HEALTH RISK ASSESSMENT AND BLACK CARBON: STATE OF ART AND NEW PROSPECTIVES

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ABSTRACT
The characterization of health risks (HRA) in a population due to air pollution is crucial for the development of effective risk management policies and strategies. HRA is a formally required tool by nations as part of the decision-making process for new programs, regulations and policies that affect air quality, so it is important for decision makers to understand what resources are needed and what limitations may exist. In the hazard identification phase at local and urban level, concentration data provided by local monitors are used, but one of the main shortcomings is that population exposure estimates based on these data are often limited by the sparse geographic-temporal coverage of the measurements. Often the HRA evaluation does not take into account the complex chemical composition of the suspended particulate and therefore the different toxicity and oxidation potential associated with it. Current air quality standards for particulate matter (PM) use the mass concentration of PM (PM_{10}, $PM_{2.5}$) as a metric, but particles from combustion sources are more relevant to human health compared to particles from other sources and the impact of policies to reduce PM from combustion processes, is relatively small when estimating the effects for a reduction in total mass concentration. This research highlights the value of black carbon (BC) particles as a possible additional indicator in the management of air quality in Turin (north Italy), one of the most affected Italian cities by smog where a high number of asthmatics and allergic people are exposed every day to PM concentrations higher than the legal limits. According to the Council on Clean Transportation, Turin is among the top 100 cities in the world with a higher number of deaths due to respiratory diseases caused by transport. BC could be a valuable additional air quality indicator to assess human health risks caused by primary combustion particles.
Keywords: air pollution, black carbon, indicators.

1 INTRODUCTION

Air pollution was the fourth leading risk factor for early death worldwide in 2019, surpassed only by high blood pressure, tobacco use, and poor diet [1]. In 2019, air pollution moved up from the fifth to the fourth leading risk factor for death globally (Global Air 2020, www.who.airpollution.it), continuing to exceed the impacts of other widely recognized risk factors for chronic disease like obesity (high body-mass index), high cholesterol, and malnutrition (Fig. 1). Over the last several decades scientists have continued to build an extensive body of evidence on the risks that breathing poor-quality air poses to human health and our environment, perhaps the most extensive evidence that exists for any environmental risk factor. Exposure to air pollution has serious health consequences [2]. To better understand the burden of disease that air pollution places on society, there is scientific evidence of its effects on health. Short-term exposure to air pollution can damage health; for example, high-pollution days can trigger asthma symptoms, cause a local spike in hospitalizations or even deaths related to respiratory and cardiovascular diseases [3]. There is a broad scientific consensus that long-term exposures to air pollution contribute to an increased risk of illness and death from ischemic heart disease, lung cancer, chronic obstructive pulmonary disease (COPD), lower respiratory tract infections (e.g., pneumonia), stroke, diabetes and, more recently, adverse birth outcomes, and that the public health burden from these exposures is much greater than that from short-term exposures [4]. Ongoing

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studies continue to explore the role of air pollution in the development of asthma, cognitive impairments and other effects (e.g., chronic kidney disorders). Air pollution is estimated to have contributed to 6.67 million deaths (95% IU: 5.90 to 7.49 million) worldwide in 2019, nearly 12% of the global total [5]. Air pollution is the main environmental risk factor for premature death, with its total impact exceeded only by hypertension (10.8 million, 95% IU: 9.51 to 12.1 million), tobacco use (8.71 million, 95% IU: 8.1 to 9.3 million) and food risks (7.94 million, 95% IU: 6.5 to 9.8 million). Every year, far more people around the world die from exposure to air pollution than from road traffic accidents, an estimated 1.28 million in 2019 [1]. This large disease burden reflects the substantial contribution that long-term exposures to air pollution make to chronic noncommunicable diseases, approximately 80% of the air pollution burden is attributed to noncommunicable diseases. $PM_{2.5}$ and ozone together contribute up to 40% of deaths from COPD, a debilitating lung disease [6]. As shown in Fig. 2, air pollution also contributes to 30% of lower respiratory tract infections and 20% of infant mortality in the first month of life [7]. The air pollution burden of each of these diseases is borne differently in different countries around the world. These variations reflect various social, economic and demographic factors (in addition to exposures) that affect the underlying health and vulnerability of populations to air pollution in specific regions. To reduce the disease burden attributable to each of these diseases and to each air pollutant, each country will need to explore and understand its own data. Some of this data is available to the international scientific community (e.g., exposures and mortality rates/days) on the State

