Environmental Research 193 (2021) 110515

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

The impact of COVID-19 on air quality levels in Portugal: A way to assess traffic contribution

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ARTICLE INFO

Keywords:
Air pollution
Monitoring
NO_2
PM_{10}
Traffic contribution
COVID-19

ABSTRACT

The pandemic caused by coronavirus COVID-19 is having a worldwide impact that affects health, the economy and indirectly affects the air pollution in cities. In Portugal, the number of cases increased continually (32700 confirmed cases as of May 31, 2020), which has affected the health system and caused movement restrictions which in turn affects the air pollution in the country. This article analyses the indirect effect produced by this pandemic on air pollution in Portugal, by comparison of data from a period of movement restriction of the citizens by the government – COVID lockdown period (March–May 2020) with data from baseline conditions (mean of the mirrored periods from the five previous years (March–May from 2015 to 2019)). Air quality data – in particular NO_2 and PM_{10} hourly concentration - from more than 20 monitoring stations spread over mainland Portugal was used to perform this evaluation. The mean reduction observed on pollutant concentrations was higher for NO_2 (41%) than for PM_{10} (18%). For NO_2, mean reductions were more significant in traffic (reaching values higher than 60% in some monitoring stations) and background urban sites than in rural stations. The reduction of NO_2 concentration observed in traffic sites were compared to the estimation of traffic contribution by the incremental method, suggesting that this latter approach is not consistent (lower in same sites and higher in others) and alerting to the careful use of this approach in future works.

1. Introduction

On March 11, 2020, the World Health Organization (WHO) declared that the COVID-19 – disease caused by the new Coronavirus SARS-CoV-2 – had been characterized as a pandemic (WHO, 2020). In Portugal, the first case was confirmed on March 2, 2020. To date (May 31, 2020), there are 32700 confirmed cases and 1424 deaths, being Lisbon the city with most confirmed cases (2409) (Direção-Geral da Saúde, 2020). On March 12, 2020, all schools closed, and on 19 Portugal decrees the state of emergency that includes mandatory confinement and movement restriction of the citizens. The public transportation was reduced and non-essential business such restaurants, bookshops, fitness centers, or shopping malls were closed.

Despite the negative impacts of COVID-19 there are also some positive indirect effects on environment, such as reduction of noise, reduction of greenhouse gases emissions (GHG) (Zambrano-Monserrate et al., 2020), in addition to air pollution and related health benefits. Recent researches are being published reporting air quality improvements associated with social distancing measures, and consequent decrease of economic activity. For example, Zambrano-Monserrate et al. (2020) used the Copernicus satellite data to analyse data of particulate matter ($PM_{2.5}$) in China and observed approximately 20–30% reduction in February 2020 (month average) when compared to monthly averages of February 2017, 2018 and 2019. However, Wang et al. (2020) highlights that large emissions reductions would not help avoid severe air pollution in China when meteorology is unfavourable. Nevertheless, another recent study in China estimate that improved air quality during the quarantine period avoided a total of 8911 NO_2 related deaths and a total of 3214 $PM_{2.5}$ related deaths, 73% of which were from cardiovascular diseases and chronic obstructive pulmonary disease (COPD) (Sharma et al., 2020). In India the nationwide from 24th March to May 3, 2020 was responsible by 50% reduction of PM_{10} and $PM_{2.5}$ concentrations compared to the pre-lockdown in the megacity of Delhi (Mahato et al., 2020). A study conducted by Nakada and Urban (2020) in the biggest Brazilian city, São Paulo, showed reductions on NO (up to 77.3%), NO_2 (up to 54.3%), and CO (up to 64.8%) concentrations were observed in the urban area during partial lockdown compared to the five-year monthly mean. By the other hand, an increase of

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https://doi.org/10.1016/j.envres.2020.110515
Received 9 August 2020; Received in revised form 16 November 2020; Accepted 18 November 2020
Available online 23 November 2020
0013-9351/

approximately 30% in ozone concentrations has been observed. In terms of Europe, the number of studies published are still limited but already point out for similar behaviour and reductions of air pollutants (Baldasano, 2020; Collivignarelli et al., 2020; Sicard et al., 2020; Tobías et al., 2020).

