Atmospheric particles in the surrounding area of the Lisbon airport: characteristics, sources and impacts

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Abstract

Throughout 2020 and 2021, particulate matter was sampled in an elementary school in the vicinity of the Lisbon Airport. This study aims to estimate the contribution of anthropogenic and natural sources to the atmospheric aerosol and estimate its deposited dose in the human respiratory tract, as well as to assess the impact of the COVID-19 lockdowns on particulate matter concentrations. PM_{10} sampling was performed by a Leckel MVS6 sampler, between February 2020 and July 2021, while its source apportionment was performed by the EPA PMF model, and its deposition in the human respiratory tract was estimated by the ExDoM2 dosimetry model. The results showed that the reduction in human activity caused a reduction of 32% in PM_{10} and of 42% in BC levels, between the pre-pandemic and the pandemic periods. The EPA PMF model revealed that the lockdowns caused reductions in the contribution of anthropogenic pollutant sources, namely traffic emissions, to the total PM_{10} mass. The ExDoM2 dosimetry model showed that the deposition of PM_{10} in the respiratory tract of children decreased by 39%.

Keywords: Particulate Matter; Lisbon; Airport; Source Apportionment; Inhaled Dose; COVID-19.

1. Introduction

Air pollution remains a huge environmental problem in both urban and rural areas (WHO, 2018). In particular, exposure to particulate matter (PM), resulting in cardiovascular, respiratory, and oncological diseases, is responsible for the premature death of millions of people worldwide (WHO, 2018). PM concentrations intensify in numerous urban centers, as it is in these areas that anthropogenic sources of pollutants are concentrated in large numbers. Despite the extensive literature regarding this pollutant and its impacts, its complex nature makes it difficult to develop effective control measures, besides these measures focus on exposure to ambient air concentrations, while the population spends most of the time in indoor microenvironments (Life Index-Air, 2021).

Aviation is an important sector for the economy and a means of transport with great relevance for the world population, however, it is an important source of air pollutants that influence Air Quality (AQ), not only in the vicinity of airports but also in more distant areas. The rising number of flights worldwide is increasing the relevance of aircraft pollutant emissions with regard to their impacts on the environment and climate. Consequently, air pollution in the vicinity of airports, especially in the form of PM, due to its known adverse effects on human health, severely influences public opinion, the scientific community and policy makers. However, the lockdown imposed by most countries to reduce COVID-19 transmission have led to a significant reduction in air pollutant emissions, particularly from the aviation sector, as European air traffic recorded in the year 2020 was 55% lower than in the year 2019 (EUROCONTROL, 2021). The fluctuations in AQ caused by the lockdown during the COVID-19 pandemic can help to understand the links between urban activities, namely air and road traffic, and AQ, creating a unique opportunity to reflect on how these activities should recover after the pandemic.

One of the most susceptible populations to develop health problems as a consequence of exposure to PM are children (EPA, 2021). As they live and attend a school in the vicinity of a focus of pollutant emissions, such as the Lisbon Airport, the risk to which these children are subjected is increased. Considering that PM concentrations higher than outdoor concentrations have been recorded in the classrooms of several Lisbon schools

(Chalvatzaki et al., 2020; Faria et al., 2020), it becomes necessary to assess the integrated exposure of these children to this pollutant, in order to develop a solid scientific knowledge about the impacts of aviation on children's health, to motivate an informed decision making, regarding the implementation of efficient mitigation measures.

This work aims to characterize the atmospheric particles near the Lisbon Airport and using modeling techniques to quantify the contribution of their emission sources and also assess the deposition of PM in the human respiratory tract. This work also takes advantage of the fact that the number of flights and the volume of road traffic were affected by the pandemic, since it relies on data collected before and after the beginning of the pandemic, allowing to compare both periods, in order to understand how the lockdown affected the AQ and human health.

2. Materials and methods

2.1. Study area characterization

Sampling was performed in an elementary school, located in Camarate. The sampling site (Figure 1) is located in an industrialized area of Lisbon, 200 m from the boundary of the airport and 450 m from the center of its only runway in operation, thus being under a strong influence of emissions from the airport. Concerning road traffic emissions, these are also found to influence the study area's AQ, since two of the highways with the highest traffic volume in Lisbon, Segunda Circular and Eixo Norte-Sul/IP7, are located about 3 km and 700 m, respectively, from the sampling site. Regarding industrial emissions, there is a bituminous concrete production unit in close proximity to the sampling site. Moreover, with the Atlantic Ocean about 20 km away, the study area's AQ is also considerably influenced by the marine aerosol (Almeida et al., 2013). In addition, the sampling site is surrounded by residential buildings, which hinders the atmospheric dispersion of pollutants.

