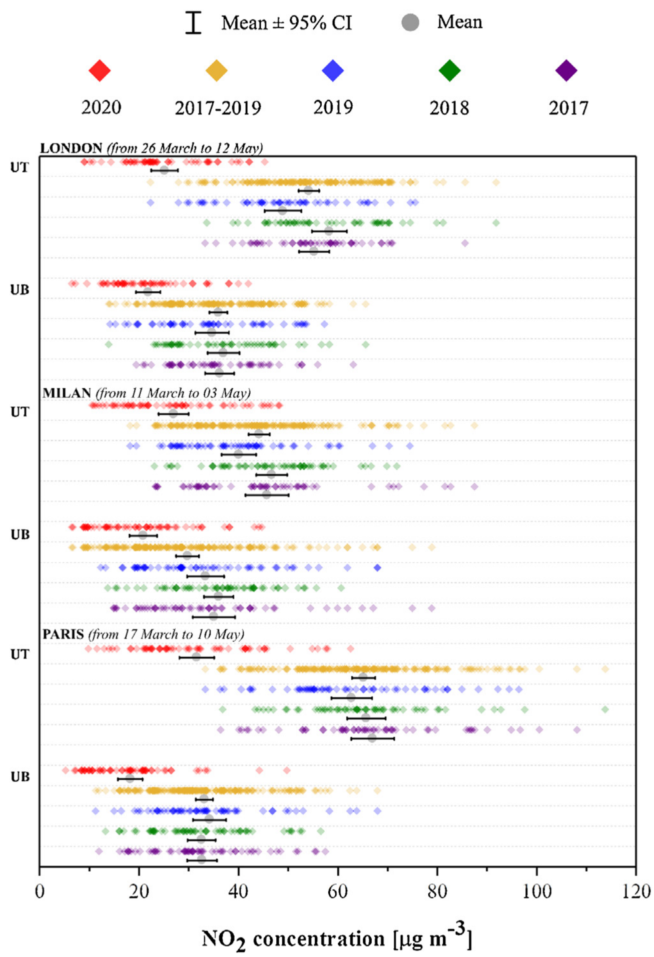

Fig. 3. NO_2 concentration during lockdown in 2020 and in the same period of 2019, 2018, and 2017. For the reduction of NO_2 concentration in UT and UB stations during lockdown and the comparison with previous years, please see Table 3.

the lockdown, the NO_2 concentration was 26.9 ± 2.9 μg m^{-3} and 20.8 ± 2.7 μg m^{-3} in the UT and UB control units, respectively. Also in this case, the reduction compared to the average value of previous years (2017–2019) was significant: 39.0 % in the UT control units and approximately 40.2 % in the UB control units (44.2 ± 2.1 μg m^{-3} in UT and 34.8 ± 2.1 μg m^{-3} in UB). In Paris, during the lockdown, the NO_2 concentration was similar to that measured in London and Milan (31.6 ± 3.4 μg m^{-3} and 18.2 ± 2.4 μg m^{-3} in the UT and UB control units, respectively) with a marked decrease compared to the average value measured in 2017–2019 (65.2 ± 2.3 μg m^{-3} in UT and 33.1 ± 1.7 μg m^{-3} in UB): 51.5 % in UT and approximately 45.0 % in UB control units. In general, absolute values indicated that the decrease was decidedly more evident in the UT stations than in the UB stations.