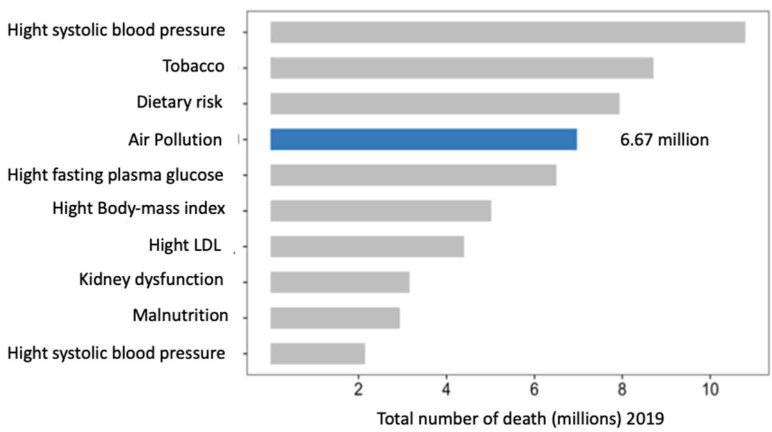

Figure 1: Global ranking of risk factors by total number of deaths from all causes in 2019 [8].

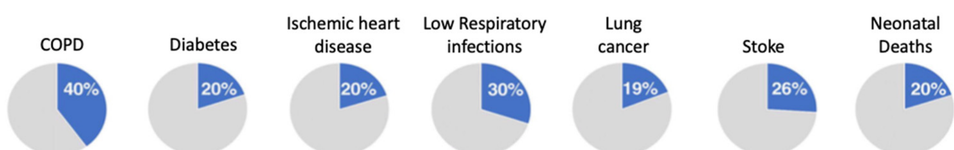

Figure 2: Percentage of global deaths from specific causes attributable to total air pollution [8].

of Global Air website, while other data can be found on the Global Burden of Disease website.

