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COVID-19 lockdown effects on air quality by NO_2 in the cities of Barcelona and Madrid (Spain)

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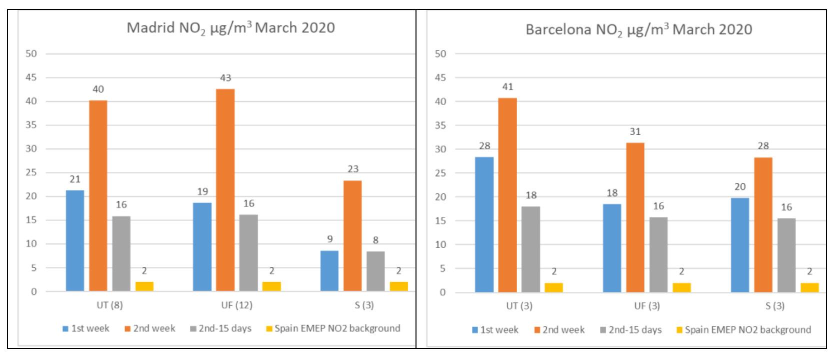
HIGHLIGHTS

- The reduction in NO_2 concentrations in Barcelona and Madrid (Spain), under COVID-19 lockdown during March 2020 were 50% and 62%, respectively
- New urban mobility policies, must be adopted to accelerate implementation of truly ambitious low emission areas (LEZ).
- The COVID-19 pandemic defines the need to apply an environmental and sustainable policy based on the reduction of air pollution levels.

GRAPHICAL ABSTRACT



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ABSTRACT

During the months of March and April 2020 we witnessed the largest-scale experiment in history in terms of air quality in cities. Any prediction of this experiment's results may be obvious to science, as it was totally expected, the air quality has improved substantially. Simply stated, it comes as no surprise. The lockdown has made it possible to quantify the limit of decrease in pollution in light of this drastic reduction in traffic, in Madrid and Barcelona showed a significant decrease of the order of 75%. In the case of Spain's two largest cities, the reductions of NO_2 concentrations were 62% and 50%, respectively. Hourly measurements were obtained from 24 and 9 air quality stations from the monitoring networks during the month of March 2020. These results allow us to see the limits that can be achieved by implementing low emission zones (LEZ), as well as the amount of contamination that must be eliminated, which in the cases of Madrid and Barcelona, represent 55%. This value defines the levels of effort and scope of actions to be taken in order to ensure that both cities achieve a clean and healthy atmosphere in terms of NO_2.

1. Introduction

COVID-19 has made us the first generation to experience a global pandemic on this scale, which is a singular moment, as the health, environmental and socio-economic consequences are reaching levels that are unprecedented in human history. The wholly exceptional lockdown measures that have been imposed render our city streets empty, practically without any vehicles. The lockdown measures have involved us in an involuntary experiment, and we can respond to the actual situation with the following question: If we eliminate nearly all combustion vehicles from cities by allowing only public transport and the transport of basic supplies, what would be the air quality? Never in our wildest dreams would we have imagined it possible to conduct the largest-scale experiment in history in terms of air quality in cities.

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In many parts of the world, lockdown measures have resulted in especially clean air in urban areas, news abounds with reports of exceptionally blue skies and very good visibility. Observations reveal a drastic drop in gas and particle pollution over most areas in conditions of confinement, with ten major cities under lockdown (IQAir, 2020): Delhi, London, Los Angeles, Milan, Mumbai, New York, Rome, São Paulo, Seoul and Wuhan. All of these metropolises have shown reductions ranging between −9% and −60% compared to 2019 data, and between +2% and −55% compared with the prior four-year average. Aerosol reduction in India is spectacular: "After just a week of reduced human activities, NASA satellite sensors observed aerosol levels at a 20-year low for this time of year in northern India" (NASA, 2020); Sharma et al. (2020) analyse the lockdown effect on India and obtain a reduction in the air quality index (AQI) of between 44 and 15% on the different areas. A preliminary analysis over Barcelona reported improvements in air quality while under lockdown measures (Tobias et al., 2020). In addition, Muhammad et al. (2020) have satellite data released by NASA and ESA to analyse the impact on air quality over areas of Europe, China and North America; and Dantas et al. (2020) analysed the impact of the COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro (Brazil). The results from Wang and Su (2020) indicate that the outbreak of COVID-19 significantly reduced the concentration of nitrogen dioxide (NO_2) and improved China's air quality in the short term while significantly contributing to global carbon emission reduction; however, in the long run, there is no evidence that this improvement will continue.

Different studies indicate that COVID-19 has a greater degree of aggressiveness when the air is polluted, although the number of studies is limited. Based on data from the United States, Wu et al. (2020) have found that a small increase in long-term exposure to PM2.5 leads to an increase in the death rate of COVID-19, at a magnitude of increase that is 20 times greater than observed for PM2.5 and all causes mortality. The results of this study underscore the importance of continuing to enforce air pollution regulations to protect human health during and after the COVID-19 crisis. Ogen (2020) use the tropospheric NO_2 obtained from the Sentinel-5P satellite to explain the spatial variation of mortality cases in 66 administrative regions in four European countries; the data show two main hotspots of NO_2: northern Italy and the Madrid metropolitan area, chronic NO_2 exposure could be a major contributor to the high COVID-19 mortality rates observed in these regions. Two recent studies using data from northern Italy (Coccia, 2020; Conticini et al., 2020), indicate as a main conclusion that cities with a high level of contamination have a higher probability of COVID-19 infections. The results of Zhu et al. (2020) for 120 cities in China indicate that there is a significant relationship between air pollution and COVID-19 infection. Air pollution would be considered a cofactor that helps increase the pandemic effects, a discussion in this regard can be found in CEA (2020). Setti et al. (2020) have hypothesized that the SARS-CoV-2 virus may be present in particle matter (PM) during the spread of infection, based on evidence that is already available for other viruses. Some very preliminary results could support this hypothesis, as this phenomenon occurs with some bacteria that are transported by Saharan dust. However, this hypothesis needs much more research, since it currently has little consensus and many uncertainties.