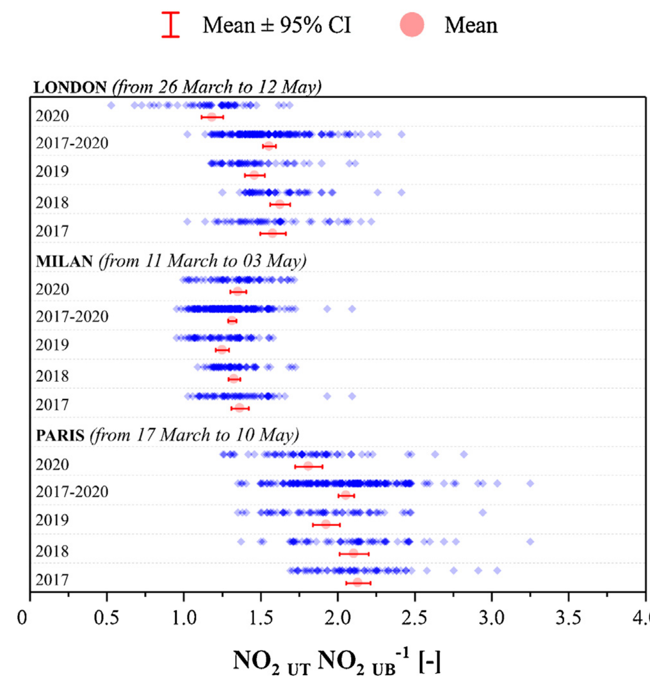

Fig. 4. Ratio between NO_2 concentration in UT and UB control units during lockdown in 2020 and in the same period of 2019, 2018, and 2017.

Table 4
Number of days with an average NO_2 concentration higher than 40 μg m^{-3}.

	2020	2019	2018	2017
LONDON [Number of days: 48]				
UT	4	37	45	45
UB	2	16	19	18
MILAN [Number of days: 54]				
UT	9	26	39	33
UB	3	16	20	17
PARIS [Number of days: 55]				
UT	16	52	54	54
UB	2	12	14	13

The average daily NO_2 concentration of 40 μg m^{-3} was chosen as a reference to better understand the effect of the lockdown. The days in which the average NO_2exceeded this value were counted and compared with those recorded in the same period of previous years. All cities show a marked improvement in air quality with a drastic decrease in the number of exceedances in both UT and UB stations (Table 4). However, cities nevertheless showed that the daily average of 40 μg m^{-3} was exceeded, in particular in the UT stations (London: 4/48; Milan; 9/54; Paris: 16/55).

During lockdown, the ratio between NO_2 measured in UT and UB control units remained substantially unchanged compared to that measured in previous years, except for London (Fig. 4). In this city, the NO_2 ratio was 1.6 ± 0.1 in 2017–2019 and 1.2 ± 0.1 in the lockdown phase while in Milan (1.3 ± 0.1 in 2017-2019 and 1.4 ± 0.1 in 2020) and Paris (2.1 ± 0.1 in 2017-2019 and 1.8 ± 0.1 in 2020) remained almost the same.

3.3.2. Traffic impact

By analysing the trend of the average daily concentrations of NO_2 in the cities and comparing the values measured in UT and UB control units, the contribution of traffic in the various years has been quantified (Fig. 5). In 2020, a sharp decline of NO_2 concentration was highlighted. The contribution of traffic in London, Milan and Paris dropped to 3.3 ± 1.3 $\mu g\ m^{-3}$, 6.1 ± 0.8 $\mu g\ m^{-3}$, and 13.4 ± 1.5 $\mu g\ m^{-3}$, respectively. In London total lockdown, NO_2 dropped by 71.1 %, 80.8 % and 78.7 % compared to 2019, 2018, and 2017, respectively. A similar situation can be highlighted in Paris where the decline reached 80 % (in comparison with 2018). During lockdown in Milan, the reduction was 42.4 % compared to 2018 and 2017 but it was lower compared to2019 (−8.6 %).

4. Discussion and future outlooks

Comparing the data of 2020 with those recorded in previous years, a marked decrease in NO_2 concentration was highlighted (Fig. 3). The general improvement of air quality in metropolitan areas during the lockdown has already been widely discussed in several studies. For example, Bao and Zhang (2020) assessed the air quality in 44 cities in China during the period of stringent travel restrictions. They showed a 25 % decrease in NO_2 on average, compared with a 70 % reduction in travel. Briz-Redón et al. (2021) studied the concentration of NO_2 in some Spanish cities during the lockdown highlighting a statistically significant reduction in 10 out of 11 cities, greater in the most populated areas (i.e. Madrid, Barcelona, Sevilla and Valencia).

In this work, the analysis focused on the comparison between UT and UB stationsshowing a reduction in the concentration of NO_2 in both types of stations (Table 3). These results agree with the study of Baldasano (2020) who estimated an average reduction of 62 % and 50 % of NO_2 in Madrid and Barcelona during the total lockdown.

