AIR EMISSION AND POLLUTION LEVELS DURING THE PANDEMIC IN THE GREATER ATHENS AREA, GREECE

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1. INTRODUCTION

Lockdown restrictions due to the COVID-19 pandemic led to air, road and marine traffic limitations as well as to limitations of economic activities causing thus considerable reductions of air pollutant emissions and air quality levels. As a result, the COVID-19 pandemic provided scientists and policy makers with the unique opportunity to study an unprecedented large scale experiment, namely the effects of containment measures on emissions from various sources and, consequently, on air pollutant levels. In this framework, several studies were conducted in Europe and elsewhere showing important NO_2 and PM_{10} decreases, 38-65% and 8-48% respectively (Baldasano, 2020; Gama et al., 2021; Wyche et al., 2021; Collivignarelli et al., 2020; Sicard et al., 2020).

In Greece, two similar studies were found, indicating an average decline of mean tropospheric NO_2 by 11-15% whereas total emissions over Greece declined by around 10% (Koukouli et al. 2021) and, at an urban background station in central Athens, significant concentration decreases ranging from 32 to 42% for NO_2, CO, CO_2, $PM_{2.5}$ and BC concentrations (Grivas et al., 2020).

The present work aims at studying the impact of traffic restrictions, due to pandemic, on air pollutant emissions and on atmospheric pollutant concentrations in the Greater Area of Athens (GAA), Greece. The study focused on three air pollutants, NO_2 and PM_{10} and C_6H_6 because they reveal air quality standard exceedances for three representative monitoring stations in the GAA (Figure 1). The air pollutant levels for the period March to May 2017-2020 were examined and compared to the corresponding emission levels and emission reductions due to COVID-19 containment measures.

Purpose of the study is to draw useful conclusions on air pollutant sources and their impact on air quality levels and to provide policy makers with useful information regarding the efficiency of current or future measures and policies towards air pollution abatement and to comply with current air quality standards.

2. MATERIALS AND METHODS

2.1 Collection of Input Data

The data required include statistical fuel consumption for all fuel types per sector and usage (e.g. road traffic, heating, industry) and indices for the industrial production and economic turnover per sector from the Hellenic Ministry of the Environment and Energy, to reliably estimate emissions from all sources in the GAA. Moreover, road, air and marine traffic data were obtained from the Region of Attica, the Hellenic Civil Aviation Authority (HCAA, 2021) and the Piraeus Port Authority (PPA). Air quality measurements were acquired by the National Air Pollution Monitoring Network (NAPMN) for the urban-traffic station of Patission and the semi-urban industrial

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station of Elefsina and by the PPA for the Piraeus Port station (Figure 1).

Fig. 1. Location of monitoring stations.

2.2 Calculation of Air Pollutant Emissions

Calculation of air pollutant emissions from all sources was carried out by adopting the methodologies applied in the Greek National Inventories under the United Nations Framework Convention on Climate Change (UNFCCC) and the National Emissions Ceiling (NEC) Directive (EU 2016/2284) (EEA, 2019; EU, 2016) for the lockdown period (March-May 2020) and for comparison, for the same period of the previous years (2017-2019).

Road traffic emissions were estimated by applying Tier 3 methodology through use of the last version of COPERT V (Ntziachristos et al., 2009). Tier 1 was applied to calculate emissions from heating (EEA, 2019) by considering the mean monthly fuel consumption per fuel type.

For air traffic emissions, a Tier 3 approach was applied based on the combination of energy consumption and air traffic data, derived from the national energy balance, the HCAA and EUROCONTROL. Similarly, for the Piraeus Port emissions, detailed (Tier 3) calculations were carried out by use of the vessel traffic data as provided by the Piraeus Port Authority (EEA, 2019).

Finally, for the determination of industrial emissions, Tier 1, Tier 2 and Tier 3 methodologies were applied, as foreseen for each sector in the National Emission Inventory under the NEC Directive (EU 2016/2284), (EEA, 2019). Additionally, to calculate emissions for the periods examined, except from fuel consumption data for the respective sectors, financial indices and production rates were considered as well.