The substantial improvement in air quality does not represent any surprise or novelty, as might be expected. What is important now is quantify the decrease in pollution due to this sharp reduction in the traffic cities, thus allowing us to know the limits of measures should be applied for improving air quality. Low emission areas (LEZ) have had a positive impact on air quality in many European cities (London, Berlin, Milan, and Paris, among others) [https://urbanaccessregulations.eu/]. This constitutes one of many measures that have been implemented in cities to improve air quality, especially in terms of nitrogen oxide and particles. Madrid implemented a limited LEZ (5 km^2) in December 2018; and Barcelona, before the pandemic, had planned to put a limited LEZ (95 km^2) into effect on April 1, 2020. The lockdown situation allows us to find the contamination levels that can be achieved by this type of measure.

The objective of this work is to assess the NO_2 hourly observations in the metropolitan areas of Madrid and Barcelona during the month of March 2020, with the aim of evaluating the effects on air quality produced by the Spanish government's lockdown (MPRCMD, 2020a). This study takes into consideration, both the resulting reductions in traffic and the specific meteorological conditions during this month of March. In addition, the observations of March 2020 are compared with the corresponding NO_2 values for the month of March of the years 2018 and 2019. The data analysis compares the same time period with only the two immediately preceding years, due to the implementation of LEZs in both cities and other measures to improve air quality, such as changing the composition of the vehicle fleet and the mobility structure. Furthermore, the year-on-year meteorological variation is considered, as well as other factors. This analysis allows knowing the scope of the air quality improvement plans and the measures already in operation, specifically regarding efforts to achieve a clean atmosphere. Section 2 describes the methods used. Section 3, provides the analyses of traffic reduction due to lockdown, meteorological conditions, and variations in surface air quality while also offering some discussion on the scope of air quality improvement plans. Finally, the conclusions are presented in Section 4.

2. Materials and methods

The impact of the adopted lockdown measures on air quality in the metropolitan areas of Madrid and Barcelona has been evaluated, specifically by analysing the observations of the air quality monitoring networks. Focused on nitrogen dioxide (NO_2) levels, exclusively for the month of March in the years 2018, 2019 and 2020. The analysis differentiates the effect of traffic reduction by discriminating between the types of air quality stations, whether they are urban traffic stations or background stations. The traffic reduction in the cities of Madrid and Barcelona due to confinement measures has also been quantified. The meteorological conditions for the month of March in the three years considered have been analysed in order to identify their possible specific influence, with special emphasis on the particularities of the year 2020.

During recent years, both the cities of Barcelona and Madrid have made important changes in pursuit of improving air quality, such introducing LEZs, reducting of space for vehicle circulation, forcing greater mobility by bycycle, introducting shared transport systems, and other such measures. For this reason, the comparative analysis is not carried out on other years, as this facilitates comparing the most similar data possible.

2.1. Madrid and Barcelona metropolitan areas

The Madrid metropolitan area is located in the centre of the Iberian Peninsula and has a population of 6.3 million inhabitants. It is the largest metropolitan area in Spain, the third largest in the European Union and the 54th largest in the world. Its economy is oriented more toward the administration and services sectors as well as logistics, while tourism constitutes another important sector. It has a highly developed transport network infrastructure. Three-quarters of a million people travel to the city for work and, together with other local commuters, they benefit from a network of high-capacity metropolitan highways and a much-used public transportation system comprising the underground network, the local commuter train and a dense network of bus routes. Over 744,000 residents of other municipalities hold city jobs, while 242,000 city residents work abroad. Although passenger flows enter and leave predominantly from the city centre, the decentralization of economic activity to the outskirts is currently modifying this pattern. Madrid's historic and modern centres are surrounded by the M30 road, complemented by two other orbital rings: the M40 and M50. It has no electrical power generation facility.

The Barcelona Metropolitan Area is located in Catalonia, in the northeast of Spain, and is centred in the city of Barcelona. With a population of more than 5 million people, it is the most populated urban area on the Mediterranean coast and one of the largest in Europe. This polynuclear urban region has a series of important urban centres that are closely related to each other and to the outside environs. This is also the case for the areas bordering the urban regions that extend around the two other major Catalan cities of Tarragona and Girona. Commercial activities constitute the main industry in the region, which is dominated by manufacturing, commerce, construction and other services. In recent times, the region has experienced a movement toward services and tourism. Starting in 1986, a natural gas network was developed for industrial and domestic use, which also resulted in six 400 MW combined cycle plants that currently provide power to the region. Its port is one of the most central commercial ports in the Mediterranean. Both the port and the airport have a high flow of people and goods. The "Barcelona Rondes" are ring roads that surround the city without interfering with the inner urban network, and they represent one of the most important infrastructures of the metropolitan road system, with their high capacity and average traffic intensities of more than 166,000 vehicles.

Regarding the emission patterns of both cities, Guevara et al. (2013) indicate that traffic in Madrid is the most predominant emission source of primary pollutants and contributes 65% of NOx, 67% of CO, 87% of PM10 and 85% of PM2.5; the airport is the second source, but to a far lesser extent: 18% of NOx, 14% of CO, 6.2% of PM10 and 7.5% of PM2.5; solvents emit 54% of NMVOCs while traffic produces 40%. In the case of the Barcelona metropolitan area, road traffic is the main source of NOx, at 59%, while the port occupies second place with 16%, similarly, traffic represents 85% of PM10 and PM2.5 emissions while the port has lower contributions of, respectively, 6.2% and 7.2%; solvents are responsible for 60% of NMVOCs, and traffic contributes 33%; the BCN port's most significant contribution is SOx, which represents more than 70% of these emissions, while traffic is the source for only 8.5%, due to the transport of merchandise by heavy vehicles.