While in UT stations the decrease is attributable to the strong traffic reduction, in UB control units the lower NO_2 recorded in the lockdown was also caused by the lower secondary emissions (e.g. from industries). In Paris, the average temperature of 2020 was higher than in previous years (Table 2) and may have further reduced the use of residential heating. This could explain the higher percentage of NO_2 abatement in UB control units compared to other cities.

During the lockdown, UK, Italy and France were hit hard by the pandemic (Fig. S1), and the presence of strict limitation rules has led to an almost total reduction of the movements of people (Fig. 2). Analysing the NO_2 ratio in the UT and UB stations in Milan and Paris, the percentage of NO_2 due to vehicular traffic has remained substantially unchanged while only a slight decrease was highlighted in London (Fig. 4). These results can be attributed to the simultaneous and decisive lowering of the NO_2 present in the background in the urban environment due to the lowering of emissions, for example in the industrial sector. The outcomes showed that the lower NO_2 in urban areas registered during the lockdown was largely due to the reduction of vehicular traffic, especially in London and Paris. In fact, the absolute value of decrease was higher in the UT stations than in the UB stations (Table 4). This result was confirmed by analysing the emission sources in the cities considered: Degrauewe et al. (2019) estimated that NO_x emissions in London, Milan and Paris derived from road transport for 50 %, 75 % and about 80 %, respectively.

In London and Paris, NO_2 contribution of traffic dropped (Fig. 5). In Milan, a significant decrease during lockdown compared to the same period in 2018 and 2017 was evidenced, while only a slight reduction was reported by comparing 2020 and 2019 data. In this case, the lower decrease could be attributed to the meteorological conditions. In fact, in 2020, the low rainfall (Table 2) favoured the accumulation of pollutants and the worsening of air quality, particularly in urban environment, while in the previous three years, unstable weather conditions favoured the dispersion of pollutants and therefore also of NO_2. The introduction in February 2019 of a new LEZ called "Area B" which covers a large part of the municipality of Milan (MoM, 2019) could be another factor responsible of this lower decrease. Cars and commercial vehicles can access "Area B" only if at least in Euro Class (EC) 1 and 4 for petrol and diesel vehicles, respectively. In October of the same year, access to EC 4 diesel cars was also prohibited (MoM, 2019, 2020). The introduction of these measures could have caused a reduction in NO_2 from vehicular traffic and therefore a less visibility of the effect of the lockdown, given the blocking of more polluting vehicles already in the year 2019. This explanation was advanced also by Gualtieri et al. (2020) in their analysis of air quality in several Italian cities during the lockdown for CoViD-19. In fact, several researches conducted in recent years have shown the positive effects of LEZs on the urban environment in terms of lower NO_2 concentration (Ferreira et al., 2015; Holman et al., 2015; Jiang et al., 2017).

From July 2019, Paris also imposed the EC 4 and 5 categories as a minimum requirement for access to light and heavy duty diesel vehicles, respectively (MoP, 2020) and in fact the most marked reduction in the contribution given by traffic is visible by comparing 2020 with 2018 and 2017. Like Milan and Paris, also London presents LEZs divided into different bands that imposed increasingly restrictive requirements on vehicles approaching the central area, but with less restrictive access requirements (at 15 December 2020) (TfL, 2020).

The results of this study made it possible to quantify the impact of an almost total limitation of traffic on NO_2 in the urban environment. In 2020 the contribution of traffic in London, Milan and Paris dropped by 71.1 % - 80.8 %, 8.6 % - 42.4 %, and 65.7 % - 79.8 %, respectively. Therefore, solutions must be indentified balancing the need for private transport but at the same time the environment protection and human health. Several cities launched various initiatives to reduce the travel time that a citizen has to make during the day, by decentralizing services. For example, Paris recently promoted the initiative Ï15-minute city(̈Martínez Euklidiadas, 2020; Moreno, 2020; Whittle, 2020) aiming to reduce travel and therefore polluting emissions. Unfortunately, the results of this initiative are not yet available but similar plans gave positive results (e.g. Portland (Oregon, U.S.A.) and Tempe (Arizona, U.S.A.) (Capasso Da Silva et al., 2019)). In general, a more rational and coordinated localization of the main public and private offices and services would allow to significantly optimize urban travel reducing pollutants emission. In this perspective, the decentralization of cultural tourism in large cities was also discussed (Barrera-Fernandez et al., 2016; Koens et al., 2018), stimulating the identification of historical, artistic and cultural points of reference also in peripheral areas to distribute vehicular traffic connected to tourism, and therefore also air emissions, between the centre and the periphery.