2.3 Analysis of Air Pollutant Measurements

The analysis of air pollutant level variations was carried out to compare the pandemic period measurements to the business-as-usual scenario with regard to the respective emissions. Beside NO_2 and PM_{10}, C_6H_6 measurements from Patission station were also included. To ensure that no other parameters exist that might influence air pollutant levels, mean monthly wind speed and temperature values were examined and no significant variation of the mean monthly values was identified. Finally, to avoid the influence of non-linear factors, such as photochemical mechanisms, non-systemic phenomena, as for example pollutant transport, incidental events etc., in the analysis implemented mean monthly emissions and concentration values were considered.

3. RESULTS AND DISCUSSION

3.1 Road Traffic Emissions

As shown in Figures 2 and 3, emission reductions, 20-40%, are depicted. The decreases are mostly due to the reduction of passenger car emissions, which overpasses 55%, whereas for trucks and buses, the reductions range from 25-30%. The above results conform with the roadmap of the containment measures application.

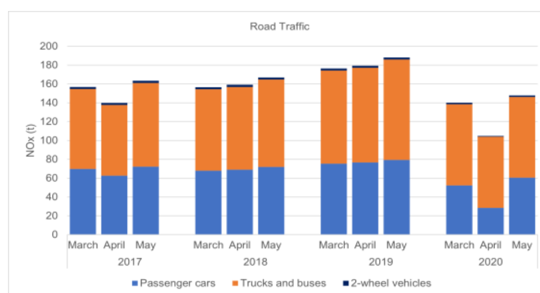

Fig. 2. Road traffic emissions per vehicle category for the period March to May 2017-2020.

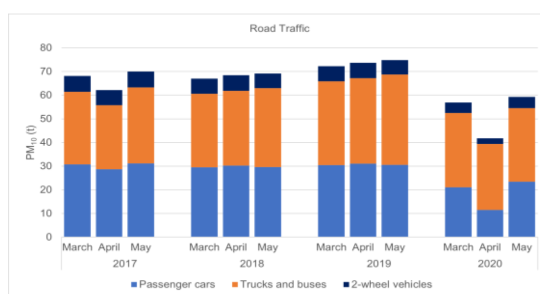

Fig.3. Road traffic PM_{10} emissions per vehicle category for the period March to May 2017-2020.

3.2 Emissions from the Piraeus Port

Total emissions from the Port of Piraeus in March 2020, remain almost identical to previous years (Figures 4 and 5). It is to be mentioned that, during the pandemic, commercial port emissions increased or remained stable, compared to previous years, whereas passenger port emissions decreased significantly from 20 to 80%.

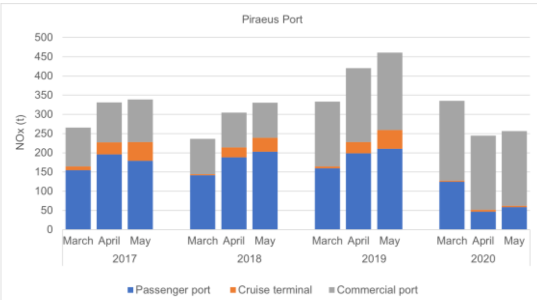

Fig. 4. Piraeus Port NOx emissions for the period March to May 2017-2020

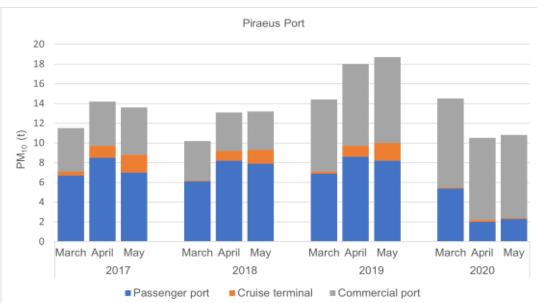

Fig. 5. Piraeus Port PM_{10} emissions for the period March to May 2017-2020

3.3 Emissions from the Athens International Airport

During the pandemic, air traffic emissions for both NOx and PM_{10}, presented a considerable reduction ranging from 35% to 90%, after having exhibited a constant increase from 2017 to 2019 (Figures 6 and 7).

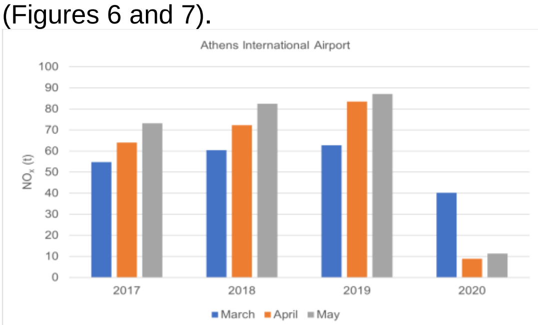

Fig. 6. NOx emissions in the Athens International Airport for the period March to May 2017-2020.