2.2. Air quality data

Exposure to NO_2 is associated with negative human health effects, both from short-term "peak" concentrations as well as long-term exposure to a wider range of NO_2 concentrations. For the latter, the European Union has established an average annual air quality limit value of 40 μg/m^3 (EU, 2008). However, due to factors such as proximity to and the intensity of local emissions, atmospheric chemistry, and meteorological conditions, substantial variations can occur in the hourly NO_2 concentrations that contribute to the average annual concentration.

The air quality stations and hourly observations were selected to determine the NO_2 reduction values according to the specific configuration of each city. Fig. 1 indicates their spatial distribution for the metropolitan areas of Madrid and Barcelona.

The city of Madrid's air quality monitoring network is made up of 24 automatic remote stations (Madrid, 2020). The distribution and typology of the stations satisfy the need to know the different contamination levels throughout the city, and they additionally fulfil the implementation criteria established by the legislation. The stations are divided into the following types: 9 urban traffic (UT), 12 urban background (UF) and 3 suburban (S). This study considers all of them.

The air quality monitoring network in Barcelona and Catalonia is managed by the Generalitat de Catalunya and is made up of 124 automatic remote stations distributed across 15 air quality zones (XVPCA, 2020). This work uses 9 stations centred in the city of Barcelona, complemented by various circles. The stations used are: 3 urban traffic, 3 urban background and 3 suburban.

3. Results and discussion

3.1. Lockdown and traffic reduction

The publication of the March 14th Royal Decree 463/2020, which declared a state of alarm in Spain due to the COVID-19 health crisis (MPRCMD, 2020a), imposed the lockdown of all non-essential industries and activities. Stores, hotels, and restaurants were ordered to close down, as well as shopping and administrative centres. Limitations were placed on mobility and teleworking became obligatory, wherever possible. These measures were reinforced on March 27 (MPRCMD, 2020b), again allowing only essential services to remain in operation. This limitation on daily trips around the entire Spanish territory has resulted in severe limitations on traffic, among other effects. Highly notable decreases in vehicular mobility have occurred, as well as in the volume of other relevant activities such as port and airport operations. The lockdown made not only the second half of March 2020 completely anomalous in terms of air pollution, but also the entire month of April due to the confinement measures being continued in order to fight COVID-19. All this has caused a drastic drop in emissions. Fig. 2 shows two photos of the empty streets of Madrid and Barcelona due to the lockdown during the second half of March 2020.

The data provided by the General Directorate of Traffic (DGT, 2020) are as follows: 1) long-distance movements fell 72.41% compared to an equivalent day, and 43.71% for heavy vehicles; 2) traffic across the borders with Portugal and France decreased by 79.28% and 83.18%, respectively; 3) entries to and exits from the cities of Madrid and Barcelona decreased by 80% and 82%, respectively; and 4) fuel sales have fallen 83% for gasoline and 61% for diesel, mostly due to the percentage of trucks in the vehicle fleet. Traffic data inside of Madrid and Barcelona indicate a significant decrease in vehicles: 77% within the Madrid M-30 ring road (Madrid, 2020) and 74.6% within those of Barcelona (BCN, 2020). Compared to a typical business day, 1.24 million fewer trips were made by private vehicles. In both cities, public transport conducted only 10% of the usual trips. Taxis performed only 5% of their previous services. Travel by bicycles and other personal mobility vehicles also saw an 87% reduction. In addition, airport travel decreased by 97% and train passengers by 91.9%. This entire dataset clearly indicates the magnitude of the reduction in mobility.

The traffic reduction has also had consequences for noise. Measurements for a central area in the city Barcelona, indicate an average decrease in sound pressure of 50%, dropping from 67 to 61 dB (BCN, 2020). This complementary data reinforces the tremendous effect that the lockdown had on reducing traffic.

The decrease in activity across different sectors provided by Google (2020) clearly reflects high levels of reduction as a specific result of the lockdown measures (Table 1). This data indicates changes in visits and lengths of stay at different locations compared to the baseline.

3.2. Weather patterns

The analysis of meteorological patterns for the years 2018, 2019 and 2020, using monthly climatological reports from the Spanish State Meteorological Agency (AEMET, 2018, 2019, 2020a). All the data used in this section use the meteorological reference period 1981–2010.

3.2.1. March 2020

The month of March 2020 began with the storm Karine causing strong to very strong winds and widespread rains. March also ended with unstable weather, which had been dominant throughout the month with various episodes of intense rainfall. It was only in the second week of March when rainfall was scarce, due to an anticyclone. The most outstanding episodes occurred in the form of various storms from March 1 to 6. It should be noted that the state's declaration of lockdown coincided with the prevailing stable weather in the second week