However, this study also highlighted the possible limitations of traffic limitation interventions. Despite the significant reduction in the NO_2 concentration, Milan and Paris still showed several days with average NO_2 concentrations higher than 40 $\mu g\ m^{-3}$ (Table 4). In order to reduce the pollution, the limitation of road traffic could be not enough, but a vision also aimed at rethink the vehicles and their polluting effects should be developed. Regarding this aspect,

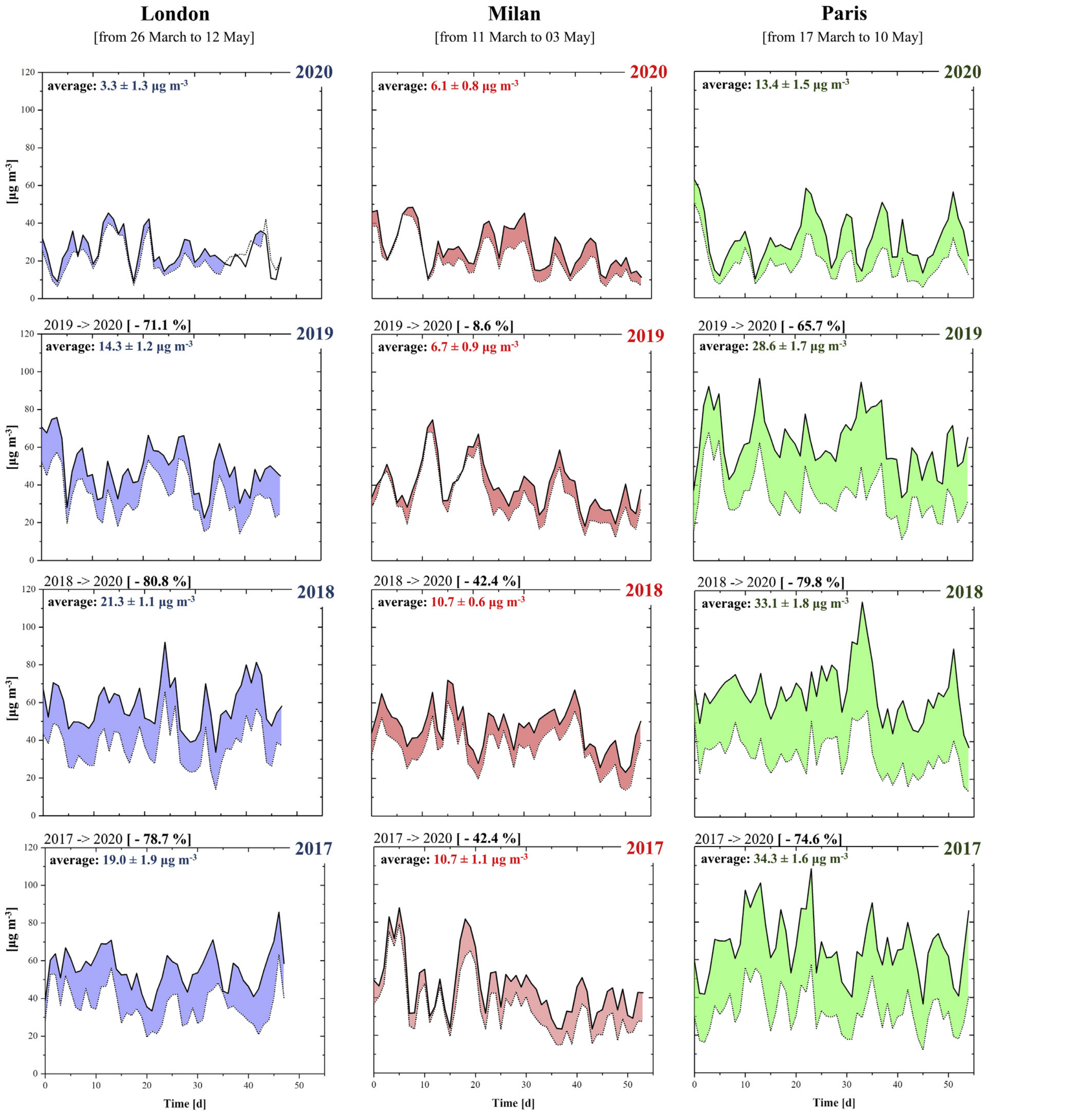

Fig. 5. Average concentration of NO_2 in London, Milan, and Paris during total lockdown and in the same period of the previous years (2019, 2018, and 2017). Coloured area represents the positive difference between daily average NO_2 values measured in UT (continuous lines) and UB (dot lines) control units.

the potential of the sector is very high considering that at least 40 % of the vehicle fleet is fuelled by diesel (65 % in Paris) (Tab. S1). Only in Milan, according to the most recent data (early 2018), more than 1,000,000 vehicles with high NO_x emissions were still in circulation (MoM, 2019).

According to the environmental challenge launched by the European Union with aims to reduce the emissions of CO_2 by 2030 (EC, 2020), there are several experiences of automotive industries reconverted following the “green automotive” concept (Koronis et al., 2013; Zailani et al., 2015). As reported in literature, on this point there was also the consensus of the stakeholders (FC, 2019). Due to CoViD-19, the automotive sector and the related supply chains entered a crisis, with a sharp decline in sales until the end of May 2020 (Fernandes, 2020; Gillingham et al., 2020), so the good intentions intended to produce non-polluting vehicles arrested. However, it would seem to be excluded that this negative impact definitively prejudices the path of those good intentions, to whichthe factors of economic utility were not and are not extraneous. Therefore, a confrontation between the stakeholders of the automotive industry is strongly suggested to verify the consequences that the economic crisis caused by the pandemic has determined andto draw the consequent findings.

5. Conclusions