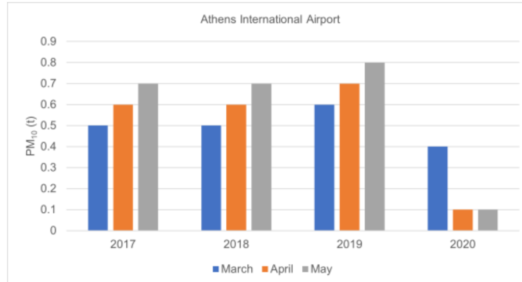

Fig. 7. PM_{10} emissions in the Athens International Airport for the period March to May 2017-2020.

3.4 Emissions from Heating

Heating emissions revealed increases of the residential sector and decreases of the commercial sector for both NOx and PM_{10} (Figures 8 and 9). In total, NOx emissions from heating remain almost unvarying in March, whereas they drop by 8% and 28% in April, and May. PM_{10} emissions increase by 7 and 18% in March and April whereas in May they remain practically stable. However, the NOx decreases occurred are low in absolute values and could hardly affect the corresponding concentration levels. PM_{10} emissions exhibit a more significant increase in April, still, the increase shown is low in absolute values, especially in the central area of Athens where biomass burning is limited.

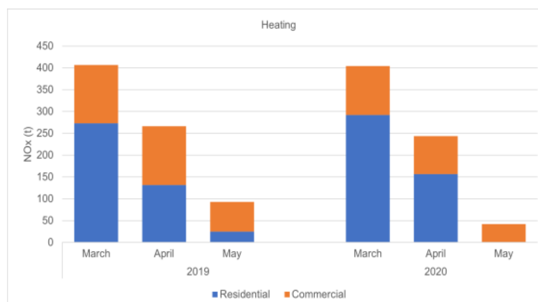

Fig. 8. NOx emissions from residential and commercial heating for the period March to May 2019-2020

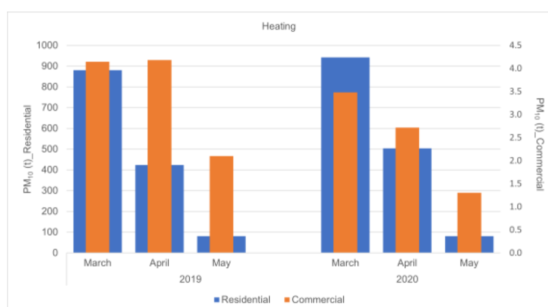

Fig. 9. PM_{10} emissions (t) from residential and commercial heating for the period March to May 2019-2020.

3.5 Emissions from Industry

Industrial emissions increase in 2018 relatively to 2017, whereas in 2019 and 2020 significant reductions occur due to and the partial replacement of petroleum products by natural gas. In 2020, comparatively to 2019, emissions present slight differences except from April, when they decrease by 25-30%, due to fuel consumption decrease (Figures 10 and 11).

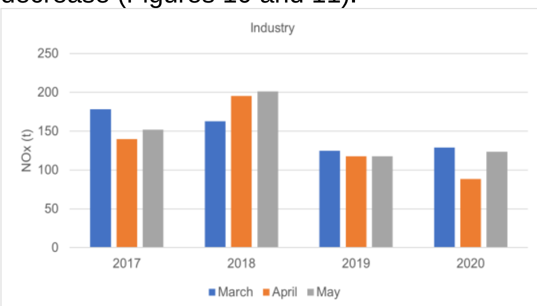

Fig. 10. NOx emissions (t) from industry for the period March to May 2017-2020.

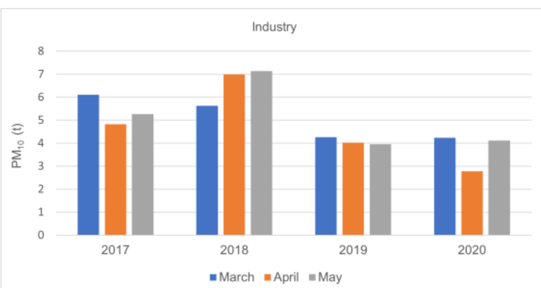

Fig. 11. Particulate Matter (PM_{10}) emissions (t) from industry for the period March to May 2017-2020.