This study aims to evaluate the impacts on Portuguese air quality during the state of emergency (partial lockdown) due to the COVID-19 pandemic, assessing both the reductions verified in each pollutant type and estimating the traffic contribution in each type of monitoring sites. The main strengths of this work are related to the analysis of the impact of COVID-19 pandemic on the different type of environments (rural, suburban and urban) and the different type of conclusions addressed for these distinct environments support it. Besides that, this type of analysis allowed to test the coherence and identify the limitations of the "incremental method" (Lenschow et al., 2001; De Leew et al., 2001), which is often applied to assess traffic and urban background contribution (for example in supporting the e-reporting activities under the European Commission regulations).

2. Data

In order to analyse the effects of the pandemic caused by the COVID-19 virus on air quality in Portugal, atmospheric pollutants concentration data was collected from the national air quality monitoring network (QUALAR, 2020) located in mainland Portugal.

Several pollutants are continuously measured in these sites (namely sulphur (SO_2), nitrogen oxides (NO, NO_2, NOx), carbon monoxide (CO), Ozone (O_3), and the suspended particles with fractions less than 10 µm (PM_{10}) and less than 2.5 µm ($PM_{2.5}$)). However, this study will focus on NO_2 and PM_{10} since these are the most critical pollutants in urban areas, with exceedances every year in the main urban centers – see Fig. 1 – mainly associated to traffic, domestic and industrial sources (Monteiro et al., 2007).

Air quality is strongly influenced by meteorological conditions and atmospheric emission sources and strengths, exhibiting thus pronounced seasonal patterns (Gama et al., 2018). To minimize the influence of meteorological and seasonal variability in our results, the impact of COVID-19 lockdown in air quality is assessed by comparing air quality data collected during the pandemic (2020) with baseline conditions based on 5-year averaged data (2015–2019). This methodology was based in the assumption that 5-year baseline conditions were long enough to reduce inter-annual variability in meteorology and atmospheric pollutants concentrations, and to minimize the influence of seasonal variability in our results.

Air quality monitoring stations presenting 90% or more of available data during the study period have been selected, for each pollutant. Data from 34 measurement sites has been used, including 9 rural, 14 urban background and 11 urban traffic air quality monitoring stations (see Fig. 2). However, not all of these sites present data for both pollutants. For both NO_2 and PM_{10}, a total number of 24 air quality monitoring stations have been considered.

Other relevant data to better characterize and investigate the impact of lockdown, in particular over air quality, is the reduction on transport activity. The Google COVID-19 Community Mobility database (Google LCC, 2020) has provided free access to mobility data around the world, which is used in this study as a proxy for transport activity. Fig. 3 presents the mobility trends estimated for Portugal for transit stations (e.g., places like public transport hubs such as subway, bus, and train stations), and for places of work, compared to a baseline day, which represents a normal value for that day of the week. The baseline day is the median value from the 5-week period Jan 3 – Feb 6, 2020.

It is clear that a significant reduction on mobility was registered during the period 16 March- 2 May, with reduction rates superior to 50% (50–80%). This was observed in all region of Portugal, but higher rates were verified in Lisbon area (purple line). The restarting of activities after the 2nd of May are traduced in slight increase (positive trend) of mobility data.

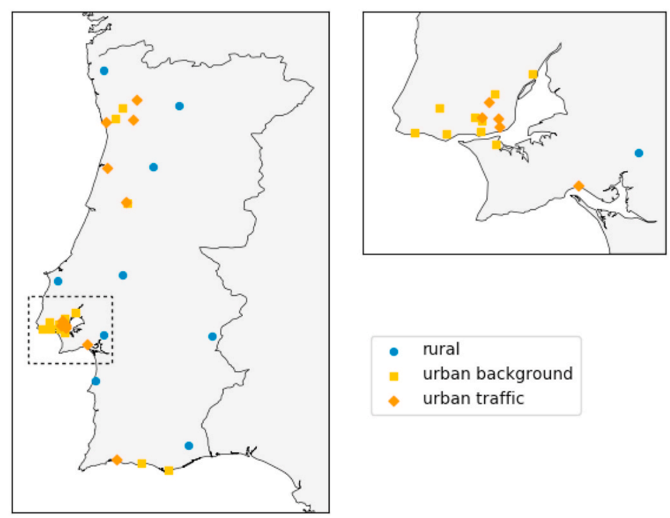

Fig. 2. Location of the selected air quality monitoring stations over Portugal, with zoom over Lisbon, and their classification.