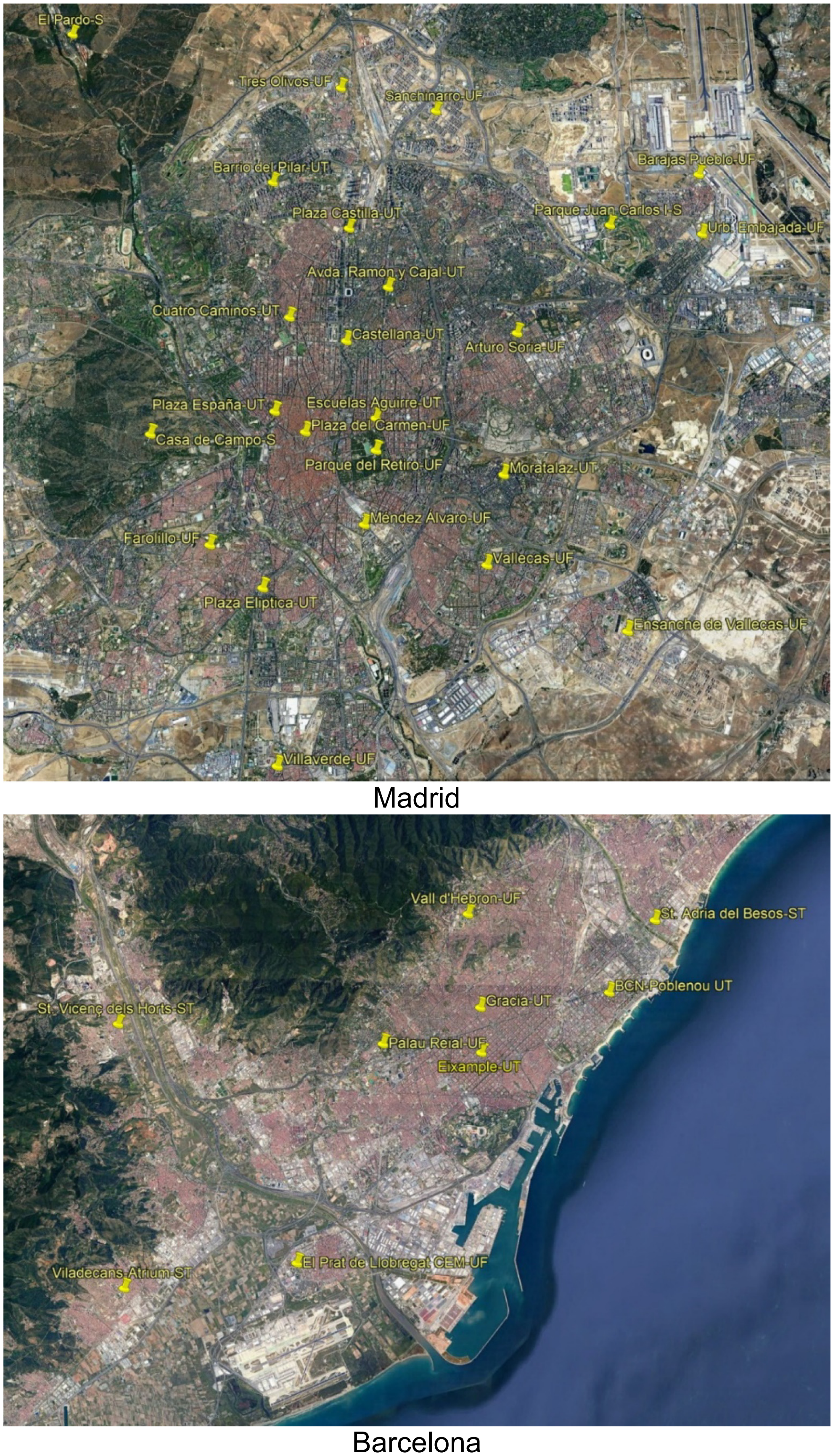

Fig. 1. Maps of Madrid and Barcelona, with the locations of the air quality monitoring stations used.

Fig. 2. The streets of Madrid and Barcelona empty of traffic during the second half of March 2020 due to lockdown.

of March changing to atmospheric instability with moderate rains and winds (Fig. 3).

This divides the month of March 2020 into three periods of distinct meteorological behaviour: the first week with clearly unstable and very windy weather; the second week with atmospheric stability; and finally the second fortnight, which returned to moderate, rainy and unstable weather (AEMET, 2020b).

3.2.2. March 2018

The month of March was very similar in the years 2018 and 2020, although the temperatures in 2018 were colder than usual while they maintained a normal pattern in 2020. The accumulated insolation was lower than the normal value, while the rainfall in both years shared an equivalent pattern between extremely wet and very wet days due to several successive storms. The high number of rainy days stands out: in the Retiro (Madrid), it rained for 19 days; and Catalonia saw an average of 65 mm in 2018 and 67 mm in 2020, representing, respectively, 166% and 170% of the reference value. Regarding intense rainfall events throughout the month of March 2018, it should be noted that the first fortnight of the month experienced a continuous succession of storms and fronts while, in the second fortnight, only the March 17 to 19 episode stands out.

3.2.3. March 2019

In March of the year 2019, the temperatures were higher than normal, with the accumulated insolation throughout the month reaching more than 30% above the normal value. It was a month that fluctuated between dry and very dry, with an average rainfall over Spain of 26 mm, which is 55% of the 47 mm average for this month. March 2019 stands as the second driest month of the 21st century, behind 2012, and it is the eighth driest since 1965. The central area of the peninsula was dry, with only 2 days of rain in the Retiro (Madrid), and the Barcelona area was extremely dry. As for episodes of intense precipitation, only March 5 to 7 stands out, due to a cold front.

3.3. Analysis periods defined by meteorological conditions and emissions

Due to the different circumstances for the month of March 2020 in the Iberian Peninsula, as a result of both the meteorological conditions and the lockdown measures, a very unique period of time has been generated. The different distinct situations throughout the month make it totally unique from the perspective of air quality.

Due to weather conditions, three time periods are established (see Fig. 2):

- ➢ In the first week, weather conditions favored the cleansing of the atmosphere, as they were especially windy.
- ➢ In the second week, meteorological conditions favored the accumulation of the pollutants;
- ➢ the second fortnight, which returned to moderate, rainy and unstable weather.

Due to emissions conditions, two time periods are established:

- ➢ the first two weeks with the usual emission pattern
- ➢ in the middle of the month and during the weekend on March 14 and 15, the lockdown was established and led to a strong change of emissions, essentially due to the reduction in traffic.

This makes the analysis of air quality data for this unique March month of the year 2020 especially interesting to know the pollution responses of the two largest cities in Spain: Barcelona and Madrid, with respect to:

1) a situation dominated by different meteorological conditions, and
2) a situation of extreme emission reduction due to COVID-19 lockdown measures.

3.4. NO_2 in March 2020

Analysis of monitoring network's measurements of concentrations in order to compare them during the first week, second week, and

Table 1
Decrease in activity across different sectors due to lockdown between March 14 and 29, 2020 (Google, 2020).

