How Covid-19 lockdown affected air pollution in Europe — a multi-city analysis

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Introduction

Concawe has undertaken a city-level analysis to quantify the ways in which the Covid-19 lockdown measures have had an impact on air quality in Europe. This article presents the results of the analysis for particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3).

Following the emergence of the novel coronavirus SARS-CoV-2 in late 2019, when the first case was reported in the city of Wuhan in China, the Covid-19 pandemic outbreak has had significant health and economic consequences for the world.[1] As of January 2021, SARS-CoV-2 has globally infected more than 100 million people and caused more than 2 million deaths.[2] In Europe, more than 19 million cases and 450,000 deaths have been reported, with the UK, France, Spain and Italy being the most affected countries.[3]

After the virus had spread across Europe, most European countries began to introduce lockdown measures, starting in mid-March 2020, to mitigate the infection rate. Depending on the level of Covid-19 impact in each country, as well as country-specific situations and response capacity, European governments began, and continue, to adopt different types of interventions including partial or full closure of national/international borders, various restrictions on travel, closure of schools, and numerous economic responses as well as restrictions on social mobility. These efforts to prevent the virus spreading have inevitably led to a significant drop in emissions of air pollutants from several sectors, most notably from road transport and aviation.[4]

The changes in air pollutant emissions resulting from the sudden decrease in economic activities, and the subsequent impact on air quality, have been the objective of several studies during the past year since the Covid-19 pandemic started. For example, Guevara *et al.*[5] used a bottom-up approach that considered a wide range of information sources (e.g. open access and near real-time measured activity data, proxy indicators, etc.) and prepared an open-source dataset of daily, sector- and country-dependent emission reduction factors for Europe associated with the Covid-19 lockdowns. Their estimates showed average emissions reductions of 33% for NO_x, 8% for NMVOCs, and 7% for SO_x and $PM_{2.5}$ across 30 European countries (EU-27 plus UK, Norway and Switzerland). For all pollutants except SO_x, more than 85% of the total reduction was attributed to road transport. In addition, all studies conducted so far[6,7,8,9,10,11,12] agree that there has been a profound reduction in NO_2 concentrations[1] as a consequence of the implemented lockdown measures, while for $PM_{2.5}$ a consistent reduction cannot yet be seen because the response of $PM_{2.5}$ emissions and PM formation during the lockdown is more complex. On the other hand, the majority of studies indicate an increase in O_3 concentrations during the lockdown, which is mainly attributed to the titration effect of NO_x emissions.

Among the different initiatives that have been undertaken over the past year to study how the lockdown measures implemented in Europe have impacted air quality, the European Environment Agency (EEA) launched an online data viewer which includes hourly data for PM and NO_2 as measured by approximately 3,000 monitoring stations across European countries during the period 2018-2020.[13]

[1] There have been exceptions which show that, in some cases, the reduction in NO_x levels was less obvious (i.e. German Federal Environment Agency study: https://www.cleanenergywire.org/news/diesel-driving-bans-table-lockdown-shows-low-effect-german-nox-levels-state-sec). This could be explained by the fact that the reduction in emissions from road activity might relate more to newer vehicles with more advanced NO_x control technology, and not to older vehicles or vehicles that emit more NO_x and were still operating (e.g. delivery vans).

Based on the hourly measured concentrations, the data viewer provides daily, weekly and monthly average concentrations of these pollutants at a city level, which allows the user to track the changes occurring as a result of the lockdown measures.

Data from the EEA's data viewer have been used as the basis for a city-level analysis that Concawe has undertaken to quantify how the lockdown measures have impacted air quality in Europe. This article presents the results of the analysis for $PM_{2.5}$ and NO_2 concentrations in five European cities (Athens, Brussels, Madrid, Milan and Paris). Like most of the research studies undertaken to date, the analysis covers the first lockdown period, from March to June 2020. However, the analysis was extended to assess the impacts of the relaxation of measures during the summer period, as well as the re-implementation of lockdown measures during autumn-winter 2020 to prevent a second wave of the virus, on concentrations of $PM_{2.5}$ and NO_2. In addition, the analysis was further extended to assess the response of O_3 concentrations to the imposition of lockdown measures. Since the EEA's data viewer does not currently include data for O_3, Concawe used hourly data taken directly from the EEA's Air Quality e-Reporting database.[14] The main findings of the analyses for each pollutant are presented in the following sections.

It should be noted that, because Covid-19 restriction measures have been developed and implemented differently among European countries, the results that follow provide a means for a qualitative assessment of the effects of the lockdown measures on air pollutant concentrations, as well as an indication in quantitative terms of the spatial/temporal patterns and the magnitude of changes in concentrations. However, a direct quantification of the impact of Covid-19 restriction measures on pollutant concentrations cannot be derived from these data as other factors may play a role. For example, meteorological variability[2] is one key factor that determines the transport and fate of air pollutants, and will subsequently also have an impact on air pollutant concentrations and their variability from one year to another. A more detailed analysis will be needed to provide an in-depth assessment of the influence of these factors.