2.2. Sampling and measuring equipment

The sampled PM_{10} was collected on Teflon filters using a Leckel MVS6 sampler operating at a flow rate of 2.3 m^3/h, over 24 h periods. A total of 100 PM_{10} samples were collected between February of 2020 and July of 2021.

To obtain the particle size distribution, a Sioutas cascade personal impactor was used. This impactor collects airborne particles on Teflon filters across the five following size ranges: < 0.25, 0.25-0.5, 0.5-1, 1-2.5 and > 2.5 µm. An SKC Leland Legacy pump was used to suck the air into the impactor, over 24 h periods. Before each sampling took place, a BGI tetraCal® flowmeter was used to adjust the pump's flow rate to 9 L/min. A total of 6 samples were collected between March and June of 2021.

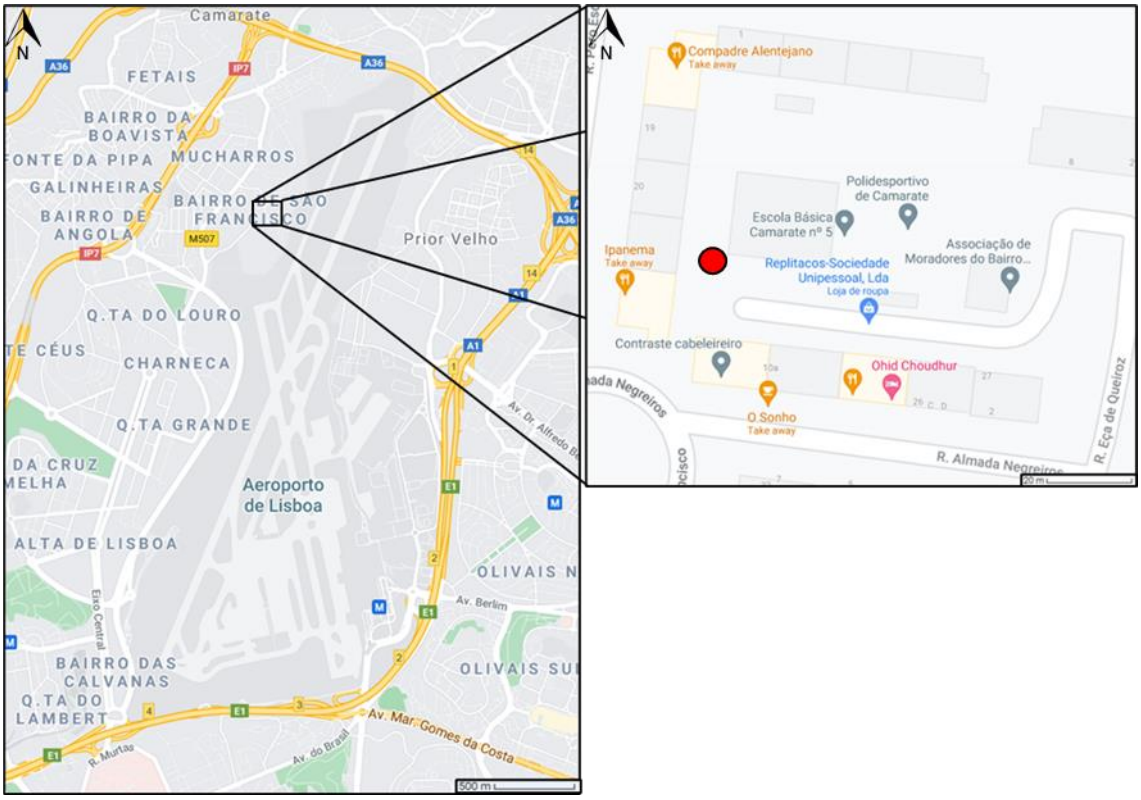

Figure 1 - Study area and sampling site (represented by the red circle).

In order to measure PM_{10} concentrations in real time and originate its average hourly concentrations, a DustTrak DRX Aerosol Monitor 8533 was used. It operated on 25 days between March and June 2021.

2.3. Gravimetric and chemical analysis

The PM mass collected on each filter was determined by gravimetry using a 0.1 µg sensitivity UMT5 balance, in a controlled and clean laboratory. The initial and final mass of each filter was obtained as the average of three measurements.

The chemical analysis of the filters was performed by the Multi-wavelength Absorption Black Carbon Instrument (MABI) to obtain the fraction and source (traffic (BC_{tr}) or biomass burning (BC_{bb})) of the sampled BC, by Particle Induced X-Ray Emission (PIXE) to measure the chemical elements in the samples (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Y, Zr, Mo, Ba, and Pb), and by Ion Chromatography to measure the water-soluble ions in the samples (Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, Cl^-, NO_3^-, and SO_4^{2-}).