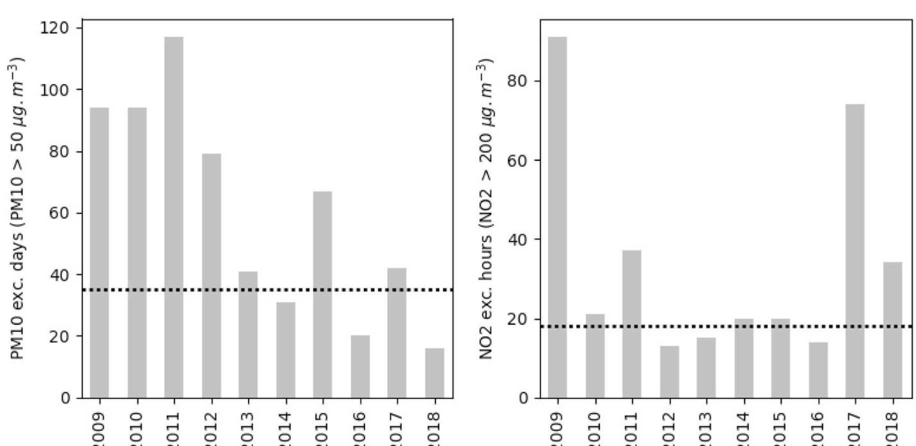

Fig. 1. PM_{10} and NO_2 exceedances to the daily and hourly legislated limit values for the protection of human health, respectively, registered in Avenida da Liberdade (LIB) station, located in Lisbon center, over the last ten years (2009–2018). Dashed lines identify the allowed number of exceedances per year, according to the Directive 2008/50/EC.

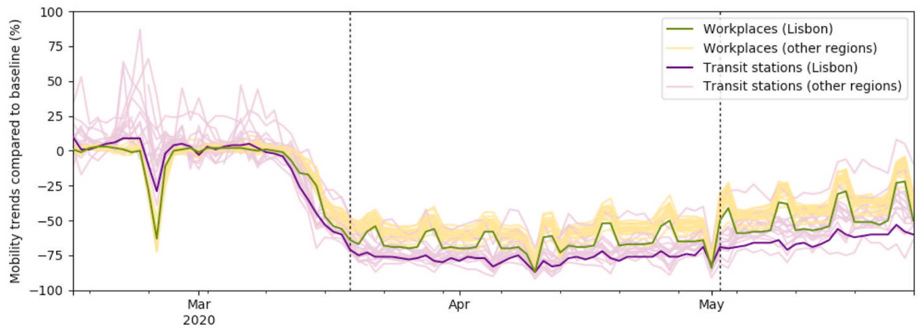

Fig. 3. Mobility trends for transit stations and for places of work, estimated for Portuguese Districts, between 15 February and May 25, 2020, compared to baseline. Dashed lines identify the beginning and end of the State of Emergency.

3. Reduction on pollutants concentration

The impact of COVID lockdown in air quality will be assessed/analyse per type of pollutant, namely NO_2 and PM_{10}, as already mentioned – section 3.1, and also per type of monitoring station, classified in terms of environment and influence – section 3.2.

3.1. Per pollutant

Fig. 4 presents the hourly timeseries of spatial averaged PM_{10} and NO_2 concentrations observed from 1 January to May 31, 2020, and also the correspondent baseline concentrations (5-year averaged data, from 2015 to 2019). Different time periods are identified in the plots: a dark blue period before COVID lockdown (from 1 January to 15 March) and a blue period that corresponds to lockdown or partial lockdown days (from 16 March to 31 May). Dashed lines identify the beginning and end of the State of Emergency. Fig. 5 presents the correspondent daily mean profiles for both pollutants for the period of lockdown or partial lockdown days. As previously, blue data corresponds to lockdown or partial lockdown days (period from 16 March to May 31, 2020) while red data groups the correspondent baseline concentrations (5-year averaged data of the period from 16 March to 31 May, from 2015 to 2019). This colour legend will be used during the rest of the figures.