	Retail & recreation	Grocery & pharmacy	Parks	Transit stations	Workplaces	Residential
Spain	−94%	−76%	−89%	−88%	−64%	22%
Catalonia	−94%	−75%	−90%	−88%	−64%	21%
Madrid Community	−94%	−72%	−92%	−89%	−65%	22%

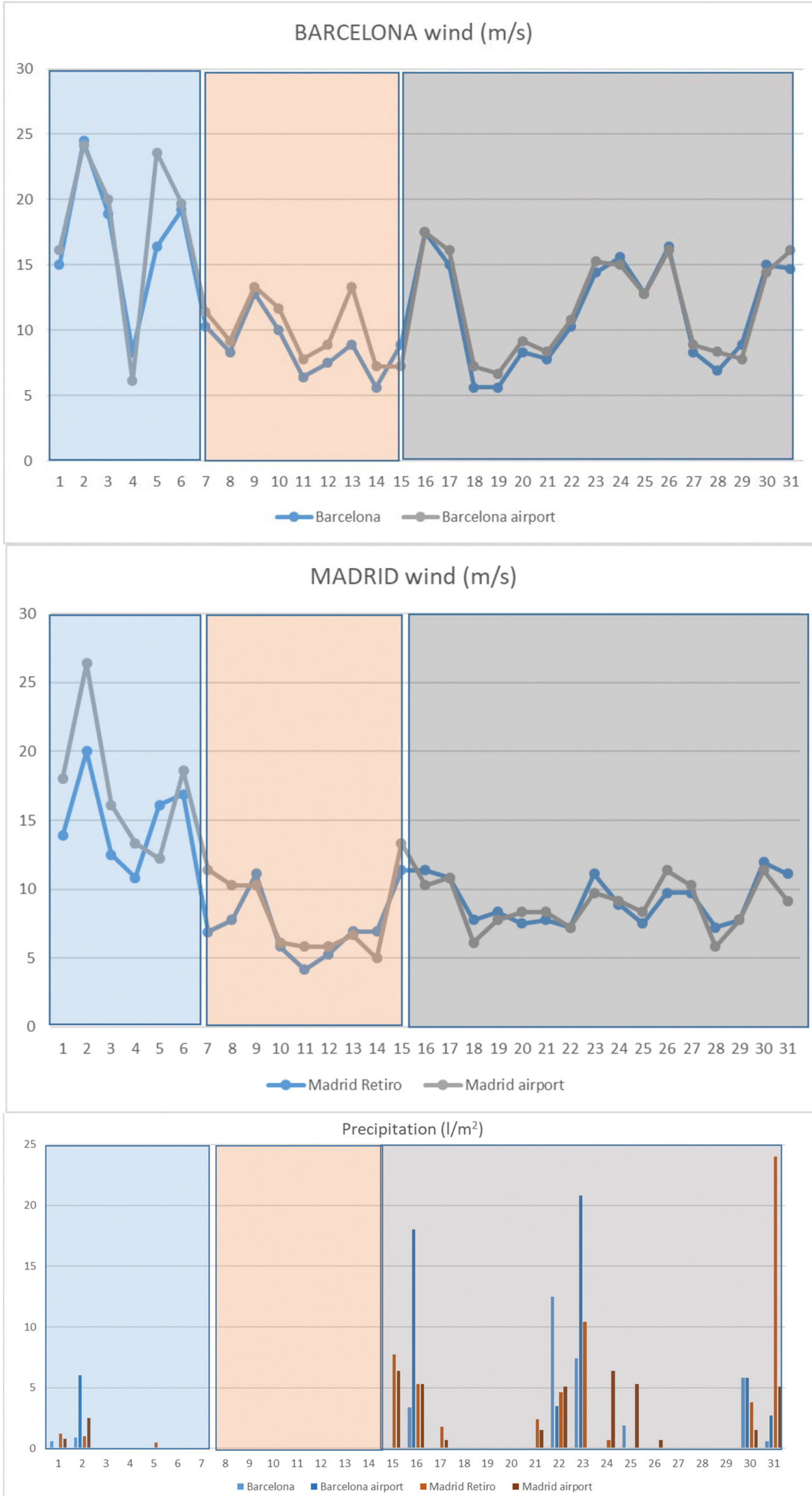

Fig. 3. Wind and precipitation in Barcelona and Madrid during March 2020.

second fifteen days (see Fig. 4), all of which represent the three very different situations during the month of March. The results are indicated in Table 2.

In the case of Madrid, NO_2 concentrations fell in all 23 stations by an average of 53% during the first week compared to the second week, due to windy weather conditions; while the reduction due to traffic