2.4. Source apportionment model

In order to determine the sources of the sampled PM_{10}, the EPA PMF (Positive Matrix Factorization) model was used. This model associates the concentration of each chemical component of PM_{10} with the chemical profiles of its major sources and their contributions to the total PM_{10} mass, therefore, the model requires as input data the concentrations and uncertainties of the chemical components of PM_{10} and the number of major sources.

2.5. Dosimetry model

The PM_{10} dose deposited in the elementary school students' respiratory tract, after inhalation, was estimated by the dosimetry model ExDoM2. This dose depends on several factors, such as the concentration and the duration of the exposure, the PM_{10} physicochemical characteristics, the time-activity pattern and the characteristics of the exposed individuals (Martins et al., 2015). Therefore, the model requires as inputs the particles' average hourly concentration, size distribution, density (1.5 g/cm^3), and shape factor (1), the exposure duration, and age (5-10 years), gender (male and female), breathing type (nose), and physical activity level of the exposed individuals (Chalvatzaki et al., 2018).

The model estimated the PM dose deposited in five regions of the respiratory tract: the anterior nasal passage (ET1), the posterior nasal passage, pharynx, and larynx (ET2), the bronchial region (BB), the bronchiolar region (bb), and the alveolar-interstitial region (AI). This estimation was performed for four distinct scenarios (Figure 2).

Among the four scenarios, the only input data that varied was the average hourly PM_{10} concentration. However, these concentrations were only measured for the 3rd scenario, so, to obtain the remaining scenarios' concentrations, some assumptions were made. To convert the 3rd scenario to the 1st scenario, the concentrations were multiplied by the ratio (1.64) found between the pre-pandemic and the pandemic PM_{10} concentrations obtained by the gravimetric analysis. Then, the conversion from the 1st scenario to the 2nd scenario, and from the 3rd scenario to the 4th scenario was given by:

$$C_{in} = F_{inf} \times C_{out} + C_{ig}$$

where C_{in} is the indoor PM_{10} concentration, C_{out} is the outdoor PM_{10} concentration, F_{inf} (0.55 µg/m^3 for home and 1.13 µg/m^3 for school) is the infiltration factor, and C_{ig} (4.41 µg/m^3 for home and 26.08 µg/m^3 for school) is the concentration of indoor generated PM_{10} (Life Index-Air, 2021). Finally, the integrated exposure is given by the sum of the number of hours spent in each microenvironment multiplied by the average hourly PM_{10} concentration of the respective microenvironment.

For the PM size distribution, one of the distributions obtained by the gravimetric analysis of the filters used in the Sioutas impactor was selected, assuming that it remained constant between the different scenarios.

Finally, the time-activity pattern adopted for the model was the one presented in Table 1.

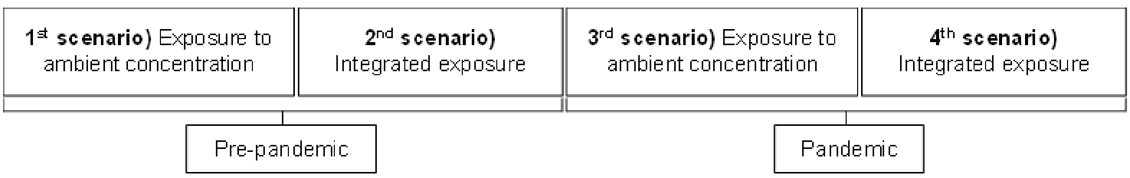

Figure 2 - Scheme of the four scenarios considered by the dosimetry model.

Table 1 - Typical weekday time-activity pattern of the elementary school students.

Hours	Activity	Microenvironment
00:00-08:00	Sleep	Home
08:00-09:00	Light activity	Outdoor
09:00-13:00	Sitting	School
13:00-14:00	Light activity	Outdoor
14:00-17:00	Sitting	School
17:00-18:00	Light activity	Outdoor
18:00-22:00	Sitting	Home
22:00-24:00	Sleep	Home

2.6. Air and road traffic data

The number of daily flights arriving at and departing from the Lisbon Airport were acquired from the database provided by EUROCONTROL (EUROCONTROL, 2021a). The daily variation in road traffic volume in the Lisbon Metropolitan Area was obtained through Apple's mobility trends reports (Apple, 2021).

2.7. Statistical analysis

The statistical tests in this work were performed using the STATISTICA software. Since the samples were independent from each other, the statistical test selected to assess the significance of variations in atmospheric concentrations of pollutants between the different phases of the pandemic was the nonparametric Mann-Whitney U test.

3. Results and discussion

3.1. Lockdown effects on air and road traffic

In the overall sampling period during the pandemic there was a reduction of approximately 68% in the number of flights compared to the pre-pandemic period. For the road traffic volume, the reduction was of approximately 36% between the two periods. These variations are shown in Figure 3.