The reduction in both pollutants' concentration during the lockdown and partial lockdown period is evident in the timeseries and daily profiles plots. In the case of PM_{10}, between 1 January to 15 March and 16 March to 31 May (see Fig. 4), an average reduction of around 7 μg/m^3 (corresponding to 30%) is observed, while for NO_2 the mean difference is about 12 μg/m^3, representing a reduction of 55%. However, part of this reductions may be due to the seasonal variability of pollutants in the atmospheric boundary layer (Gama et al., 2018). When comparing the period of 16 March to 31 May, for 2020 (lockdown or partial lockdown days) and for 2015–2019 (baseline concentrations), lower reductions are found (18% for PM_{10} and 41% for NO_2). The peak observed in the PM_{10} timeseries during the intermediate period (around 19th March), which also affects the mean weekly profile, is associated with a strong dust episode that impact the south of Iberian Peninsula (SDS-WAS, 2020).

Both daily and weekly profiles of PM_{10} indicates a delta of about 5 μg/m^3 between the two distinct periods, while this bias is around 10 μg/m^3 for NO_2. In both cases there is a flatness of the daily profiles after the lockdown (the two daily peaks characteristic of traffic influence are less relevant over the day). This indicates that the impact of the COVID lockdown was higher for NO_2 than for PM_{10}. In fact, NO_2 is a direct-traffic pollutant while PM_{10} has other relevant sources besides the road transport.

3.2. Per type of station

Fig. 6 presents the hourly timeseries of spatial averaged PM_{10} and NO_2 concentrations observed during the lockdown or partial lockdown days and for baseline conditions, per type of monitoring station. For PM_{10}, to remove the influence of the strong desert dust episode which occurred around 19th March and that could lead to misinterpretation of the results, the lockdown or partial lockdown period was considered from March 21 onwards. The AQ stations were grouped in terms of its classification on both environment (rural/urban) and influence (background/traffic) (Jolya and Peuch, 2012).

The differences found per type of station are usually high (red period), for both pollutants. These discrepancies are mainly between the

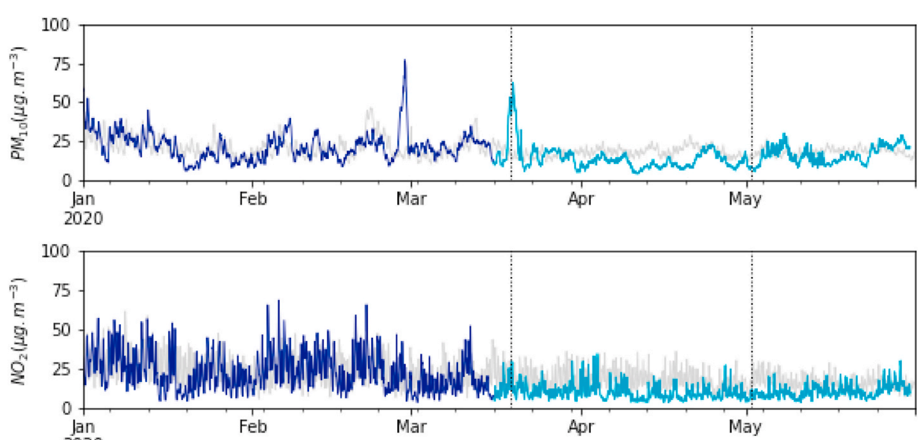

Fig. 4. Timeseries of spatial averaged PM_{10} and NO_2 hourly concentrations observed from 1 January to May 31, 2020 (blue lines), and the correspondent baseline concentrations (gray line, which depicts 5-year averaged data, from 2015 to 2019). Dashed lines identify the beginning and end of the State of Emergency. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