In 2006, the WHO published a report on the average levels of PM_{10} in Italian cities recorded from 2002 to 2004 [9]. The population covered in this report consists of residents of Italian cities with over 200,000 inhabitants for which the environmental data needed for the analysis were available, these cities are Turin, Genoa, Milan, Trieste, Padua, Venice-Mestre, Verona, Bologna, Florence, Rome, Naples, Catania and Palermo. The impact on health of air pollution was very large with 8,220 deaths per year, on average, attributable to concentrations of PM_{10} above 20 mg/m^3. This corresponds to 9% of all-cause mortality (excluding accidents) in the Italian population over 30 years of age. The impact on short-term mortality was calculated with 1,372 deaths, or 1.5% of total mortality in the entire population. Hospital admissions attributable to PM_{10} were of a similar magnitude. The presence of ozone at concentrations above 70 mg/m^3 represents 0.6% of all causes of mortality. The WHO study used an updated and extended dataset and considered 25 adverse health outcomes and various exposure scenarios. Compliance with European Union legislation can lead to substantial savings in terms of diseases avoided, therefore local authorities, through policies that mainly aim at reducing emissions from urban transport and energy production, can contribute to obtaining significant benefits in terms of health. In Italy, the VIIAS Project (Integrated Assessment of the Impact of Air Pollution on the Environment and Health) carried out in the framework of the initiatives of the Disease Control Center (CCM) of the Ministry of Health (www.viias.it), coordinated by the Department of Epidemiology of the SSR of Lazio, carried out the assessment of the health impact of atmospheric pollution by publishing interesting results: in 2005, an estimated 34,552 deaths from natural causes attributable to long-term exposure to $PM_{2.5}$ and 23,387 deaths from exposure to NO_2; in addition 1,707 deaths from diseases affecting the respiratory system are attributable to exposure to ozone. The report underlines the inequalities of health effects on the Italian territory: pollution affects the north and in general urban areas congested by traffic and proximity to industrial areas. Even domestic heating, especially due to the increase in the use of biomass (mainly wood and pellets) is responsible for the worsening of air quality and the consequent impact on health. It was possible to appreciate the health effects of pollution over time. In 2010 there was an important decrease in the effects of $PM_{2.5}$ (21,524 deaths) and NO_2 (11,993 deaths), due to the reduction of emissions and the reduction in consumption attributable to the economic recession. The results of the project indicate that the consumption of biomass for heating as an element of trade-off between climate policies and air quality, produce a health impact worse than that which has already occurred with the decrease in emissions due to the economic recession. It is currently not possible to have a systematic measurement of the effects of the city motor vehicle traffic reduction policies in terms of black carbon (BC) reduction as this pollutant is not measured in real time and in a timely manner by the entire monitoring network of Arpa Piemonte in Turin city. The importance of implementing specific multi-sectorial projects on urban scale would be of considerable scientific interest. Integrating the data of the Arpa control units with real-time data collected by low-cost instrumentation and with clinical information relating to lung function (Fig. 3) represents an interesting scientific approach to be implemented at local scale with specific urban projects dedicated to HRA.

2 TRADITIONAL PM INDICATORS FOR HEALTH RISK ASSESSMENT

Atmospheric particulate matter (PM) is the most widely used indicator for estimating the health impact of atmospheric pollution on the human population and is among the pollutants

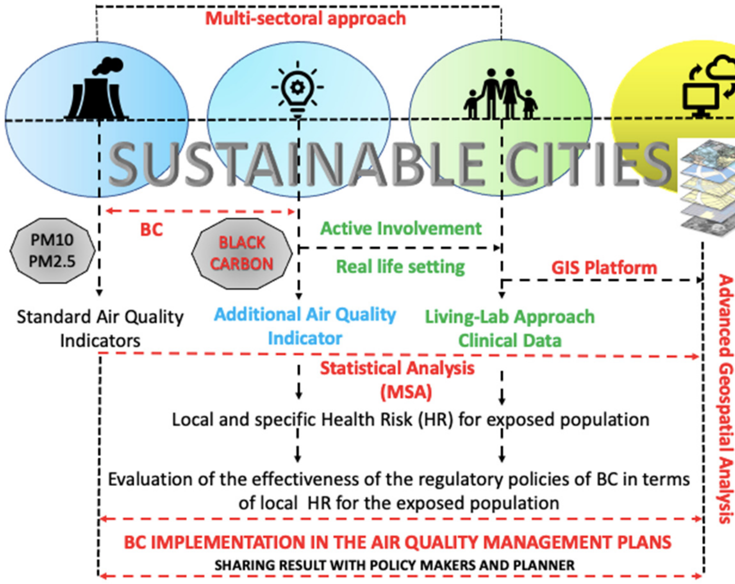

Figure 3: Multidisciplinary approach and inclusion of BC as proxy traffic indicator on an urban scale.