3.2. PM_{10} daily average concentrations

In the sampling period prior to the start of the pandemic, 12 PM_{10} samples were collected, and their daily average concentrations ranged from 16.9 to 48.2 µg/m^3, with an average of 35.7 ± 9.0 µg/m^3. In the following sampling period, after the first lockdown, a total of 41 PM_{10} samples were collected, whose daily average concentrations ranged from 5.1 to 105.1 µg/m^3, with an average of 24.2 ± 15.4 µg/m^3. During the next sampling period, which ran during the second lockdown, the number of samples collected was 15, with a daily average PM_{10} concentration of 32.7 ± 14.0 µg/m^3, a minimum of 10.8 µg/m^3, and a maximum of 63.2 µg/m^3. Finally, during the last sampling period, after the end of the second lockdown, 32 PM_{10} samples were collected, with daily average concentrations ranging from 8.5 to 52.2 µg/m^3, with an average of 20.5 ± 10.4 µg/m^3. Globally, the daily average PM_{10} concentration decreased by 32%, from 35.7 ± 9.0 µg/m^3 in the pre-pandemic period, to 24.3 ± 14.1 µg/m^3 in the pandemic period.

According to the statistical tests, the pre-pandemic PM_{10} concentrations were significantly different from the concentrations recorded in the pandemic period ($p < 0.05$). Similarly, the number of flights and the volume of road traffic were significantly different between both periods ($p < 0.05$). These results suggest that the decrease in PM_{10} concentrations were at least partially due to the reduced air and road traffic. This deduction is supported by the results of a study developed by Gama et al. (2021). According to this study, the average PM_{10} concentrations recorded at more than 20 AQ monitoring stations, distributed across mainland Portugal, decreased on average 30% between the beginning of 2020 (January 1 to March 15) and the first lockdown period (March

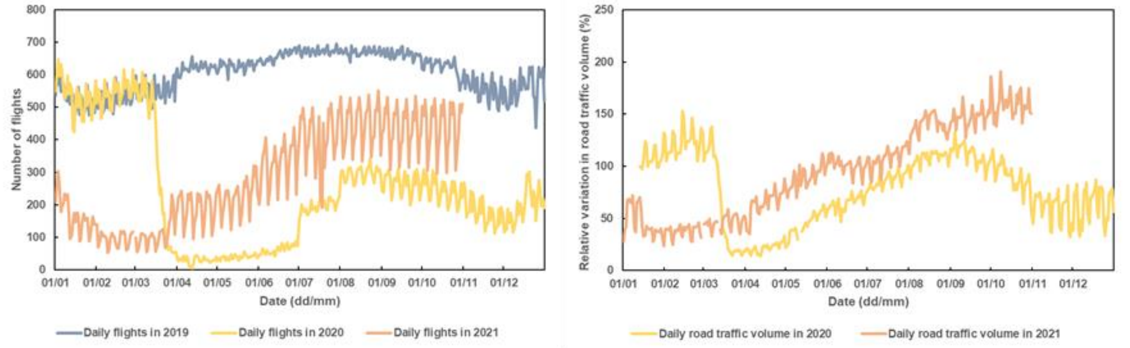

Figure 3 - Number of daily flights arriving at and departing from the Lisbon Airport between January 1, 2019 and October 31, 2021, on the left. Relative variation in road traffic volume in the Lisbon Metropolitan Area between January 13, 2020 and October 31, 2021, on the right.

16 to May 31) (Gama et al., 2021). In addition, traffic AQ monitoring stations had the largest relative reduction in PM_{10} concentrations, showing the impact that the decrease in road traffic volume had on the pollutants concentrations (Gama et al., 2021).

Since PM_{10} concentrations are influenced by the emissions from different natural sources and different weather conditions, they are not always proportional to the level of human activity. Moreover, the effect of these factors was felt in this work as higher PM_{10} concentrations were recorded during the second lockdown period, compared to the two deconfinement periods, while anthropogenic emissions were lower during the lockdown, compared to the two deconfinement periods. This was due to the occurrence of air mass transport episodes from Northern Africa, rich in mineral dust, recorded on several days of the second lockdown period.