3.6 Air Quality Levels

In Figures 12-14, NO_2, PM_{10} and C_6H_6 concentrations are presented for the period March-May 2017-2020, for which a regression analysis was also conducted to investigate relations between concentrations and emission sources.

3.6.1 Nitrogen Dioxide (NO_2)

Urban traffic stations

Patission station is situated in an area with heavy traffic, densely populated with important commercial uses and presents the maximum NO_2 levels measured in the NAPMN of the GAA, with a mean annual concentration of 73 μg/m^3 in 2019. In general, NO_2 levels decreased in 2020, by 20, 40 and 13% for March, April and May respectively, whereas the corresponding traffic emissions declined by around 21, 41 and 21% (Figures 2 and 12).

In the regression analysis conducted, the results showed a strong relation of NO_2 levels and road traffic emissions (R^2=0.85). The PPA station is located in the Passenger Port of Piraeus and is expected to be affected mostly by marine traffic emissions from passenger ships but also by the intense road traffic at the periphery and inside the port area. The mean annual concentration for 2019 was 51 μg/m^3, exceeding the annual limit by 11 μg/m^3, while similar concentrations occurred for the previous years (Figure 12). Passenger port emissions decrease by 22 and 76.5% in March and April 2020 respectively, whereas mean NO_2 levels decrease by 46 and 69%. This significant decrease shows the impact of the passenger port on air quality. It should be noted that, in the case of the Piraeus Port, the decrease of marine traffic causes an additional decrease of road traffic emissions, which locally would exceed the mean road traffic emission decrease for the GAA.

The results obtained are in accordance with the findings of similar works elsewhere. In more detail, the respective reductions at traffic stations located in four European cities (Nice, Rome, Valencia and Turin) range from 57%-73% (Sicard et al., 2020) whereas in Ontario, Canada, a decrease of 67% was found (Adams, 2020).

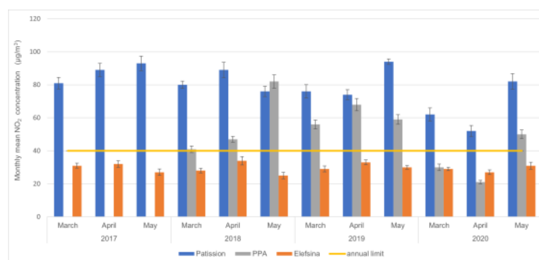
Fig. 12. Monthly mean NO_2 concentrations (μg/m^3) in the stations of Patission, the PPA (Passenger Port of Piraeus) and Elefsina for the period March to May 2017-2020. Error bars represent the standard error.

Semi-Urban background station

Elefsina is a city located in the Thriassion plain, in Western Attica, in proximity to industrial installations, logistics and freight facilities. The station is situated in the residential area of the town of Elefsina, with mean annual concentrations of 25-27 μg/m^3 (Figure 12), and susceptible to being affected by the industrial and commercial activities in the greater area. Nevertheless, these activities have not been significantly influenced by the containment measures. Mean NO_2 levels in March do not vary in comparison to previous years, whereas in April, a decrease of around 20%

is observed. This behaviour might comply with the variation of industrial emissions, notwithstanding, the regression analysis conducted did not show any correlation with either road traffic or industrial emissions.

3.6.2 Particulate matter (PM_{10})

In general, PM_{10} levels do not exceed current air quality limits set by the EC, either daily or yearly, with the exception of the PPA station for which, in 2019, the daily limit was exceeded 58 and 40 times, respectively. Although, in urban environments, particulate matter is connected to road traffic, it presents a significant connection to residential and commercial heating as well (Chan et al, 2021; Menut et al., 2020)

Urban traffic station

In the PPA station (Figure 13), PM_{10} levels drop substantially, by 45, 53 and 14% for March, April and May respectively. Given that the respective road traffic emissions declined by 21, 43 and 21% (Figure 3), these concentration decreases seem to be connected to other sources as well, especially shipping emissions which show a decline of around 22% in March, 77% in April and 72% in May (Figure 5). Nonetheless, similarly to NO_2, the linear regression analysis revealed a significant correlation with road traffic emissions (R^2=0.94) whereas the correlation with passenger ship emissions is not so important (R^2=0.61).