most frequently associated with various health outcomes [10]. According to some authors most risk assessment studies are still based on a two-decade-old system and neglect recent research on inhalation rate and PM size [10]. To overcome this problem, the level of risk must be explored by applying PM monitoring with high spatial and temporal resolution because it is of crucial importance to investigate methods of monitoring particulate inhalation in real time [10]. The commonly identified targets for exposure to atmospheric particulate matter are people who travel on foot, by bike, those who reside in highly trafficked areas or near specific sources. Children, the elderly and individuals already suffering from cardiovascular and respiratory diseases are usually classified as more vulnerable, in fact they present worsening and exacerbations of health conditions due to breathing and inhalation of particulate matter [11]. In particular, babies and children are more prone to respiratory problems such as cough, phlegm and bronchial asthma attacks [12]. Furthermore, children are the most vulnerable subjects to exposure to environmental dust because they are more likely to ingest large quantities of dust due to the habit of putting their hands in their mouths [13]. The PM, in addition to being inhaled directly by the person, can be deposited on the body and hands and it is therefore introduced directly into the body even following this path [14]. Furthermore, with regard to inhalation, it must be said that the respiratory rate in children (3–12 years) is double that of an adult, so this physiological parameter should be integrated in exposure studies [15]. Furthermore, people who tend to do more sports and be outdoors will also have higher rates of exposure to air pollution and the increases in active transport (bike/foot) leads to increased inhaled dose of air pollution [16]. Studies have shown a relationship between chronic exposure to particulate matter and increased risk of premature birth and low birth weight of newborns [8]. Older people, on the other hand, may already have undiagnosed heart/lung disease. The composition of PM is very complex because it may contain various toxic substances that have serious and different effects on human health.

Studies on the composition of atmospheric particulate matter are still lacking which should be encouraged especially in urban areas most affected by air pollution. In the specific case of Turin (north Italy), the fraction of carbonaceous pollutants of primary nature (IRIDE project, 2012, www.istituto-iride.com) constitutes (on average) a fraction of atmospheric particulate $PM_{2.5}$ between 9% and 16% (with a primary coefficient (OC/EC) of 0.67 and 1.8 respectively). Also including the inorganic primary components, the total primary fraction emitted directly as it is into the atmosphere and for which it is possible to act locally for remediation purposes, can be estimated on average between 33% and 40% of $PM_{2.5}$. This percentage refers to all the contributions of the different sources present in the specific study area of Turin (IRIDE Project). It is understandable the need for pervasive and cross-linked monitoring over the entire urban area for an assessment of the individual contributions of the most significant types of sources (traffic, heating and point emissions). The current health risk assessment from air pollution does not have the efficiency necessary to reduce the level of risk of exposure to particulate matter in European cities, precisely because the pervasive high resolution space–time monitoring is still missing and is more and more important to incentive pervasive and multidisciplinary projects. From the international studies [1] it can be seen that the research area relating to ambient air is more developed than those of other areas (occupational exposures) due to the sampling and the size of the PM studied. (health risk assessment of air pollution/general principles, www.euro.who.int).