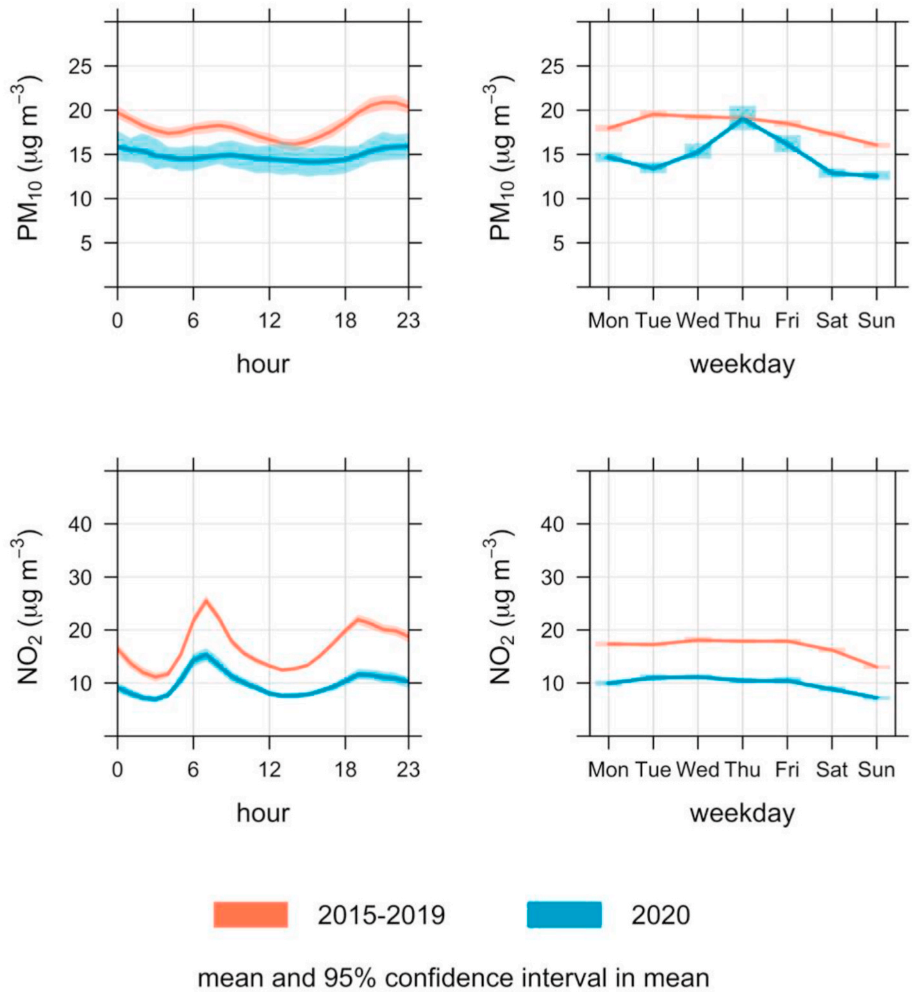

Fig. 5. Daily mean profiles of spatial averaged PM_{10} and NO_2 hourly concentrations observed during the period of lockdown or partial lockdown days (from 16 March to May 31, 2020) and the correspondent baseline concentrations (5-year averaged data of the period from 16 March to 31 May, from 2015 to 2019).

rural and urban environments, but in the case of NO_2, the differences are also significative between background and traffic influences.

The COVID lockdown (blue period) flattened the urban daily profiles, mainly for PM_{10}, and reduced the magnitude of the two-daily peaks associated with traffic (more expressive for the NO_2). In rural areas there is no impact on the concentration of NO_2 (small reductions (<10%) were observed), but for PM10 there are more expressive (>20%). Regarding the urban sites, for PM_{10} a mean reduction of about 16% is observed in background sites and up to 27% in traffic locations. The averaged values of PM_{10} are now always below 20 μg/m^3 in traffic sites, which is less than half of the daily limit value of 50 μg/m^3 legislated to human health protection. For NO_2, the mean reductions registered in urban areas are higher: 30% in background sites and about 50% in traffic locations.

4. Estimating traffic contribution

The high reductions verified in traffic activity (Google LLC, 2020) during the COVID emergency state will allow to estimate the real contribution of the road transport sector on the pollutants concentrations measured in traffic sites, in particular analysing NO_2, the most traffic-related pollutant. This can be then compared to the contribution estimated with the incremental method (Lenschow et al., 2001; De Leew et al., 2001), an approach developed and often adopted to estimate this type of contribution based on spatial concentration increments: two urban locations (representative of traffic and background urban sites) are compared and the difference between both locations gives the impact of the traffic on air quality.