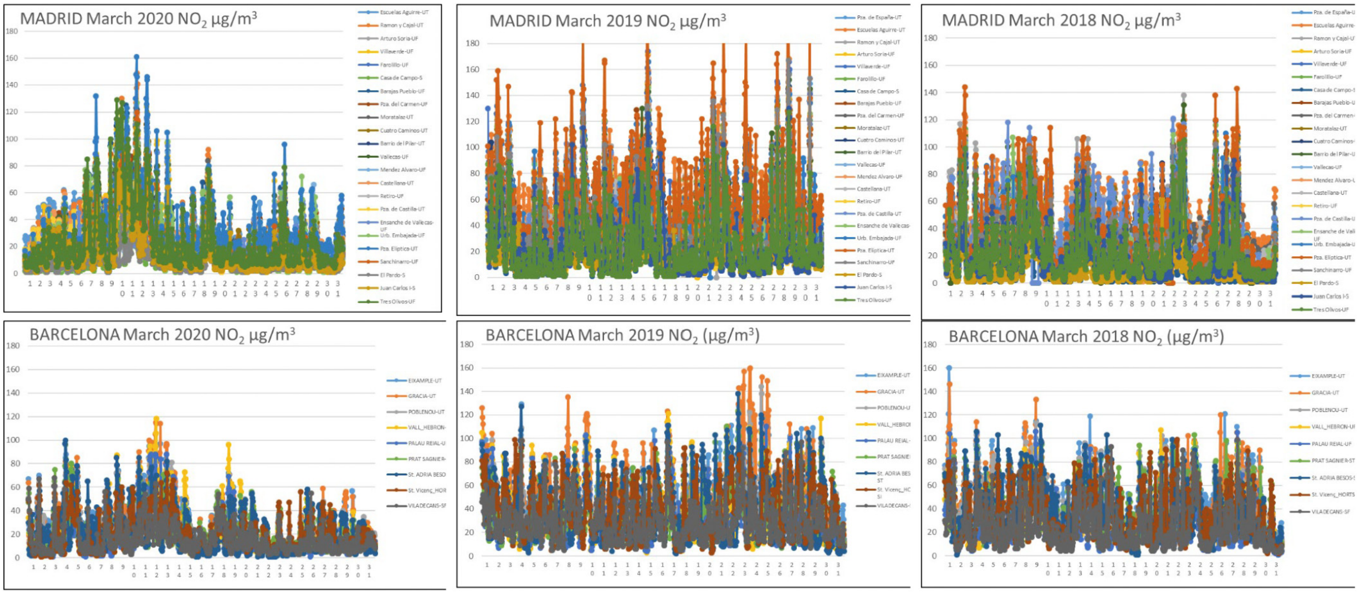

Fig. 4. NO_2 hourly concentration in Madrid and Barcelona, March 2020, 2019 and 2018.

reductions was 62%. If the second fortnight is compared with the first week, the reduction is only 18% (good meteorological conditions for air quality vs. very strong traffic reductions). Finally, when comparing the data of the second fortnight (very strong traffic reductions) with that of the first fortnight (mixture of good and bad meteorological dispersive conditions for air quality), the reduction is only 49%.

Logically, different results are found in Madrid when carrying out the analysis by station type: UT (8), UF (12) and S (3). The reductions in concentrations of NO_2 are, respectively, 47%, 56%, and 63% during the first week compared to the second week; while the reductions due to lockdown traffic restrictions were 61%, 62% and 64%. Comparing the second fortnight with the first week, the reductions are only 26%, 13% and 2%; and comparing the second fortnight to the first fortnight shows reductions of 49%, 48% and 48%.

In the case of Barcelona and its metropolitan area of influence, according to all of the 9 stations analysed, the concentrations of NO_2 fell on average by 34% during the first week compared to the second week, due to windy weather conditions, while the reduction due to lockdown reductions was 50%. When comparing the second fortnight with the first week, the reduction is only 23% (good meteorological conditions for air quality vs. very strong traffic reductions). Finally, comparing the data of the second fortnight (very strong traffic restriction) with that of the first fortnight (mixture of good and bad meteorological dispersive conditions for air quality), the reduction is 42%.

The analysis carried out by station type: UT (3), UF (3) and S (3) in Barcelona, show reductions in NO_2 concentrations, respectively, of 30%, 41%, and 30% during the first week with respect to the second week; while the reductions due to lockdown traffic restrictions were 56%, 50% and 45%. Comparing the second fortnight with the first week, the reductions are only 37%, 15% and 21%; and comparing the data of the second fortnight with that of the first fortnight shows reductions of 49%, 38% and 36%.

These results clearly indicate what can be expected from a meteorological situation that generates good dispersive conditions compared to an extreme reduction in emissions, as well as to the current situation of chronic contamination. The percentages of improvement are more notable in the case of Madrid (62% vs. 53%) than in Barcelona (50% vs. 34%). Both cities are discovering what it means to breathe clean air.

3.4.1. Maximum hourly peak values of NO_2

Another very interesting result is the difference found between the maximum hourly peak values of NO_2 in these three periods of March.

Table 2
Mean concentrations, maximum value ratio and reductions in NO_2 due to the lockdown, March 2020, 2019 and 2018 in Madrid and Barcelona (Spain). Average are for all types of stations, UT (urban traffic), UF (urban background) and S (suburban).

March 2020 NO_2 (µg/m^3)	Madrid				Barcelona			
	Average	UT (8)	UF (12)	S (3)	Average	UT (3)	UF (3)	S (3)
Month conc.	23.0	23.3	23.5	12.3	22.1	26.4	20.4	19.8
1st week	19.2	21.3	18.6	8.6	22.2	28.4	18.5	19.7
2nd week	40.9	40.2	42.5	23.4	33.4	40.7	31.3	28.3
1st-15 days	30.7	31.3	31.3	16.4	28.2	34.9	25.3	24.4
2nd-15 days	15.8	15.9	16.2	8.5	16.4	18.0	15.7	15.5
2nd-15 days vs. 1st-week %	−18%	−26%	−13%	−2%	−23%	−37%	−15%	−21%
2nd-15 days vs. 2nd-week %	−62%	−61%	−62%	−64%	−50%	−56%	−50%	−45%
1st-week vs. 2nd-week %	−53%	−47%	−56%	−63%	−34%	−30%	−41%	−30%
2nd-15 days vs. 1st-15 days %	−49%	−49%	−48%	−48%	−42%	−49%	−38%	−36%
Maximum value ratio								
1st week vs. 2nd-15 days	1.06	1.05	1.11	0.91	1.26	1.19	1.21	1.37
2nd week vs. 2nd–15 days	1.65	1.62	1.70	1.53	1.33	1.43	1.28	1.30
Comparison with the years 2019 and 2018								
Month conc.	36.1	42.7	35.0	20.7	40.3	49.1	34.4	37.4
2nd-15 days 2020 vs. month 2019%	−56%	−63%	−54%	−59%	−59%	−63%	−54%	−59%
Month conc.	29.4	37.7	28.5	14.2	36.1	44.6	30.6	34.4
2nd-15 days 2020 vs. month 2018%	−46%	−58%	−43%	−40%	−55%	−60%	−49%	−58%

In Madrid and Barcelona, the maximum values were slightly higher during the first week than in the second fortnight, except in the Madrid suburban stations. The average ratio for all stations in Madrid was 1.06; performing the analysis by station type: UT (8), UF (12) and S (3) the relationship values are, respectively, 1.05, 1.11 and 0.91. For the Barcelona area, an average ratio of 1.26 is obtained; and by station type: UT (3), UF (3) and S (3) the relationship values are, respectively, 1.19, 1.21 and 1.37.