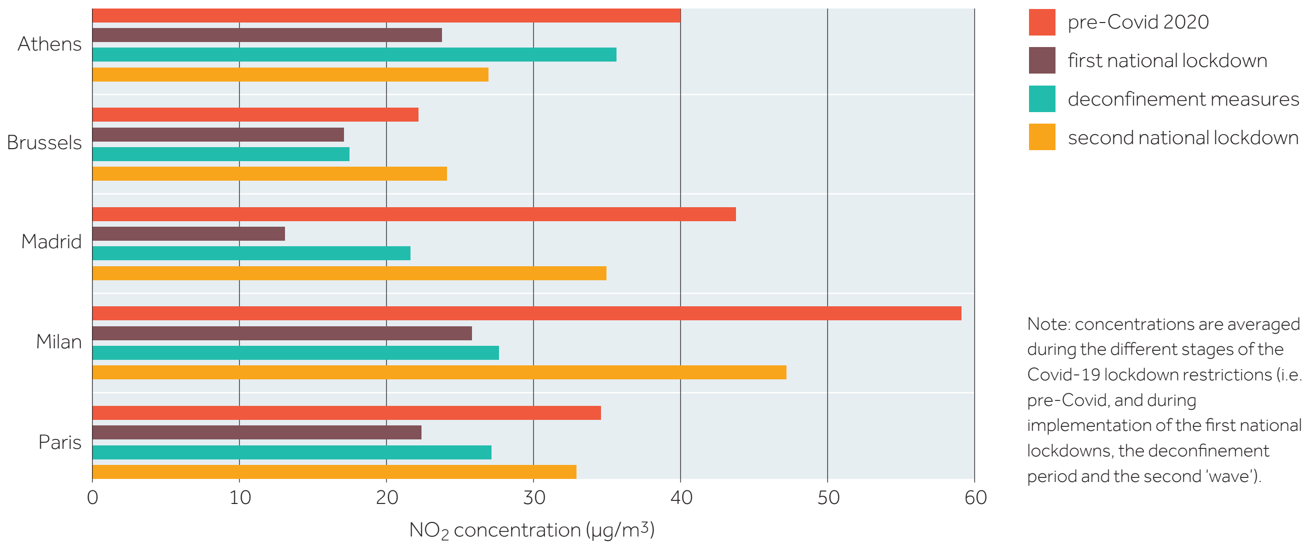
NO_2 concentrations

Figure 1 on page 23 shows the trends of NO_2 concentrations in 2020 in the five European cities considered. The concentrations are averaged over the different stages of the Covid-19 pandemic and lockdown measures at the national level (i.e. before the Covid-19 pandemic began, and during the lockdown period, the relaxation of lockdown measures, and the second wave of the virus). It should be noted, however, that the implementation date,[3] as well as the types of measures introduced, may differ between countries.

[2] For example, the month of February 2020 was exceptionally warm in Europe: it was 1.4 °C above the second warmest February on record in 2016,[15] which led, for example, to lower NO_2 concentrations than normal in February, while in the month of November 2020, the predominant conditions were drier than average, with below average precipitation notably in the central and western part of the continent and parts of the Iberian Peninsula.[15] Thus, weather variability has a substantial influence on surface concentrations of pollutants.

[3] https://covid-statistics.jrc.ec.europa.eu/RMeasures

Figure 1: Daily NO_2 concentrations in 2020 in the five European cities analysed in the study



Note: concentrations are averaged during the different stages of the Covid-19 lockdown restrictions (i.e. pre-Covid, and during implementation of the first national lockdowns, the deconfinement period and the second 'wave').

In all cities analysed, the results show that NO_2 levels were higher during the pre-Covid period (January to early March, 2020) compared to the periods that followed the Covid-19 pandemic. The analysis also confirms that, as seen in earlier studies, with the implementation of restriction measures during the first lockdown period, all cities experienced a significant reduction in NO_2 concentrations compared with pre-Covid levels. This reduction exceeded 20% in all cities, with Milan and Madrid experiencing reductions of up to 55% and 70%, respectively. The lower NO_2 levels can be largely attributed to the significant reduction in NO_x emissions from road transport which, in most European countries, amounted to a reduction of 50–80%. This was a result of the significantly lower levels of traffic congestion, which also had an indirect effect on NO_x emissions from vehicles by allowing the diesel exhaust treatment systems to operate at optimum temperatures. Following the deconfinement measures that began in May, NO_2 levels showed an increasing trend in all cities, but nevertheless remained lower compared with pre-Covid levels. The results also show that the re-implementation of restrictive measures to prevent the spread of the second Covid-19 'wave' was not as effective in reducing NO_2 concentrations as the measures taken during the first lockdown period. In most of the cities analysed, NO_2 concentrations continued to show an increasing trend, while in Brussels, NO_2 levels were comparable to those during the pre-Covid period. This trend could partially be explained by the fact that, during the first lockdown period, the restrictive measures were extremely strict and fairly uniform among European countries, while during the second Covid-19 'wave' period, restrictive measures varied more among countries, being less strict compared with the first period and eventually having a less profound impact on traffic congestion.[4]