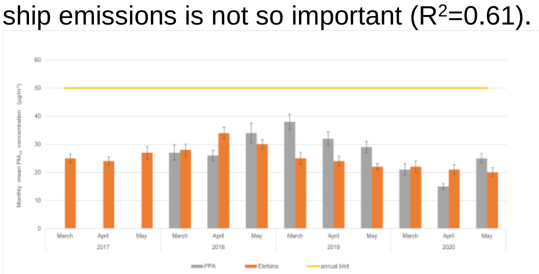

Fig. 13. Monthly mean PM_{10} concentrations (μg/m^3) in the stations of the PPA (Passenger Port of Piraeus) and Elefsina for the period March to May 2017-2020. Error bars represent the standard error.

Semi-urban background station

In Elefsina, PM_{10} levels show a slight decrease of approximately 10% during the period March-May 2020 (Figure 13). This finding, most probably, reveals the impact of heating emissions, while no correlation was found between concentrations and other emission sources.

3.6.3 Benzene (C_6H_6)

Patission urban traffic station

Benzene is mainly associated with emissions from petrol vehicles but also with biomass burning. The mean annual concentration limit is 5 μg/m^3 and it was exceeded in Patission station in 2017 and 2018. However, in March 2020, the monthly mean benzene concentration is significantly reduced (-50%), while, in April 2020, the concentration is even lower (Figure 14) and shows a sharp decrease of 80%. These reductions seem to reflect emission decreases from petrol vehicles as demonstrated by the strong correlation between benzene levels and petrol consumption (R^2=97%). Contrary to the previous months, in May 2020, C_6H_6 concentration increased by 167% comparatively to April 2020, as a consequence of the lifting of measures.

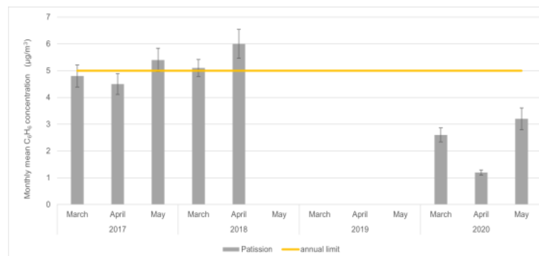

Fig. 14. Monthly mean C_6H_6 concentrations (μg/m^3) in Patission station for the period March to May 2017-2020. Error bars represent the standard error.

4. Conclusions

Restrictions due to COVID-19 led to a unique opportunity to study the changes in air pollutant emissions and mainly in air quality levels with the aim to identify realistic and effective air pollution mitigation strategies. Three air pollutants (NO_2, PM_{10} and C_6H_6) were investigated and their concentration levels were related to the corresponding emissions from all sources for the period March-May 2017-2020.

From the emission calculations performed, the most significant decreases occur in traffic emissions, including road, air and marine traffic. Road traffic emissions exhibit reductions, comparatively to previous years, ranging for NOx, from 20 to 40% in March and April 2020, respectively. Likewise, for the same period, PM_{10} emissions decreased by 25 and 40%. The decreases encountered are mostly due to the reduction of passenger car emissions (30-60%), whereas for trucks and buses, the corresponding reductions are lower (25-30%). All the above results conform with the roadmap of the containment measures application. Total emissions from the Port of Piraeus remain constant in March and drop by 40% in April 2020, as a result of the substantial decrease, up to 80%, of coastal navigation and cruise ships emissions, whereas commercial ships emissions remain unchanged.

The enforcement of traffic restriction measures led to reductions of air pollutant emissions and, consequently, to air pollution abatement as well. In the urban-traffic stations examined, the mean NO_2 reductions encountered for March and April 2020 are of the order of 20 and 40%, respectively. Also, a strong relation between NO_2 levels and road traffic emissions was identified (R^2 = 0.80-0.85) indicating the type of measures needed in order to eliminate exceedances.

In general, PM_{10} levels do not exceed current air quality limits and they exhibit lower decreases than NO_2 concentrations, as being related to traffic and heating as well, with the latter being rather stable during the lockdown period.

Benzene concentrations were significantly reduced by 50% to 80%, in March and April, respectively as a result of the significant decrease of passenger vehicle traffic.

Overall, the analysis conducted, provided useful data concerning the relation of emission sources to high air pollutant levels. The information delivered can be used to assess, ex ante and ex post, the efficacy of future or current environmental policy interventions in order to reduce long term exposure to air pollutants.

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