3.3. BC daily average concentrations

In the sampling period preceding the pandemic, while the BC_{bb} daily average concentration ranged between 0 and 400 ng/m^3, with an average of 263 ± 133 ng/m^3, the daily average concentration of BC_{tr} ranged from 600 to 4369 ng/m^3, with an average of 2631 ± 1091 ng/m^3. In the sampling period following the first lockdown, the daily average BC_{bb} concentration ranged between 0 and 580 ng/m^3, with an average of 261 ± 116 ng/m^3, and the daily average BC_{tr} concentration ranged from 418 to 5531 ng/m^3, with an average of 1696 ± 1174 ng/m^3. In the sampling period during the second lockdown, daily average concentrations of BC_{bb} and BC_{tr} had minimums of 134 ng/m^3 and 336 ng/m^3, maximums of 683 ng/m^3 and 3225 ng/m^3, and averages of 308 ± 142 ng/m^3 and 1288 ± 803 ng/m^3, respectively. In the last sampling period posterior to the second lockdown, the daily average BC_{bb} concentration ranged from 4 to 390 ng/m^3, with an average of 240 ± 97 ng/m^3, and the daily average BC_{tr} concentration ranged from 188 to 2826 ng/m^3, with an average of 1134 ± 597 ng/m^3. Globally, between the pre-pandemic and the pandemic sampling periods, the daily average concentrations of BC_{bb} and BC_{tr} ranged from 263 ± 133 ng/m^3 and 2631 ± 1091 ng/m^3 to 261 ± 117 ng/m^3 and 1422 ± 975 ng/m^3, respectively, which translates to decreases of 1% and 46%. The daily average BC concentrations decreased by approximately 42%.

The statistical tests proved that while BC and BC_{tr} concentrations were significantly different between the pre-pandemic and the pandemic sampling periods ($p < 0.05$), this was not the case for BC_{bb} concentrations ($p > 0.05$). Since BC is a primary pollutant mostly emitted by anthropogenic sources, while PM_{10} can be both primary and secondary, in addition to its natural component significantly influencing its total concentration, the reduction in human activity resulting from the lockdown measures naturally translated into a greater decrease in BC concentrations than in PM_{10} concentrations.

3.4. PM_{10} source apportionment

The EPA PMF model identified six PM_{10} sources. These are associated with: 1) secondary aerosol, identified by the water-soluble ions SO_4^{2-}, NO_3^- and NH_4^+; 2) non-exhaust traffic emissions caused by brake and tire wear, lubricating oil combustion and road dust resuspension, identified by the elements Cu, Zn, Ti, Cr, Mn, Se, Fe, Al and Si; 3) the combustion of fuel oil and biomass, identified by BC and by the elements Ni, P and Br; 4) mineral dust, identified by the elements Al, Si, Ti and Fe; 5) marine aerosol, identified by the water-soluble ions Cl^-, Na^+, Mg^{2+} and K^+; and, finally, 6) exhaust traffic emissions, identified by BC and by the water-soluble ions NO_3^- and K^+ (Almeida, 2004; Calvo et al., 2013).

Figure 4 demonstrates how the implementation of lockdown measures during the pandemic changed the contribution of the different sources of atmospheric particles to the sampled PM_{10} concentration. According to the statistical tests, the contributions from secondary aerosol, non-exhaust traffic emissions, fuel oil and biomass combustion, and exhaust traffic emissions varied significantly between the pre-pandemic and the pandemic sampling periods ($p < 0.05$). Of these four sources, the daily average contribution from secondary aerosol was the only one that increased, in this case from 2902.1 ± 2799.7 ng/m^3 to 6374.7 ± 4925.8 ng/m^3, which is equivalent to an increase of about 119.7%. While the daily average contribution from non-exhaust traffic emissions decreased from 9411.3 ± 4161.9 ng/m^3 to 2636.4 ± 2161.3 ng/m^3 (-72.0%), the daily average contribution from fuel oil and biomass combustion decreased from 3825. 6 ± 1877.5 ng/m^3 to 1427.9 ± 1732.9 ng/m^3 (-62.7%), and the daily average contribution from exhaust traffic emissions decreased from 9632.3 ± 6336.7 ng/m^3 to 4443.4 ± 5067.2 ng/m^3 (-53.9%). On the other hand, the daily average contribution from mineral dust increased from 1837.2 ± 1291.8 ng/m^3 to 1913.9 ± 2068.8 ng/m^3 (4.2%), while the daily average contribution from marine aerosol decreased from 10465.2 ± 8894.5 ng/m^3 to 6771.5 ± 7925.5 ng/m^3 (-35.3%), however, statistical tests revealed that they did not vary significantly between the pre-pandemic and the pandemic sampling periods ($p > 0.05$).

The statistical tests applied to PM_{10} and to all its constituent species revealed that, except for the chemical elements Al and Si and the water-soluble ions Cl^-, SO_4^{2-}, Na^+, NH_4^+ and Mg^{2+}, the mass concentrations of the remaining species recorded in the pandemic period differed significantly from those recorded in the pre-pandemic period ($p < 0.05$). These variations are presented in Figure 5.