When the maximum values of the second week versus the second fortnight are considered, the obtained ratios logically are clearly higher, with an average ratio for Madrid of 1.65 for all stations. Carrying out the analysis by station type: UT (8), UF (12) and S (3) the ratio values are 1.62, 1.70 and 1.53, respectively. For Barcelona, the average ratio is 1.33, and by station type: UT (3), UF (3) and S (3) the relationship values are 1.43, 1.28 and 1.30, respectively.

These results indicate that a strong traffic reduction decreases the maximum hourly peak values more so than do good dispersive weather conditions. However, both cities respond differently, as Barcelona sees a greater effect of less intense maximum values for air quality due to good weather conditions; while in Madrid it is the effect of traffic reduction that is more significant.

The differences between the two cities are essentially due to two reasons. The first is that both zones have different dispersive capacities (Gonçalves et al., 2009a, 2009b), and the second is that the specific general meteorological conditions on the Iberian Peninsula during March 2020 did not affect both zones exactly the same way. The Madrid area clearly has continental conditions, while Barcelona is a coastal city on the Mediterranean Sea whose port must be taken into account in its emissions pattern.

3.4.2. Comparison of March 2020 with the years 2018 and 2019

The comparison NO_2 hourly values for the second half of March 2020 with the values for the month of March in the two previous years: 2019 and 2018 (see Fig. 4), both of which were meteorologically different. 2019 was characterized by stable weather that favored poor air quality conditions, while 2018 was characterized by unstable weather that favored the dispersion of pollution. The results indicate that, due to the lockdown, the average reduction in Madrid was 56% and 46% compared to, respectively, 2019 and 2018, while in Barcelona it was 59% and 55% (see Table 2). If the analysis for Madrid is performed by station type: UT (9), UF (12) and S (3) the reduction values for the year 2019 are 63%, 54% and 59%, respectively, and for 2018 they are 58%, 43% and 40%. In the case of the Barcelona area by station type: UT (3), UF (3) and S (3) the reduction values are, respectively, 63%, 54% and 59% for 2019 and 60%, 49% and 58% for 2018. The higher reduction values for 2019 than for 2018 are due to the meteorological differences between both years.

Table 3
Contributions of traffic, city, country and long-range transports to NO_2 pollution levels in Madrid and Barcelona according the data of March 2020.

March 2020 NO_2 ($\mu g/m^3$)	Madrid			Barcelona		
	Accumulated	Specific	%	Accumulated	Specific	%
Traffic contribution	41	23	55%	41	23	55%
City contribution	18	9	24%	18	8	20%
Country contribution	9	7	16%	10	8	20%
Long-range transport and regional emissions	2	2	5%	2	2	5%

3.5. Scope of the air quality plans from COVID-19 data

The results presented in Fig. 5 are based on the concept of different contributions: long-range, regional, urban and local. They show the different levels of NO_2 at the monitoring sites in and around Madrid and Barcelona (Lenschow et al., 2001; WHO, 2006a). It should be noted that the contribution of the city is especially influenced by its geographical location and the associated atmospheric dispersion conditions, which in the case of Madrid and Barcelona is continental vs. coastal (Gonçalves et al., 2009a, 2009b). Due to the economic and urban structures of the city area, the emissions in urban hot spots essentially result from traffic intensity. The typology of the monitoring station suggests that the measured concentrations can be taken as representative of the three types: urban traffic, urban background and suburban.

The obtained results in Table 3 allow quantifying the different sources of contributions. No substantial differences are observed between the traffic stations and the background stations for the city of Madrid. The value of 2 $\mu g/m^3$ assigned to the contribution of "long-range transport and regional emissions" has been derived from NO_2 measures carried out within the framework of the EMEP-European Monitoring and Evaluation Programme network (EMEP, 2020), which is the co-operative program for monitoring and evaluating long-range transmission of air pollutants in Europe, managed in Spain by AEMET.

Traffic in Madrid contributes 55% and represents an increase in NO_2 concentration of $\Delta 23$ $\mu g/m^3$. The rest of the city's activities contribute 24% and an increase in concentration of $\Delta 10$ $\mu g/m^3$. The contribution due to the country's background is 16%, with a concentration of $\Delta 7$ $\mu g/m^3$. UPM (2017) found quite similar percentages using 2012 data, although the average concentration represented half of the measurements in the last three years. In the case of Barcelona, the traffic