[4] https://www.tomtom.com/en_gb/traffic-index/

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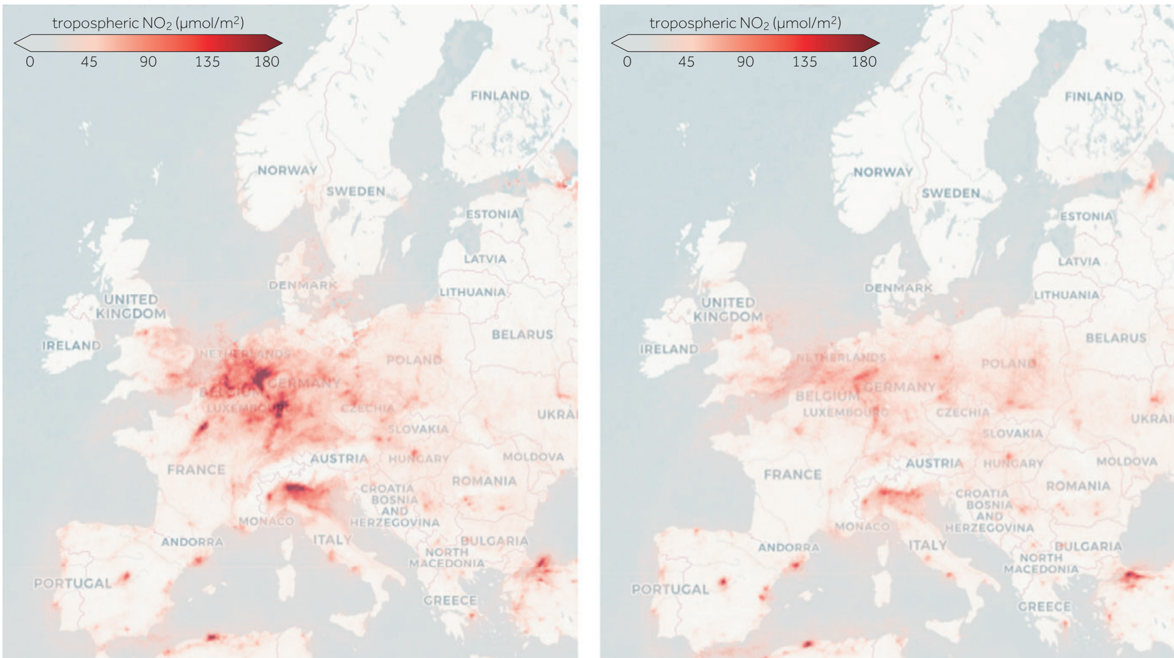
A comparison of NO_2 concentrations in 2020 with those in 2019 shows the significant impact of the restrictive measures imposed in most urban areas across Europe. Figure 2 shows the average satellite-observed vertical columns[5] of NO_2 from 15–30 March 2020 (Figure 2b), a period which corresponds to the month when lockdown measures were introduced in most countries in Europe, in comparison to the same period in 2019 (Figure 2a).[16] The maps show that most of the urban areas in central and western Europe exhibited significant lower NO_2 pollution levels in the period from 15–30 March 2020 than in the same period in 2019, while the respective NO_2 changes in eastern Europe were less profound.

Figure 2: Average NO_2 pollution levels (tropospheric vertical column) in 2019 and 2020, measured by the TROPOMI system on board the Sentinel-5P satellite

a) 15–30 March 2019 b) 15–30 March 2020



Data source: Copernicus Sentinel-5P Mapping Portal, https://maps.s5p-pal.com

The differences in NO_2 concentrations at the city level, between 2020 and 2019, can be seen in Figure 3 on page 25, which shows how the annual mean NO_2 concentrations measured at the monitoring stations changed in 2020. A reduction in NO_2 concentrations in all cities is observed in 2020, compared with 2019 levels, reaching up to a 30% reduction in Brussels. However, the respective reductions show a significant temporal variation which depends on the stage of the Covid-19 pandemic.