According to the results of the statistical tests, the concentrations of Al and Si, characteristic of the earth crust, did not vary significantly with the implementation of lockdown measures, as well as the contribution of mineral dust to the concentration of sampled PM_{10} did not vary significantly, since it is a natural source. Similarly, the concentrations of Cl^-, Na^+ and Mg^{2+}, constituents of marine aerosol, also did not vary significantly, as did the contribution of this natural source to the sampled PM_{10} concentration. With regard to PM_{10} constituents from anthropogenic sources of pollutants, there were significant reductions in their concentrations. The concentrations of the characteristic constituents of traffic exhaust emissions, BC, NO_3^- and K^+, experienced similar relative reductions. These reductions, coupled with the reduced contribution of this source to PM_{10} concentrations, suggest that the reductions recorded in air and road traffic volumes highlight the influence that the burning of fossil fuels exerted, prior to the pandemic, on the AQ of the study area, and how the implementation of lockdown measures, during the pandemic, reversed this scenario. The effects of reduced road traffic volume were also noted in reductions in concentrations of Cu and Zn, emitted by the mechanical abrasion of tires and brakes. The concentrations of Ni and Br, associated with fuel oil combustion, also suffered significant reductions, as did BC and P, associated with biomass combustion. As for the secondary aerosol, although the concentration of NO_3^- decreased significantly, while the concentrations of SO_4^{2-} and NH_4^+ decreased only slightly, the contribution of this source of PM_{10} increased significantly. This behavior is due to the fact that secondary aerosols are formed by chemical reactions involving precursor gases, emitted both by natural sources, not affected by the lockdown measures, and also by anthropogenic sources, not all of which were equally affected by the lockdowns. The precursor gases are emitted by combustion processes, energy production, agricultural activities, landfills, forest fires, biogenic emissions, and soil emissions, among others (Calvo et al., 2013). Among these sources, combustion processes, whether in transportation or industrial activities, were the most impacted ones by the lockdowns. Since this source emits mainly NO_3^- precursor gases, this justifies the large reduction in the concentrations of this chemical species compared to the reductions observed in the concentrations of the other constituents of the secondary aerosol.

3.5. *PM_{10} dose deposited in the human respiratory tract*

The ExDoM2 dosimetry model was run for the four scenarios described above, using the PM size distribution represented by Figure 6. In the 1st Scenario, PM_{10} concentrations ranged between 28.8-42.0 µg/m^3, with a daily average of 35.7 ± 4.0 µg/m^3, while in the 2nd Scenario, they ranged between 23.1-90.3 µg/m^3, with a daily average of 44.7 ± 26.3 µg/m^3. In the 3rd Scenario,

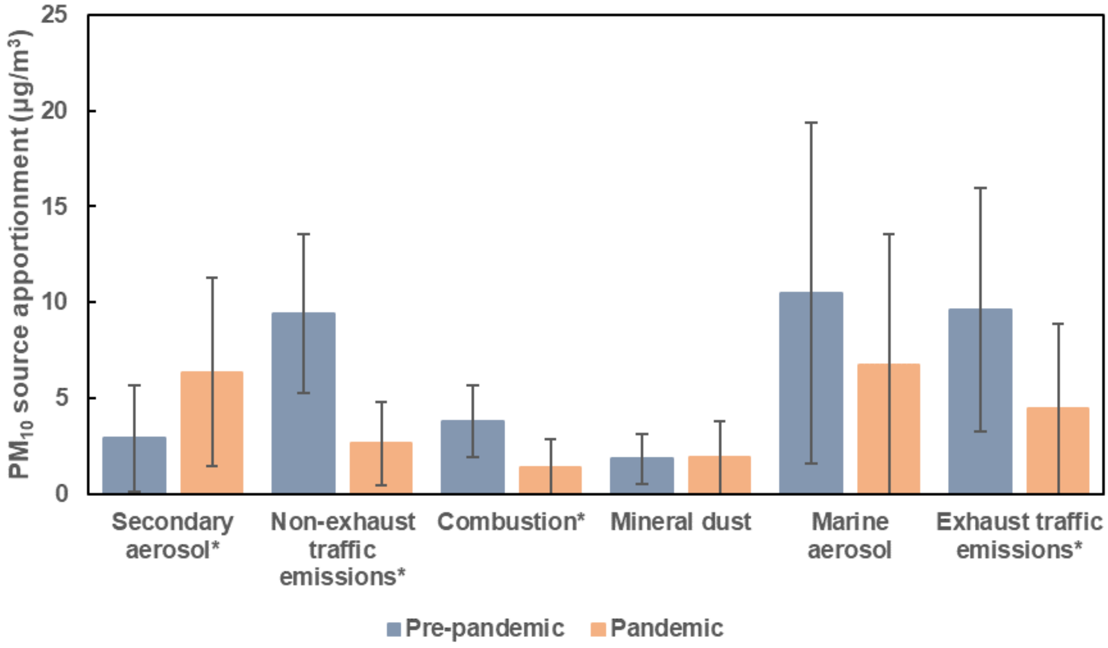

Figure 4 - Contribution of the different sources to the daily average PM_{10} concentration in the pre-pandemic and the pandemic sampling periods. Sources whose contributions varied significantly between both periods are highlighted by an asterisk.