3 BLACK CARBON AT LOCAL SCALE AS PROXY TRAFFIC INDICATOR

Current air quality standards for particulate matter (PM) use the mass concentration of PM (PM with aerodynamic diameters ≤ 10 μm (PM_{10}) or ≤ 2.5 μm ($PM_{2.5}$)) as the metric. It has been suggested that particles from combustion sources are more relevant to human health than particles from other sources, but the impact of policies to reduce PM from combustion processes is usually relatively small when estimating the effects. for a reduction in the total mass concentration [17]. Different particle sizes, composition, or characteristics can be related to specific emission sources better than other air pollutants and therefore may be considered a (more) suitable indicator. Thus, PM_{10} may be an appropriate indicator when considering the impact of resuspension of road dust, while black carbon (BC) is a more sensitive indicator for exhaust emissions from road traffic [17]. It is significant highlights the value of black carbon particles (BC) as an additional indicator in the management of air quality in a city heavily affected by smog such as Turin (northern Italy), in fact BC could be a valuable additional indicator of air quality to assess specific health risks of air quality dominated by primary combustion particles. Evidence on the health effects of black smoke (or British BS smoke) was identified decades ago and this pollution was used to recommend early guidelines for exposure limits in relation to public health protection. In the 1990s, BS was one of the most used air quality indicators in European time series studies linking mortality to pollution. The difficulty of standardizing measurements and appreciation of the health effects of non-black components of particulate matter (PM) have drawn researchers' attention to the mass concentration of inhalable or respirable suspended PM fractions such as PM_{10} and $PM_{2.5}$ (WHO Regional Office for Europe, 2000, www.whqlibdoc.who.it), therefore the BS (not regulated by air quality legislation) and the intensity of its monitoring have decreased over the years. Black carbon (BC) is a chemical component of fine particulate matter (PM ≤ 2.5 μm), is made up of pure carbon in several related forms and is formed through the incomplete combustion of fossil fuels, biofuels and biomass. In urban areas, road traffic is one of the main sources of PM [8] and it is likely that not all components of PM are equally important in causing health effects [1], in fact the attention of scientific community on the qualitative and not only quantitative aspect of PM, is always higher. Combustion particles also arise from sources from wood and coal combustion, shipping and industrial sources, and these sources can significantly contribute to the concentrations of combustion particles in the urban environment [1]. In a systematic review of the literature, Krzyzanowski et al. [17] concluded that transport-related air pollution contributes to an increased risk of death, particularly from cardiopulmonary causes, respiratory symptoms, and non-allergy-related diseases. In a more recent review of traffic-related air pollution, HEI [8] concluded that there was sufficient evidence to support a causal relationship between exposure to traffic-related air pollution and exacerbation of asthma and suggestive evidence a causal relationship with onset of childhood asthma, non-asthmatic respiratory symptoms, impaired lung function, total and cardiovascular mortality, and cardiovascular morbidity. Many authors agree that BC is a major component [9] in both anthropogenic and natural soot and causes human morbidity and premature mortality [18]. At the state of the art all the aspects concerning the BC are not yet well defined (definition, measurement methodologies and estimation of the effects) (Roberta Vecchi, www.air.unimi.it). There is growing concern in the scientific community that current mass-based PM standards are not suitable for characterizing the real health risks caused by air pollution (such as near areas with high motorized traffic on major roads or in communities dominated by wood smoke). Furthermore, emission reduction measures such as the use of particle traps or the introduction of environmental zones are believed to be effective in reducing exposure to traffic-related air pollution, but the estimated impact of such measures is relatively small when expressed in relation to a reduction in the mass concentration of PM [16]–[18]. Nitrogen dioxide (NO_2) is a regulated component of air pollution that is also used as an indicator of traffic-related air pollution in health impact assessment and air quality management. NO_2 is not a suitable indicator for assessing the effect of traffic abatement measures on exposure to combustion particles because some abatement measures, such as filters on diesel-powered vehicles, can increase NO_2 levels [7]. Furthermore, spatial gradients near roads are less pronounced for NO_2 than for black smoke (BS) and particle number due to the high background concentrations of NO_2 [17]. This is less of a concern for nitric oxide (NO) and nitrogen oxides (NO_x), which is the sum of NO and NO_2, but these components are currently unregulated and do not appear to be toxicologically important at current levels. Obviously not all the health effects associated with the mass of PM can be attributed to a marker of combustion particles for this reason it is possible to consider as a good indicator the measurements of the black carbon particles carried out at urban scale and with high spatio-temporal resolution (ion black carbon (BC), the absorption coefficient (Abs), elementary carbon (EC) and organic carbon (OC), particle number concentration, the surface area of the particles (which is of great interest on alveolar-capillary diffusion)) and specific PM components. The extent of the data available to support the health relevance of these measures varies widely. Probably the cost and complexity of monitoring to estimate personal exposure to ultrafine particles, which is characterized by particle number concentrations rather than particle mass, limits the feasibility of particle number as an additional metric. In 2003, a WHO working group recommended re-evaluating BS as an indicator of traffic-related air pollution, *but there is still no systematic comparison using PM and BC indicators to estimate health effects.* Grahame et al. examined the evidence for the effects of BC on cardiovascular health endpoints and concluded that it may be desirable to enact a BC-$PM_{2.5}$ standard [19]. Smith et al. [20] noted that although the results of their time series meta-analysis suggest greater effects per unit mass of sulfate than BC personal exposure, this distinction was less clear in the few studies that directly compared the estimated effects of both indicators. This observation points to the need to critically compare studies that measured PM mass as well as BC. BC could be a useful indicator in addition to particle mass if the health risks associated with BC are quantitatively or qualitatively different from those associated with PM mass on a unit mass basis. Many epidemiological studies base estimates of health effects on BC measurements from all sources of combustion, not exclusively from traffic, instead it would be interesting to focus on specific sources. In this basic case study, it was observed the BC concentrations from July 2018 to August 2021 in a residential area to investigate the trends of BC concentrations in relation to PM_{10} and $PM_{2.5}$ monitored in the urban station of Lingotto (Torino city).