[5] The TROPOspheric Monitoring Instrument (TROPOMI) derives information on atmospheric NO_2 concentrations by measuring the solar light backscattered by the atmosphere and the Earth's surface. In general, satellite measurements are characterised by high spatial resolution and can be suitable for monitoring polluting emission sources at a city level, while ground-based measurements have a spatial resolution which is constrained by the limited number of monitors and their proximity.

For example, in the two cities that were affected the most by very strict lockdown measures (Milan and Madrid), a significant drop in NO_2 concentrations was observed during March–May (when the first national lockdown was set) compared with 2019 levels. Levels remained low in 2020 but, as lockdown measures began to be relaxed around mid-May, the rate of reduction in NO_2 concentrations slowed down, and from July 2020 onwards NO_2 concentrations were similar to 2019 levels (Figure 4).

Figure 3: Annual mean NO_2 concentrations in 2019 and 2020 in the five cities analysed in the study

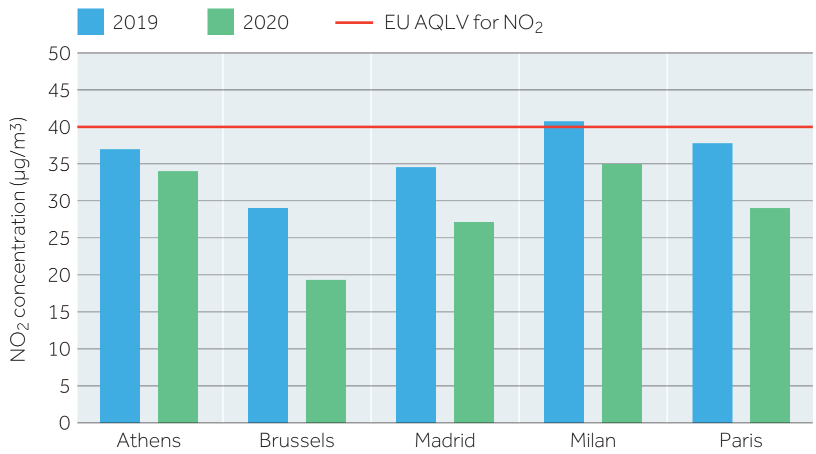
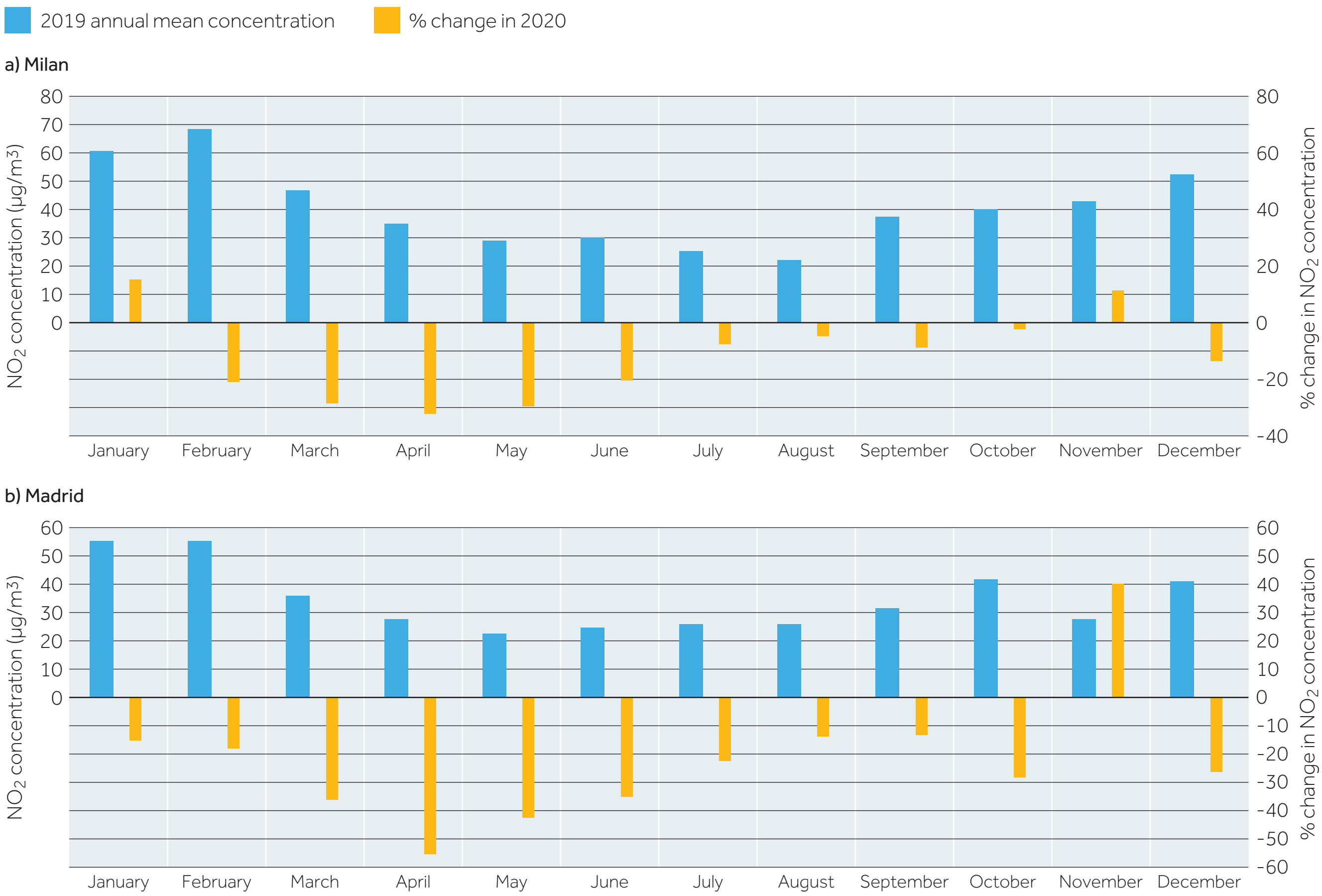