The NO_2 average concentrations measured in each of the urban traffic stations considered in this study for this pollutant are presented in Table 1, during the lockdown period as well as for the shorter period corresponding to the state of emergency. The corresponding reductions in NO_2 concentrations, calculated taking into account the mirrored periods from the five previous years (16 March – 31 May from 2015 to 2019), are also presented.

During the state of emergency, all traffic stations show reductions in NO_2 concentrations in the range of 41%–64%.

If we apply the incremental method (Lenschow et al., 2001), we are able to estimate the increment in atmospheric concentrations due to traffic emissions by computing the difference between urban traffic and urban background stations nearby. We have applied this methodology for the three urban traffic sites with higher NO_2 mean concentrations, LIB, ENT and SCB, considering the observations from the nearest background sites, ALF and RES (all stations located in Lisbon). Fig. 7 presents the daily average profiles of the urban traffic and background stations, for each pair of air quality monitoring stations, during the lockdown period (16 March – May 31, 2020) and during the correspondent baseline concentrations (5-year averaged data of the period from 16 March to 31 May, from 2015 to 2019).

A mean 37 μg/m^3 delta exist between these LIB and RES urban sites, which could suggest the order of magnitude of the traffic contribution for LIB location, estimated by the incremental approach. This contribution is higher comparing to the reduction observed during the COVID

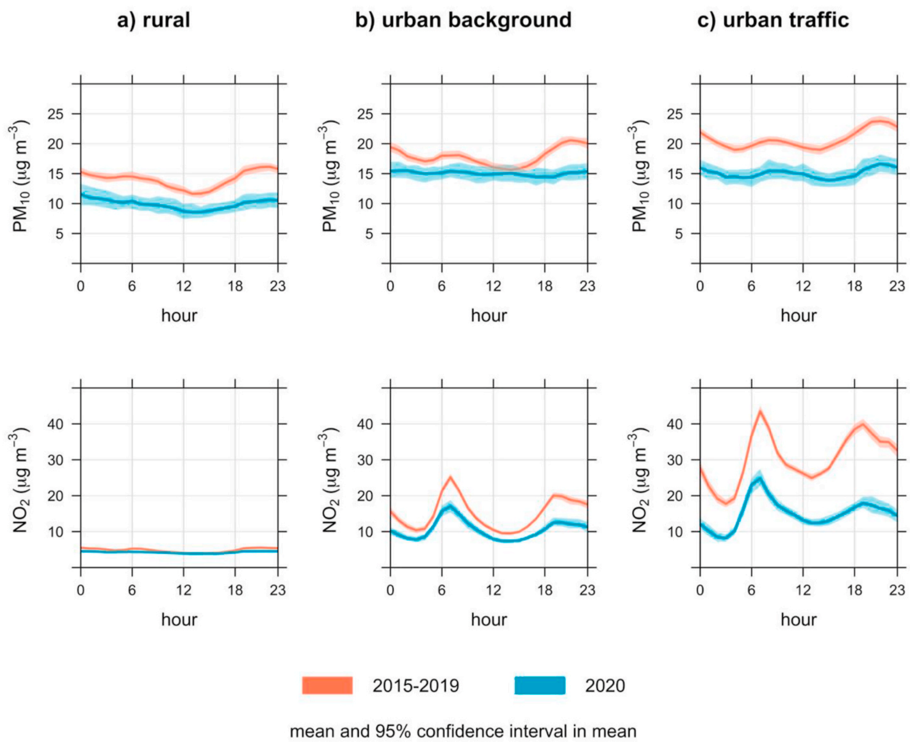

Fig. 6. Daily mean profiles of spatial averaged PM_{10} and NO_2 hourly concentrations observed at (a) rural, (b) urban background and (c) urban traffic stations, during the period of lockdown or partial lockdown days (from 16 March to May 31, 2020) and the correspondent baseline concentrations (5-year averaged data of the period from 16 March to 31 May, from 2015 to 2019).