4 CONCLUSION

Black carbon represents an important indicator in residential sites exposed to vehicular traffic but is not sufficiently monitored. In Torino city, three years of data were collected in an urban station (Fig. 4) located in Lingotto area. From the basic statistical analysis the trend of BC was observed as a more sensitive indicator to the increase in vehicular traffic, compared to PM_{10} and $PM_{2.5}$.

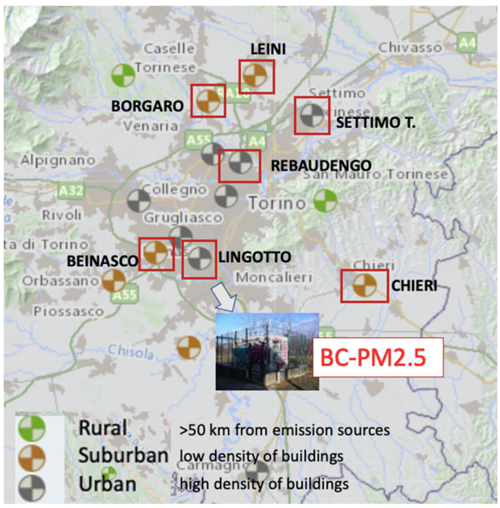

Figure 4: Location of monitoring stations for the measurement of PM and BC, managed by Arpa Piemonte (Torino, Italy).

The concentrations of PM_{10}, $PM_{2.5}$ and BC were detected by an aethalometer installed in a fixed control unit managed by the Piedmont ARPA and located in a densely populated area. Concentration trends, maximum, minimum and average, were observed for the duration of three years at a site representative of the average residential/pedestrian exposure for the city of Turin. BC measurements started in July 2018, therefore there are not complete databases on BC concentrations in Turin. The only station present in the city is Lingotto control unit and it provides hourly data that can be directly correlated to vehicle traffic data. Fig. 5 shows the average concentrations of $PM_{2.5}$ and PM_{10} detected from 2018 to 2020. The graphs show the highest concentration of polluting particulate matter during the winter period, corresponding to the focus of domestic heating. As regards PM_{10}, winter concentrations from December to February 2018 reached maximum values between 80 and 100 $\mu g/m^3$, between December and February 2019 maximum values are between 80 and 90 $\mu g/m^3$. In 2020, on the other hand, during the lockdown caused by the COVID-19 epidemic, maximum concentrations result between 60 and 100 μg/m^3. The maximum concentration of $PM_{2.5}$ recorded in Lingotto was higher during winter 2020, compared to winter 2019–2018; on the contrary, during the spring–summer season 2020 the maximum concentrations of $PM_{2.5}$ were lower than those recorded in 2018 and 2019. In fact, from April to August 2020 the maximum concentrations of $PM_{2.5}$ remained below 20 μg/m^3; perhaps the explanation is to be attributed to the lockdown and reduced vehicular mobility in the city.