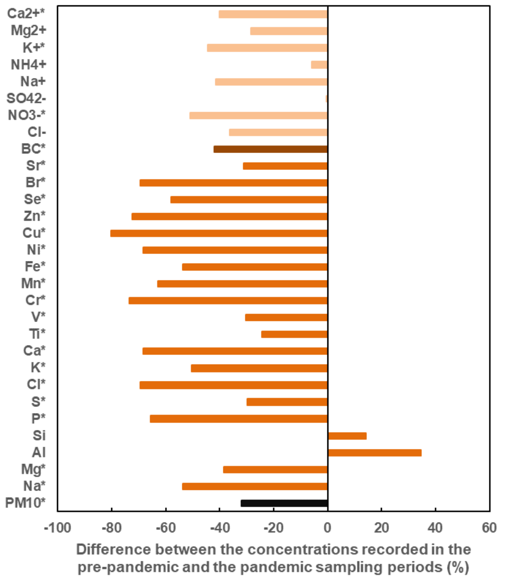

Figure 5 - Variation between the average concentrations of the sampled PM_{10} constituents recorded in the pre-pandemic and the pandemic periods. Constituents whose concentrations varied significantly between both periods are highlighted by an asterisk.

PM_{10} concentrations varied between 17.5-25.5 µg/m^3, with a daily average of 21.7 ± 2.4 µg/m^3, and in the 4th Scenario, they varied between 14.1-54.9 µg/m^3, with a daily average of 27.2 ± 16.0 µg/m^3.

In Scenario 1, the daily average PM_{10} dose deposited in the children's respiratory tract was 238.6 µg, in Scenario 2, it was 292.1 µg, in Scenario 3 it was 145.1 µg, and, in Scenario 4, it was 177.7 µg. From these results, it is possible to extract that the pandemic indirectly resulted in a 39% reduction in the daily average dose of PM_{10} deposited in the children's respiratory tract. Figure 7 reveals the daily average dose deposited in each region of the children's respiratory tract. The extrathoracic region (ET1 + ET2) received the largest portion of PM_{10} (63%), and between ET1 (41%) and ET2 (22%) regions, the ET1 region received the largest dose. This means that most of the particles did not penetrate the thoracic region, but were deposited in the upper airways, from where the particles can be easily and quickly removed by being coughed, spit out, or swallowed (Jang, 2012; Martins et al., 2015). The thoracic region (BB + bb + AI) received 37% of the daily average PM_{10} dose, and the largest portion of this fraction was deposited in the AI region (26%), while the BB and bb regions received only 3% and 8%, respectively. These values express that approximately a quarter of the daily average dose of PM_{10} inhaled by children reaches the alveolar-interstitial region, leading to the greatest risks to children's health.

When the deposited dose of pollutants in the human respiratory tract is calculated by considering integrated exposure as opposed to exposure to ambient concentrations of pollutants alone, the result becomes more faithful to reality, since there is a huge heterogeneity of pollutant concentrations between different microenvironments and the population spends most of its time in indoor microenvironments. In addition, there are also sources of pollutants in the indoor microenvironments that should not be disregarded. In this case (2nd Scenario and 4th Scenario), these considerations resulted in a higher PM_{10} dose inhaled by the children, and consequently a higher potential for them to develop health problems.

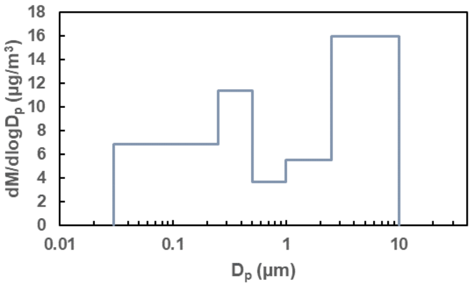

Figure 6 - PM size distribution adopted for the dosimetry model.