This work aims to selectively assess the maximum impact that total traffic blocking measures can have on NO_2. During the lockdown, the ratio between NO_2 measured in UT and UB control units remained substantially unchanged compared to that measured in previous years (except for London). This result can be attributed to the simultaneous and decisive lowering of the NO_2 present in the background. Moreover, the contribution of the traffic have been quantified highlighting a strong decrease in NO_2 concentration in lockdown (London: 71.1 % - 80.8 %; Milan: 8.6 % - 42.4 %; Paris: 65.7 % - 79.8 %). In 2020 the contribution of traffic in London, Milan and Paris dropped to 3.3 ± 1.3 μg m^{-3}, 6.1 ± 0.8 μg m^{-3}, and 13.4 ± 1.5 μg m^{-3}, respectively. In the opinion of the Authors, think solutions that rationalize and make the use of means of transport less indispensable is necessary. In this sense, for instance, initiatives to reduce the travel time that a citizen has to make during the day, by decentralizing services are suggested. Despite the significant reduction in the NO_2 concentration, in UT stations average NO_2 concentrations higher than 40 μg m^{-3} were registered for several days (London: 4/48; Milan: 9/54; Paris: 16/55). To reduce the pollution, the limitation of road traffic could be not enough, but a vision also aimed at rethink the vehicles and their polluting effects should be developed. About this aspect, there are several experiences of automotive industries reconverted for production according to the g̈reen automotivečoncept and a confrontation between the stakeholders of the automotive industry is strongly suggested.

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CRediT authorship contribution statement

Maria Cristina Collivignarelli: Methodology, Writing - original draft, Validation, Supervision. **Claudio De Rose:** Methodology, Writing - original draft, Writing - review & editing. **Alessandro Abbà:** Writing - original draft, Writing - review & editing, Visualization. **Marco Baldi:** Writing - original draft, Validation. **Giorgio Bertanza:** Methodology, Writing - original draft, Visualization, Validation. **Roberta Pedrazzani:** Writing - original draft, Visualization, Validation. **Sabrina Sorlini:** Writing - original draft, Visualization, Validation. **Marco Carnevale Miino:** Writing - original draft, Writing - review & editing, Validation, Supervision.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.psep.2020.12.029.

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.

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