Table 1
NO_2 concentrations at urban traffic stations.

AQ station	NO_2 average concentration (mg/m^3)				Reduction (%)	
	Lockdown baseline period (16 Mar-31 May 2015–2019)	Lockdown period (16 Mar-31 May 2020)	State emergency baseline period (19 Mar – 2 May 2015–2019)	State emergency period (19 Mar – May 2, 2020)	Lockdown period (16 Mar – 31 May)	State emergency (19 Mar – 2 May)
Aveiro (AVE)	20.5	8.5	21.9	7.9	58%	64%
Entrecampos (ENT)	36.6	17.1	37.6	16.5	53%	56%
Av. Liberdade (LIB)	53.2	23.1	50.6	20.3	57%	60%
Quebedo (QUE)	15.2	9.6	15.8	9.0	37%	43%
Odivelas (ODI)	22.0	12.0	22.5	12.0	45%	47%
Santa Cruz Benfica (SCB)	32.8	20.2	33.3	19.7	38%	41%

partial lockdown (30 µg/m^3) but the opposite happens in the other two analysed traffic sites (where the contribution estimated by the incremental method is lower). The mean reductions estimated by the incremental approach for SCB and ENT traffic sites are 9 and 13 µg/m^3, respectively. These values are even lower than the reduction observed during COVID partial lockdown, which was up to 13 and 19 µg/m^3 for SCB and ENT, respectively. Knowing that the road transport was the most affected emission source during the COVID lockdown in urban areas (European Data Portal, 2020), the reductions observed in NO_2 concentrations are directly associated to the traffic reduction and give us a real estimation of the traffic contribution in this site. Thus, we could estimate that the total traffic contribution could be even higher than the ones estimated here since, based on Google data, the reduction on mobility during the Emergency State period range 60–80% (see Fig. 1).

These results indicate that the incremental method is not consistent in estimating the traffic contribution and, then, should be taken carefully when used for air quality plans purposes or management strategies. Fragilities of this approach were already recently highlighted by Thunis (2018).

This research, however, is subject to two main limitations. The first one is related with the lack of access to meteorological observations from the current year (2020). Thus, when comparing pre-lockdown with lockdown air quality data, we cannot ensure that meteorological conditions are similar between the two periods, and we know that air quality is strongly influenced by meteorological conditions. Nevertheless, the long-time period used in the analysis allows to deal with the influence of the meteorological variability and to analyse the air quality (average) results in a more robust way.

A second limitation of the study is related with the assumption that changes in atmospheric pollutants concentration over the traffic environment sites - between the lockdown period and the same period from the 5 previous years - is mainly due to the reduction of atmospheric emissions from road traffic and not from changes in background concentrations. This assumption is based on the fact that these type of monitoring sites are defined as representative of the road traffic activity sector and, according to the European Data Portal (2020), road transport