Figure 4: Monthly mean NO_2 concentrations in 2019 and the percentage changes in 2020

Note: negative values indicate a decrease.

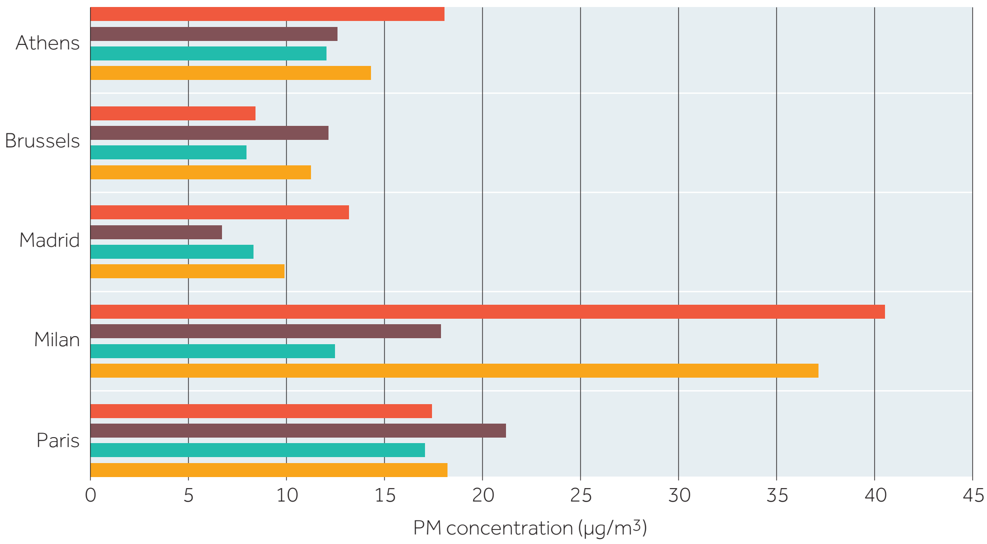


PM concentrations

Figure 5 shows the trends in PM concentrations in 2020 in the five European cities analysed. As with NO_2, the concentrations are averaged over the different stages of the Covid-19 pandemic and the lockdown measures at the national level (i.e. before the Covid-19 pandemic, and during the lockdown period, during relaxation of lockdown measures, and during the second wave of the virus).

Figure 5: Daily PM concentrations in 2020 in five European cities analysed in the study

pre-Covid 2020
first national lockdown
deconfinement measures
second national lockdown



Notes:

Data refer to $PM_{2.5}$ concentrations, the only exception being Paris as only PM_{10} data were available in the EEA's data viewer.

Concentrations are averaged during the different stages of the Covid-19 lockdown restrictions.

A variable trend in PM concentrations among the cities analysed can be seen throughout 2020; the effect of the different stages of the Covid-19 pandemic on PM levels is less clear compared with the effects on NO_2. During the first period of the implementation of restrictive measures, Athens, Milan and Madrid experienced a significant drop in PM concentrations (a drop of up to 55% in Milan). This was the general response of PM at the majority of monitoring stations in Europe.[4] However, there are areas where PM responded to the restrictive measures in a different way. For example, in Brussels and Paris, higher PM concentrations (45% in Brussels, 20% in Paris) were measured during the first national lockdown compared with the pre-Covid period. This variable PM response continued after the relaxation of restrictive measures, while during the second Covid-19 'wave', when restrictive measures were reinstated, PM concentrations in most of the cities analysed reached similar levels to those in the pre-Covid period.