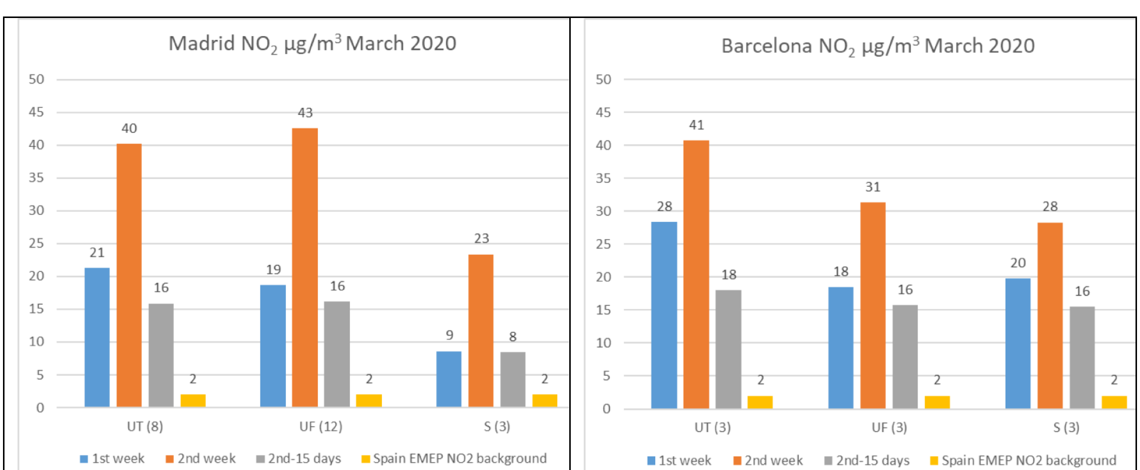

Fig. 5. NO_2 concentration levels in Madrid and Barcelona according to the station type, meteorological and emission reduction situation.

contribution is 56%, with an increase in NO_2 concentration of $\Delta 23\ \mu g/m^3$. The rest of the city's activities contribute 20% and a concentration of $\Delta 8\ \mu g/m^3$, while the country's background contribution is 20%, with a contribution of $\Delta 8\ \mu g/m^3$. Part of these differences is due to the different mobility structures of both cities and the designs of their air quality networks, as well as to differences in the dispersive capacities of their locations.

Both Madrid and Barcelona have decided to implement limited low-emission zones (LEZ). This took place in Madrid on January 1, 2019, targeting the central part of the city with a limited area of only 5 km^2. In the case of Barcelona, it was due to enter effect on April 1, 2020 after a transitional period from January 1, 2020; but it was suspended due to the COVID-19 lockdown, considering a larger area of 95 km^2, essentially the area defined by the Barcelona "Rondes" (ring roads); it will allow traffic along the ring roads, representing around 30% of the city's traffic. In both cases, all gasoline vehicles must comply with the Euro 3 (2001) standard and gas-oil vehicles with the Euro 4 (2006) standard.

The Madrid City Council launched the Air Quality and Climate Change Plan for the city of Madrid (Plan A), a local strategy approved in 2017, its implementation would imply a reduction of only 4 $\mu g/m^3$ in Madrid city wide annual NO_2 mean (Izquierdo et al., 2020). Application of the Central LEZ of Madrid in 2019 resulted in a reduction of 10 $\mu g/m^3$ for this specific area compared to the annual averages of the last 9 years., and For the entire city of Madrid the reduction was only 4 $\mu g/m^3$ (Ayt Madrid, 2020; EeA, 2020). In the case of Barcelona, it is expected that the implementation of the LEZ, in accordance with the modeling work carried out for the year 2020, will reduce the concentration of NO_2 by 11%, of NO_2, implying a reduction in NO_2 between 3.1 and 7.7 $\mu g/m^3$, depending on the area of the city (BR, 2019).

The differences are between 23 and 4 $\mu g/m^3$ in Madrid and between 23 and 3.1–7.7 $\mu g/m^3$ in Barcelona, wich clearly define the levels of effort and the scope of actions to be taken in order to ensure that both cities achieve a clean and healthy atmosphere with respect to NO_2, as the main source of these emissions is clearly urban traffic, especially from vehicles with internal combustion engines. Another issue to consider is the use of public spaces and mobility systems.

4. Conclusions

The concentration values during the second half of March were lower than the EU limit value and the WHO annual reference value (40 $\mu g/m^3$), although these standards are frequently exceeded in urban traffic stations during this same period in other years.

The situation created by the COVID-19 pandemic corroborates what the scientific community has been insisting for years, that the reduction in traffic emissions in cities has clear effects on reducing air pollution, which represents a significant improvement in public health. The pandemic has made it possible to see in the cities clean air in decades and transparent skies.

The analysis of the NO_2 hourly observations in the metropolitan areas of Madrid and Barcelona, is obtained a respective average reduction of 62% and 50%. Another salient result is that the maximum hourly peak values also show significant reductions, with ratios between 1.2 and 1.7. The improvement in air quality has occurred broadly, affecting both city centres and the peripheral areas. The consideration of the meteorological conditions has been decisive in estimating the reductions. The meteorological conditions of March 2020 have played a significant role.

Traffic with internal combustion motor vehicles represents the most important source of polluting emissions in cities, and these results confront us with a terrible dilemma. We know what can be achieved in terms of improving air quality in our cities, and we are obliged to do so, because the potential of improvement is considerable.

These results confirm previous findings in the same direction, and they should be expanded in greater spatial detail with respect to NO_2, as well as extended to other pollutants, specifically fine particles.

Once the lockdown situation ends, the results that we have learned should motivate and allow us to adopt new urban mobility policies and thus accelerate the implementation of truly ambitious low emission areas (LEZ). This study has focused on Spain's cities of Madrid and Barcelona, where the amounts of contamination to be removed are 23 $\mu g/m^3$ in front of reductions of 4 $\mu g/m^3$ in Madrid and 3.1–7.7 $\mu g/m^3$ in Barcelona according the present air quality plans.

I agree with Coccia (2020) that a comprehensive strategy for preventing future epidemics similar to COVID-19 must also be designed in terms of sustainability, and not only in regard to the health sector. The cost of air pollution as recently valued by the World Bank in terms of total welfare losses for Spain in 2013 is estimated at 49,331 million dollars, which represents 3.4% of GDP (WB, 2016).

The link is clear: air pollution is an important risk factor and contributes to the fact that the main chronic diseases increase their severity. COVID-19 pandemic defines the need for a proactive strategy, especially applying an environmental and sustainable policy based on the reduction of air pollution levels.

CRediT authorship contribution statement

Writing review & editing

Declaration of competing interest

The author declares that he is the unique author of this manuscript and he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This study does not have any funding.

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