

Measurement of black carbon concentration as an indicator of air quality benefits of traffic restriction policies within the ecopass zone in Milan, Italy

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ARTICLE INFO

Article history:

Received 14 January 2011

Received in revised form

27 March 2011

Accepted 4 April 2011

Keywords:

Air pollution

Particulate matter

Aerosols

Traffic pollution

Black carbon

Spatial variability

ABSTRACT

Traffic restrictions are an unpopular tool to mitigate urban air pollution, and a measurable improvement in air quality is needed to demonstrate the effectiveness of this measure. Previous attempts failed to detect measurable reductions of PM mass pollution within the areas subject to traffic restriction. However black carbon, which is emitted primarily by traffic sources, could be a PM metric more suitable than PM mass to demonstrate pollutant reductions. In this study we report the results of a black carbon monitoring campaign carried out in Milan, Italy, with the aim to detect - and demonstrate more suitably than PM mass - differences in local urban air quality among three zones located very closely with different traffic intensity. The study was carried out in three different days by measuring simultaneously black carbon and PM mass concentrations with fixed monitoring stations located in three main radial roads connecting the outskirts to the city center, each with three segments: 1) an outer one, with no traffic restrictions 2) an intermediate one, subject to the congestion traffic charge called "Ecopass", where a ticket is required to enter for cars equipped with engines prior to Euro 4 standard; 3) the pedestrian zone (no cars admitted) of Duomo Square in the city center, where each of the three main roads ends. The results demonstrated a sharply declining gradient in black carbon levels from the outer zone, without traffic restrictions, to the more central areas, for all of the three radial main roads. The differences in mean black carbon levels in the same day in the different traffic scheme locations were highly significant for each comparison. In contrast to the Black carbon results, mean PM₁₀, PM_{2.5}, PM₁ concentrations did not show significant differences among the different traffic zones on the different campaign days. The ratio of black carbon to PM₁₀ decreased by 47% and 62% in the Ecopass zone and in the pedestrian zone, respectively, as compared to the no-restriction zone. To the best of our knowledge this is the first study showing that within-city proximal areas with different traffic intensity are associated with different black carbon levels. These data suggest that black carbon is a highly relevant metric of traffic pollution and should be taken into consideration in demonstrating the effectiveness of air quality mitigation measures.

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1. Introduction

Atmospheric pollution from suspended particulate matter (PM) represents a risk factor for respiratory and cardiovascular diseases and for cancer, mainly due to the presence of combustion products in the composition of the PM (Dockery et al., 1993; Künzli et al.,

2000, 2010; Pope et al., 2002; Biggeri et al., 2004). Traffic emissions are of particular concern in very congested metropolitan cities, since they are associated with overall mortality increase (Hoek et al., 2002), lung cancer risk (Beelen et al., 2008), and worsening of respiratory health in children (Brauer et al., 2002; Van Roosbroeck et al., 2008; Migliore et al., 2009; Rosenlund et al., 2009). In the Milan district of northern Italy, it is estimated that emissions from vehicular traffic amount to about 55% of PM₁₀ (INEMAR, 2010), a regulated pollutant with daily concentrations limit values of 50 µg m⁻³ (as daily average not to be exceeded for

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more than 35 days in one year) according to the EU air quality directive (1999/30/EC, Annex III) and Decreto Ministeriale n. 60, dated 04/02/2002.

Long periods of high PM concentrations inside metropolitan cities are common; for example in Milan in January 2010, 16 consecutive days were recorded with a daily average concentrations greater than $50 \mu\text{g m}^{-3}$, of which 11 days had daily averages of more than $75 \mu\text{g m}^{-3}$ (Invernizzi and Ruprecht, 2010). Traffic restrictions have been introduced by several administrations (London, Stockholm, Singapore, Milan), as a measure to both reduce vehicular congestion and improve air quality within the city centers (Kelly and Kelly, 2009). Where traffic restrictions have been enforced, several benefits are immediately appreciated, such as a decrease in traffic congestion and noise reduction, a decrease in the number of road accidents, and an increase of traffic speed. However a measurable benefit in the air quality marker species measured has not been demonstrated in two cities where such changes have been studied, London and Milan, which adopted very similar measures of traffic restrictions in the city centers, the “Congestion charging scheme” (CCS) and the Ecopass, respectively. The London Municipality has been attempting to find a CCS effect on the air quality since 2003, the year of the introduction of the scheme, inside and outside the restricted zone. The analysis of NO_x annual average concentrations, has not shown substantial benefits on the pollution levels, although a larger low emission zone (LEZ) was implemented in 2008 aimed at reducing pollution, whose effectiveness has not yet been assessed (Tonne et al., 2008, 2009). In January 2008, the Municipality of Milan issued a traffic restriction regulation limited to a small area of the historical city center, requiring an entry ticket for the more polluting vehicles. A notable improvement in the air quality was predicted, with an estimated 30% reduction in PM_{10} concentrations (Milan municipality (a), 2010). The initiative was named Ecopass. The predicted improvements have not been found. A study performed in 2009 (Ruprecht and Invernizzi, 2009) did not demonstrate any difference in PM_{10} (or PM_1 and $\text{PM}_{2.5}$) concentrations between the zones with traffic restriction (Ecopass) and those without them, despite a reduction in the number of vehicles entering the zone with restrictions. Overall traffic emissions were anticipated to show a 19% reduction (Milan Municipality (b), 2010). In a second study performed during January 2010, PM_{10} concentrations within the Ecopass area were shown to be exceptionally high, similar to no-restriction zones, casting doubts on the efficacy of the restrictions to improve either air quality or to enhance public health (Invernizzi and Ruprecht, 2010). The difficulty to demonstrate a measurable benefit in air quality jeopardizes the future of the Ecopass program.