The somewhat less pronounced, and sometimes variable, effect of Covid-19 restrictive measures on PM concentrations has also been seen in earlier studies.[8,10] The high variability in PM concentrations can be explained by a number of factors, including:

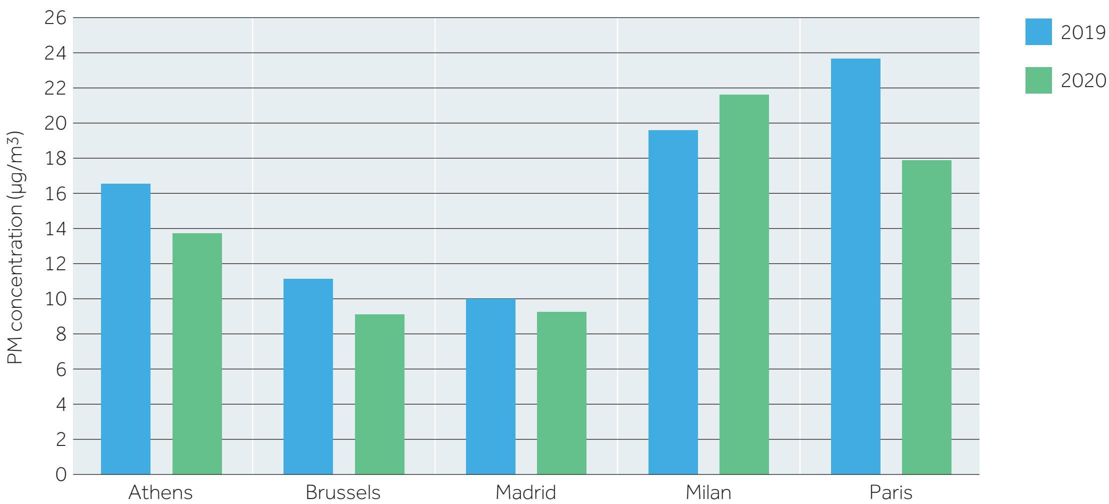
a) the complex chemical mechanism behind the formation of PM;

b) the chemical composition of PM, which may differ between the areas; and

c) the fact that PM is not directly linked to one emissions source; instead, multiple sources impact their levels, and each source may have a different response during the Covid period. For example, the reduction in road transport emissions may have resulted in lower PM emissions associated with this source, either due to lower primary PM emissions, or to lower NO_2 levels that could eventually form secondary PM. However, in several regions, as people had to stay at home for longer periods, there may have been an increase in primary PM emissions from domestic heating. In addition, the meteorological variability, as well as the contribution of emissions from natural sources, should not be neglected.

The lower impact of the restrictive measures on reducing PM levels compared to NO_2 can also be seen in Figure 6, which compares the annual mean PM concentrations in 2020 with those in 2019. In general, most cities registered lower PM concentrations in 2020 compared with 2019 levels, with Paris reaching a 24% reduction in PM levels. However, the reductions in PM concentrations were considerably less than the reductions in NO_2 concentrations; in Milan, despite the strict restrictive measures that were in place for a substantially long period, the measured PM concentrations in 2020 were higher by around 10% compared with 2019 levels.

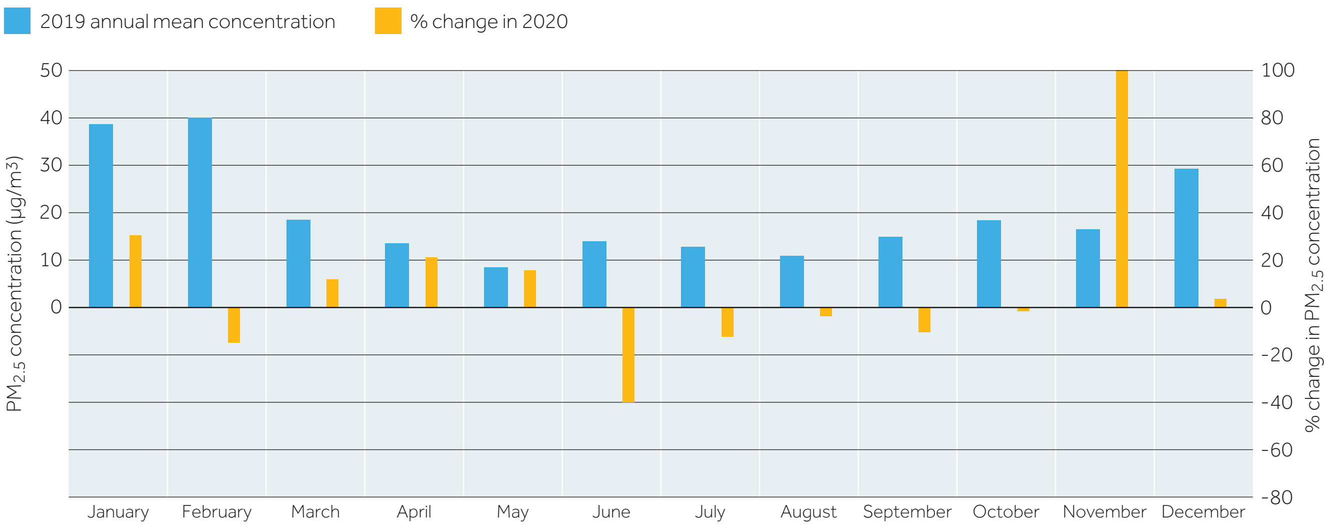
Figure 6: Annual mean PM concentrations in 2019 and 2020 in the five cities analysed in the study