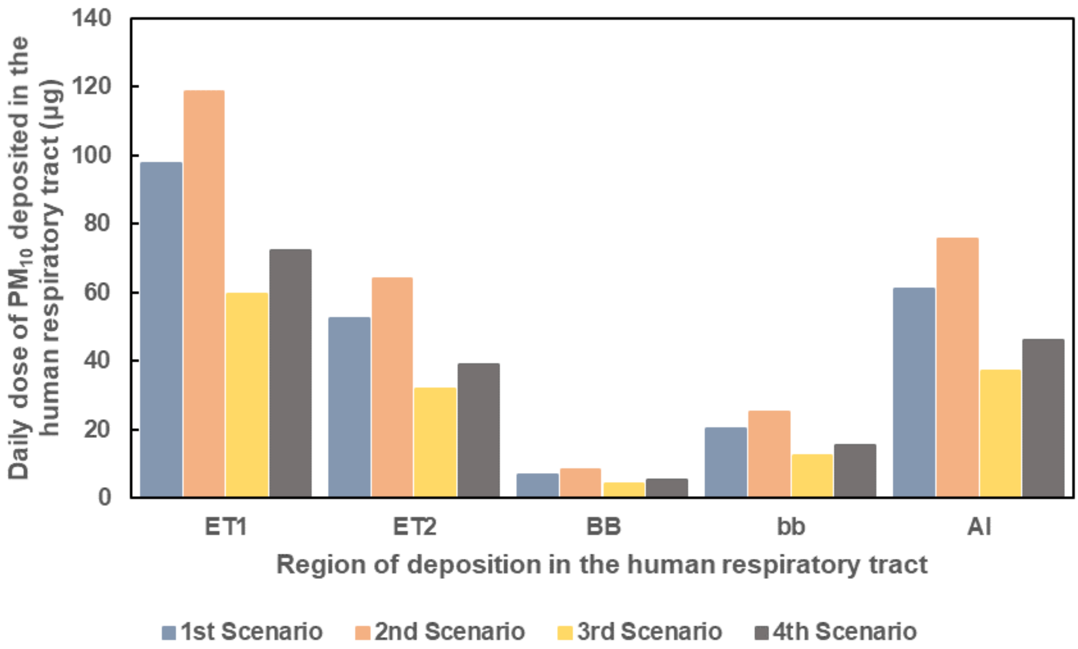

Figure 7 - Daily average PM_{10} dose deposited by region of the children's respiratory tract in the four scenarios.

The daily average deposited PM_{10} dose of the 2^{nd} Scenario is in line with the results obtained by Chalvatzaki et al. (2020), who determined that students from five schools in Lisbon would have, on average, between 182.0-351.8 µg of PM_{10} deposited daily in their respiratory tract (Chalvatzaki et al., 2020). The reduction in human activity caused a decrease in PM_{10} deposition in the respiratory tract of the children in the 4^{th} Scenario, below the levels observed by Chalvatzaki et al. (2020). This demonstrates the strong influence that pollutant emissions from anthropogenic sources have on human health, suggesting that their evolution after the pandemic should be thoroughly planned to avoid a return of air pollutant concentrations to previously recorded levels.

4. Conclusions

The gravimetric analysis of the filters used in the sampling campaigns showed the variation of PM_{10} mass concentration between the different periods covered by this study. Regarding PM_{10} mass concentration and its evolution during the pandemic, it was proved that the reduction of human activity caused a reduction in PM_{10} concentrations. Also, the concentrations of BC decreased more sharply than the concentrations of PM_{10}, since, unlike PM, BC is exclusively emitted by combustion processes that, in urban environments, are almost all anthropogenic.

The EPA PMF model presented the influence of the six identified emission sources on the atmospheric aerosol concentration in the study area and how these varied with the pandemic. The lockdowns caused reductions in the contribution of anthropogenic pollutant sources to the total PM_{10} mass. The reduction in air and road traffic volumes resulted in a decrease in their contributions of 72.0% in the case of non-exhaust emissions and of 53.9% in the case of exhaust emissions. Meanwhile, the contribution from fuel oil and biomass combustion decreased by 62.7%. Conversely, the contribution of secondary aerosol increased by 119.7%, as only some of the sources of its precursor gases were affected by the lockdowns. As for natural sources, these only suffered natural variations, unaffected by the pandemic, with the contribution of mineral dust increasing 4.2% and the contribution of marine aerosol decreasing 35.3%.

The ExDoM2 dosimetry model evaluated the deposition of PM_{10} in the respiratory tract of children. It was found that the pandemic reduced this dose by 39%, reducing the risk of these children contracting cardiorespiratory problems derived from exposure to high concentrations of PM_{10} in the future, however, this risk remains present.

According to the recorded differences in pollutant concentrations and the influence of their sources between the pre-pandemic and the pandemic sampling periods, it became evident how highly the burning of fossil fuels in the transportation sector influences the study area's AQ and, consequently, human and environmental health, and how this was severely impacted by the lockdowns.

The unique period and conditions that framed the realization of this work, give it a high scientific interest regarding the impacts of human action, particularly the transport sector, on AQ and on human health. As such, this work can be used to reflect on how these activities should recover after the pandemic.

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