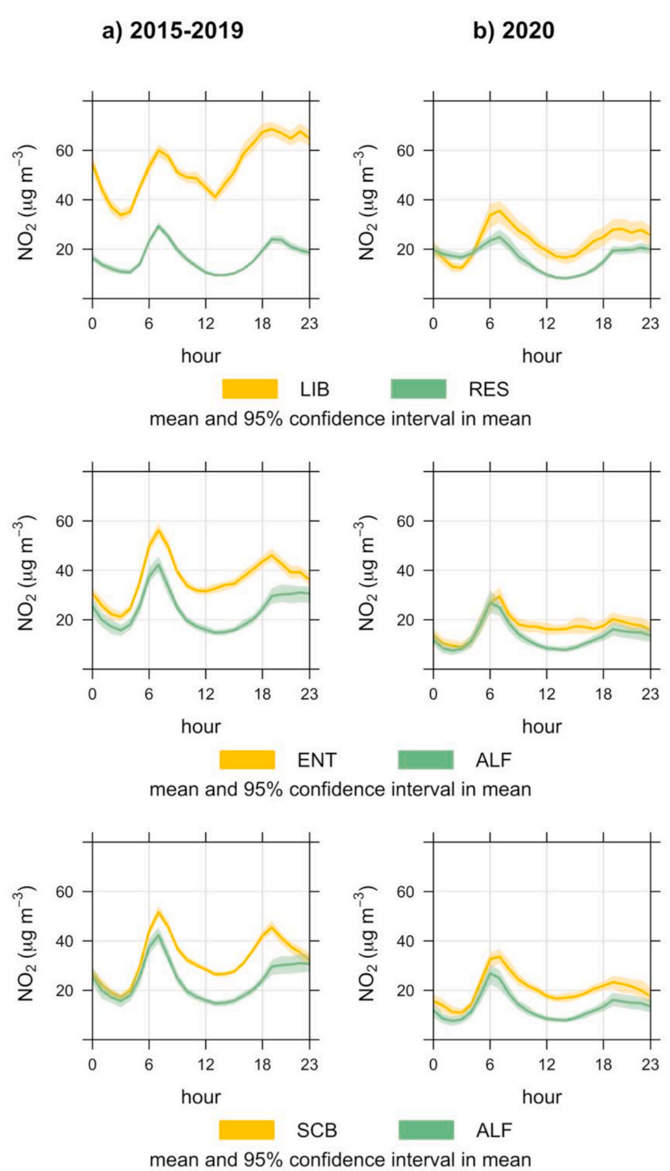

Fig. 7. NO_2 daily average profiles for LIB/RES, ENT/ALF, and SCB/ALF traffic/background station pairs, observed during the period of lockdown or partial lockdown days (from 16 March to May 31, 2020, right panel) and the correspondent baseline concentrations (5-year averaged data of the period from 16 March to 31 May, from 2015 to 2019, left panel). Traffic stations data is presented in yellow and background stations data in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

was, in fact, the most affected emission source during the COVID lockdown in urban areas.

5. Conclusions

The impact of the COVID pandemic – and its lockdown – on air pollution was assessed in detail for Portugal study case, based on NO_2 and PM_{10} concentration data collected in more than 20 monitoring sites. This analysis was done taking into account the 2.5 months COVID lockdown period (16 March – May 31, 2020) and the mirrored period from the five previous years (16 March – 31 May from 2015 to 2019). These long time periods allow to include meteorological variability and to estimate mean concentration values representative of each specific period, and to minimize the influence of seasonal variability in our results.

The analysis was done per type of pollutant and monitoring site. The reductions observed in both pollutants' concentrations were very significant, but higher in case of NO_2 (the most traffic-related pollutant, with mean reductions of 41%). The impact of the lockdown was much more expressive in the urban areas, and in particular in traffic areas, where the highest reductions of NO_2 are found (reaching values higher than 60% in some monitoring stations). This is in agreement with the mobility trend data provided by Google, which register reductions on road transport during the State of Emergence around 50–70%, depending on the day.

These large restrictions on traffic allowed to estimate the contribution of traffic on the air quality – in particular for NO_2, when comparing lockdown period with the correspondent baseline conditions. The results found for several traffic sites indicate that the incremental method – often adopted to estimate the different urban and traffic contribution to air pollution – is not consistent in estimating the traffic influence (exhibiting lower values in same cases and higher in other ones).

In terms of future projections, this improvement on air quality (in particular in urban areas) will change and finish once the economy is reactivated. In fact, the last two weeks of May already showed a slight increase on NO_2 and PM_{10} concentration levels associated to the end of the state of emergency and to the restarting activities. Nevertheless, lessons can always be learned with the worst scenarios and this one, in particular, provide us tools to better manage air quality and rethinking mobility strategies.

Credit author statement

Carla Gama: Conceptualization, Methodology, Software, Validation, Formal analysis, Helder Relvas: Conceptualization, Writing – original draft, Myriam Lopes: Reviewing, Alexandra Monteiro: Conceptualization, Methodology, Writing and Editing, Supervision.

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.

Acknowledgements

Thanks are due to FCT/MCTES for the financial support to CESAM (UIDP/50017/2020+UIDB/50017/2020), through national funds. The authors also acknowledge the Portuguese Environment Agency (APA) and the Regional Coordination and Development Commissions (CCDRs) for their effort in establishing and maintaining the air quality monitoring sites used in this investigation, and Google for the public release of COVID-19 Community Mobility Reports.

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