Interestingly, in Milan, during the months when a national lockdown was imposed during the springtime, PM concentrations were constantly above the corresponding 2019 levels (Figure 7). With the relaxation of restrictive measures in summer (June–July), $PM_{2.5}$ concentrations in 2020 were found to be lower compared with 2019 levels. The fact that activities in several sectors did not reach pre-Covid levels, and that large parts of southern Europe experienced periods of high precipitation[21] that was well above the average, could explain this trend.

Figure 7: Monthly mean $PM_{2.5}$ concentrations in 2019 in Milan, and the respective % changes in 2020

Note: negative values indicate a decrease.

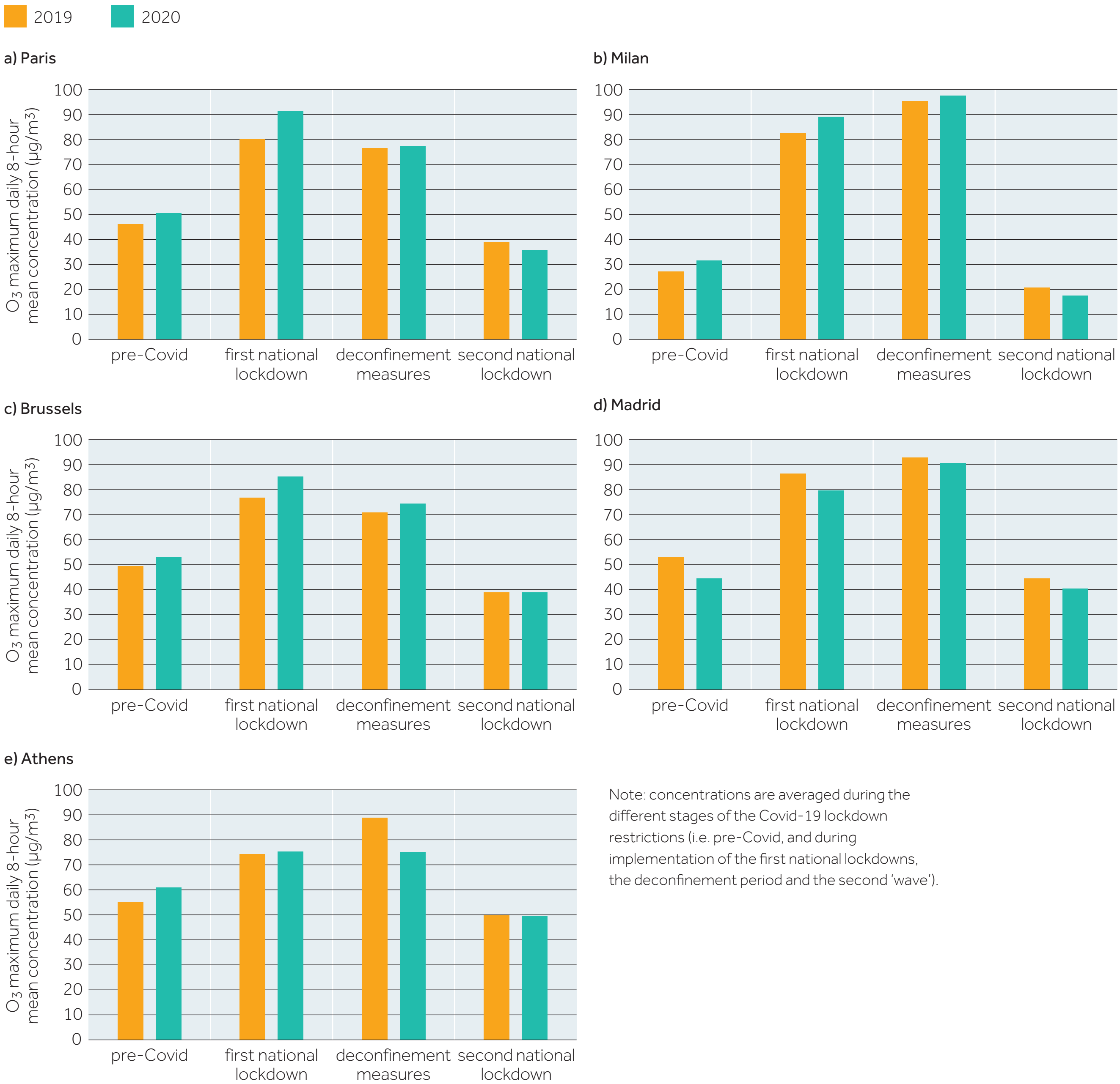


O_3 concentrations

The implementation of stringent lockdown measures, especially during the first 'wave' of Covid-19, did not seem to have a positive effect on O_3 levels. In the majority of the cities analysed in the study, O_3 levels were found to be higher in 2020 during the period when the first national lockdowns were set, compared to 2019 levels (see Figure 8 on page 29). The increase exceeded 10% in Brussels, while in Paris the increase reached approximately 15%. Similar results were also found in other studies.[9,11,17] The O_3 response can, to a large extent, be explained by the significant drop in NO_2 concentrations during the same period, which could, eventually, have favoured the formation of O_3. In general, O_3 formation is driven mainly by emissions of NO_x and VOCs through complex photochemical reactions, and depends on the VOC-NO_x ratio.[18] In most urban areas, where NO_x concentrations are in excess, O_3 formation is dominated by NO_x. In such areas, a potential reduction in NO_x emissions will result in counter-effects regarding O_3 concentrations, causing them to increase to higher levels.[19,20]

Trends in O_3 concentrations may also be enhanced by the meteorological conditions in these areas, as was the case during the first national lockdowns (March to April), when large parts of Europe exhibited significantly drier than average conditions.[21] In contrast, the Iberian Peninsula experienced significantly more precipitation during the same period, which could explain the somewhat lower levels of O_3 in Madrid during the first national lockdown compared with the corresponding 2019 levels.

Figure 8: Maximum daily 8-hour mean O_3 concentrations in 2019 and 2020 in the five European cities analysed in the study



Note: concentrations are averaged during the different stages of the Covid-19 lockdown restrictions (i.e. pre-Covid, and during implementation of the first national lockdowns, the deconfinement period and the second 'wave').

Conclusions