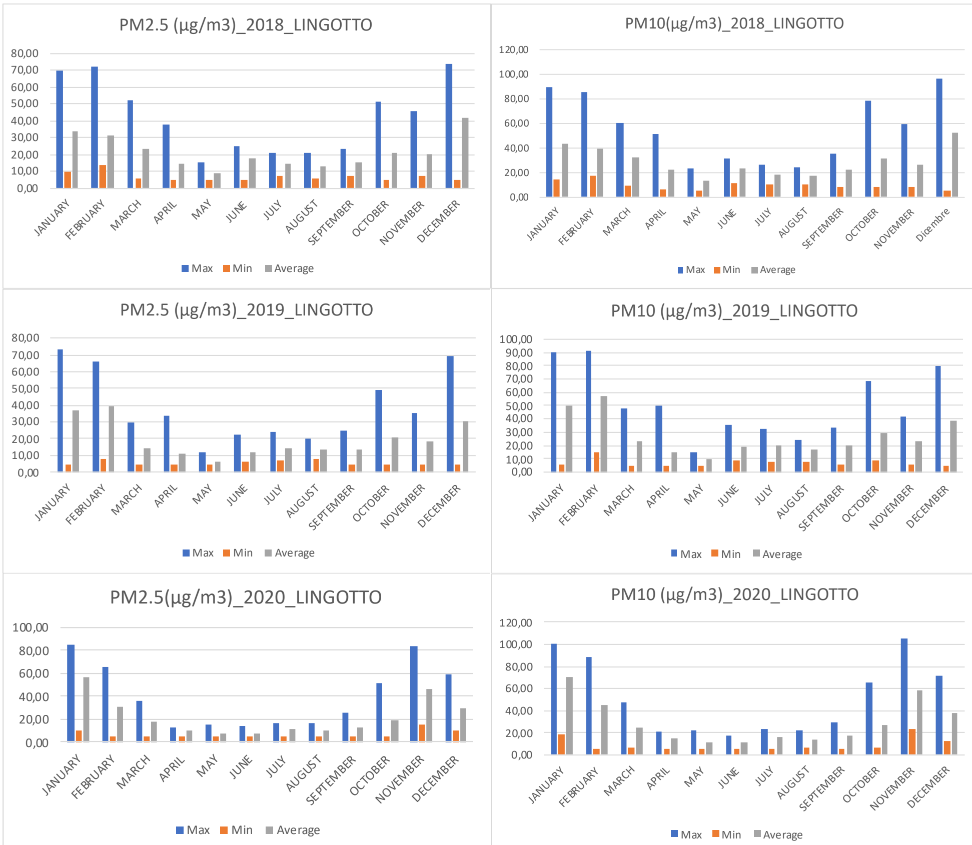

Figure 5: Monthly concentrations of PM_{10}, $PM_{2.5}$, maximum, minimum and average values for the years 2018, 2019, 2020.

Fig. 6 shows the BC concentrations from July 2018 to 2020, the different reference scale can be observed for the different pollutants: BC constitutes a small fraction of $PM_{2.5}$ while representing a significant tracer of toxicity. The highest concentrations of BC result recorded at the winter months. During the 2020 lockdown, higher concentrations of BC were recorded during the winter season, probably due to the increased use of home heating, as citizens spent more time indoors. Fig. 7 shows a comparison with the dispersive meteorological parameters and the concentrations of PM_{10}, $PM_{2.5}$ and BC in 2020. The trend of the concentrations of fine dust is inversely proportional to the parameters of meteorological dispersion, specifically in Fig. 7 it's possible to observe the relationship between dust and rainfall for the year 2020.

The most dangerous component of $PM_{2.5}$, black carbon, follows the trends of the other two particulate matrices and maximum values are observed in November (low rainfall) and January (average monthly rainfall: 100 mm).