The failure to find measurable air quality improvements resulting from the Ecopass program could be due the limited dimensions of the Ecopass zone, which represents only 4.5% of the total area of the Municipality (8.2 km^2 out of a total of 181 km^2), or because of a relatively homogenous distribution of PM concentrations. Since these may be considered to reflect regional pollution sources, they may be not suitable to discern spatial variations of local emissions within cities.

A potentially more suitable marker used to detect pollution differences between different city areas is airborne *black carbon*. Black carbon measurements were used in the recent years to study pollution due to traffic in areas close to freeways (Roorda-Knappe et al., 1999; Zhu et al., 2002; Cyrus et al., 2003; Zhang et al., 2004). Black carbon is produced by incomplete combustion of carbonaceous fuels. It is a unique primary tracer for combustion emissions, as it has no non-combustion sources, and is stable once released into the atmosphere. It absorbs light in the visible part of the spectrum, which is the basis of its detection. It is composed of chains of agglomerated graphitic spheres with particles having

aerodynamic diameters between 10 and 200 nm. If inhaled it deposits deep in the lungs, and a dose-dependent inverse association between the black carbon content of airway macrophages and lung function in children has been found (Kulkarni et al., 2006). Airborne black carbon exhibits spatial variability, being present at high concentrations in the vicinity of traffic sources, with a lognormal dispersion within 200 m of highways (Zhu et al., 2002). Because of these characteristics, black carbon can be considered an indicator of all primary aerosols from combustion and could be used to detect air quality differences within-city microenvironments with different traffic levels (Clougherty et al., 2008).

The scope of this study was to demonstrate that measurements of black carbon are a more suitable metric than the PM concentrations to identify traffic pollution differences between monitoring sites impacted by different traffic patterns. A pilot personal exposure study was previously conducted by the authors, with black carbon as well as PM_{10} , PM_1 and $\text{PM}_{2.5}$ measurements taken while walking back and forth between the no-restriction, Ecopass, and pedestrian zone: the results showed significant differences in black carbon concentrations, indicating that black carbon may be a promising traffic intensity marker (Invernizzi et al., 2010).

2. Methodology

2.1. Location of monitoring sites

We divided the city area in three sections with different geographical orientation, characterized by three main roads connecting the outskirts with the pedestrian zone of Piazza del Duomo (city center) (see Fig. 1). The monitoring sites were located on the three main roads as follows:

1. Corso Buenos Aires (no-restriction) – Corso Venezia (Ecopass zone) – Piazza del Duomo (pedestrian zone):

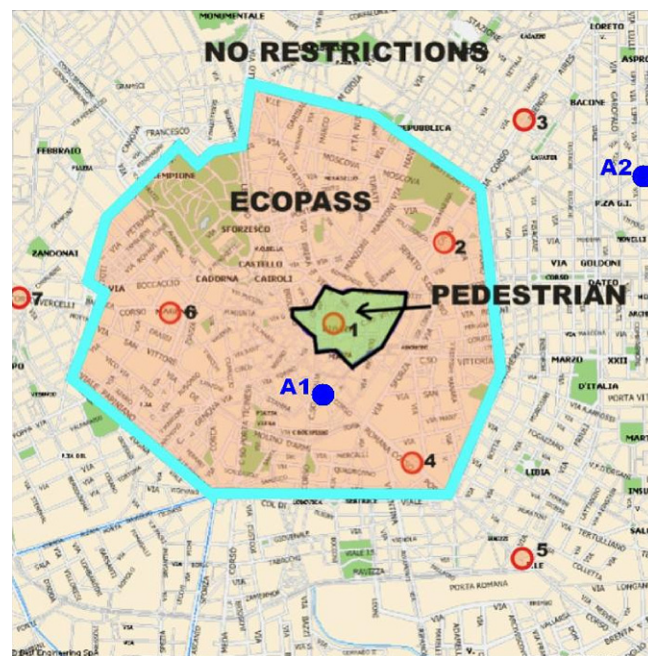


Fig. 1. Map of the three traffic zone in the Milan city center: the inner black line represents the border of the pedestrian zone, the green line indicates the border of the Ecopass zone. Number 1 indicates pedestrian zone monitoring site, numbers #2, #4, and #6 indicate the Ecopass zone sites, numbers #3, #5, #7 indicate the no-restriction zone sites. Positions A1 and A2 indicate the official fixed monitoring sites of the Environmental Protection Agency of Lombardy Region.

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