The novel coronavirus SARS-CoV-2 continues to spread around the world with severe implications for human health, as well as having major financial and societal impacts. In early 2020, the vast majority of European countries began taking measures to manage the outbreak. These measures had an impact on many of the upstream economic activities that drive emissions of air pollutants, thus affecting air quality. This study used up-to-date measured data, taken from the EEA's Air Quality e-Reporting database and online data viewer, to analyse the effects of the measures taken to avoid the spread of Covid-19 on concentrations of NO_2, PM and O_3 in selected European cities in 2020.

The results of these analyses are summarised as follows:

- On average, NO_2 concentrations in 2020 were measured to be lower than those in 2019 in all cities analysed in the study. The reduction ranged between 10% (Athens) and 35% (Brussels).
- NO_2 concentrations were significantly reduced in March-April, when the first restriction measures were put in place. The extent of the reductions varied considerably among cities, and were dependent on the types of measures implemented, with reductions exceeding 50% being observed in some cases (Milan and Madrid).
- The significant drop in transportation activity as a consequence of the lockdown measures, and the subsequent reduction in road transport NO_x emissions across Europe (i.e. around 50–80%) could, to a large extent, explain the lower NO_2 levels observed during that period.
- With the relaxation of restrictive measures starting in May, all cities experienced an increase in NO_2 concentrations, while the re-implementation of restrictive measures aimed at preventing the spread of the second Covid-19 'wave' was not as effective in reducing NO_2 concentrations as when similar measures were taken during the first lockdown period.
- The impact of lockdown measures on PM concentrations was less pronounced than for NO_2, and did not show a consistent downward response. A variable response of PM levels was seen during all stages of the Covid-19 pandemic and the lockdown measures at national level. Compared with 2019 levels, PM levels in 2020 were, on average, found to be somewhat lower, although significant temporal variations were observed. The variable changes in PM emissions from different sources as a result of the lockdown measures (i.e. decreases in road transport emissions, increases from domestic heating) and the sensitivity of PM to meteorological variables could explain this variable trend in PM concentrations.
- The implementation of lockdown measures has had a different effect on O_3 concentrations, with the majority of cities analysed experiencing higher O_3 concentrations in 2020 compared with 2019 levels, especially during the period when the first national lockdown measures were in place.

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