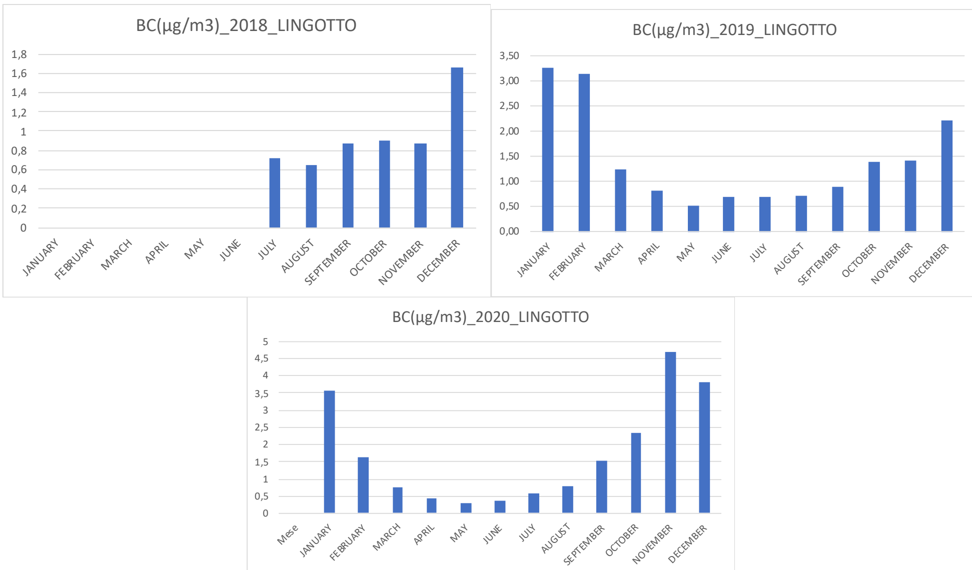

Figure 6: Average concentrations of BC from 2018 to 2020 monitored in Torino Lingotto.

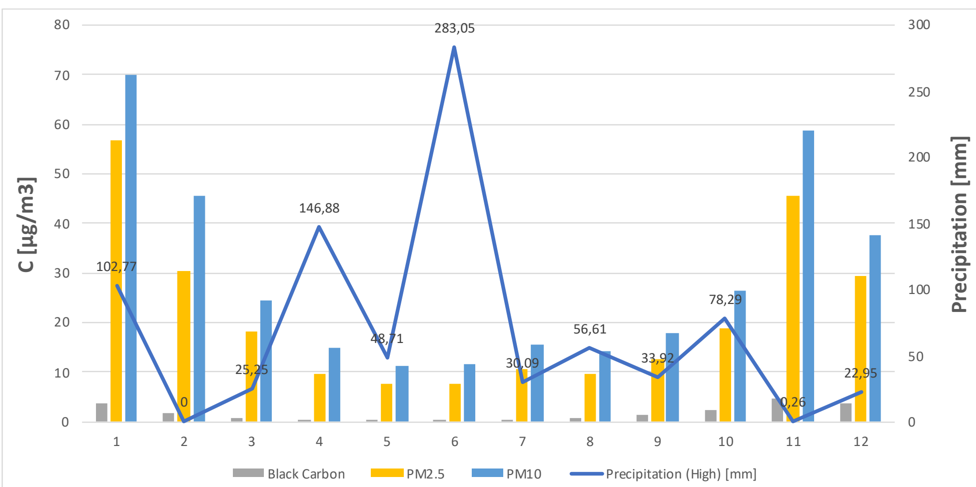

Figure 7: Relations between PM_{10}, $PM_{2.5}$, BC and the rainfall recorded in the year 2020 in Torino Lingotto.

It would be interesting to deepen the study of BC exposure precisely in the winter semester, in relation to the meteorological variables in the Turin area, but since no measurements are available, it is impossible to study the continuous trend of BC in the various points of the city. Hence the need to promote targeted projects on a local scale that can encourage low cost monitoring of the urban fabric starting with local experiments in specific urban sites (highly trafficked and green areas) in order to better understand traffic regulation policies and real exposure to BC possibly not based only on models and projections but on real-time data.

Promoting the use of BC as an additional indicator of the state of air quality would allow to deepen the knowledge on the real exposure of citizens to this marker still not regulated by air quality control policies.

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