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Review

Urban air quality: The challenge of traffic non-exhaust emissions

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HIGHLIGHTS

- Only few *in vivo* toxicity and epidemiological studies focused specifically on non-exhaust sources.
- Further experiments are needed to better separate individual contributions and health effects.
- Need of understanding of the interaction between road surface texture, moisture, chemistry, dust load and dust emission.
- Poor emission inventorying on resuspension and heavy metals.
- The optimal mitigation strategy for each climatic region is still unknown.

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ABSTRACT

About 400,000 premature adult deaths attributable to air pollution occur each year in the European Region. Road transport emissions account for a significant share of this burden. While important technological improvements have been made for reducing particulate matter (PM) emissions from motor exhausts, no actions are currently in place to reduce the non-exhaust part of emissions such as those from brake wear, road wear, tyre wear and road dust resuspension. These "non-exhaust" sources contribute easily as much and often more than the tailpipe exhaust to the ambient air PM concentrations in cities, and their relative contribution to ambient PM is destined to increase in the future, posing obvious research and policy challenges.

This review highlights the major and more recent research findings in four complementary fields of research and seeks to identify the current gaps in research and policy with regard to non-exhaust emissions. The objective of this article is to encourage and direct future research towards an improved understanding on the relationship between emissions, concentrations, exposure and health impact and on the effectiveness of potential remediation measures in the urban environment.

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1. Introduction

About 400,000 premature adult deaths attributable to air pollution occur each year in the European Region [1]. Road transport emissions account for a significant share of this burden. While important technological improvements have been made for reducing particulate matter (PM) emissions from motor exhausts, no actions are currently in place to reduce the non-exhaust part of emissions such as those from brake wear, road wear, tyre wear and road dust resuspension. These “non-exhaust” sources contribute easily as much and often more than the tailpipe exhaust to the ambient air PM concentrations in cities, and their relative contribution to ambient PM is destined to increase in the future, posing obvious research and policy challenges.

This report overviews the main outcomes of the international experts workshop “Urban Air Quality: The Challenge of Non-exhaust Traffic Emissions”, held in Barcelona (Spain), in July 2013 jointly organized by BDebate (an initiative of Biocat and ‘la Caixa’ Foundation) and the Institute of Environmental Assessment and Water Research (IDAEA) of the Spanish National Research Council (CSIC) as an immediate follow up of a workshop held in Amsterdam, 2012 [2]. The aim of the present workshop was to highlight the major and more recent research findings in four complementary sessions and to identify the current gaps of research and policy with regard to non-exhaust emissions. The objective of this article is to encourage and direct future research towards an improved understanding on the relationship between emissions, concentrations, exposure and health impact and on the effectiveness of potential remediation measures in the urban environment. A complete overview of the workshop is available at http://www.bdebate.org/en/forum/urban-air-quality-challenge-non-exhaust-road-transport-emissions.

2. Health effects

Traffic-related PM plays an important role in the development of adverse health effects, as documented extensively in acute toxicity and epidemiologic studies [3–8]. Although there are few *in vivo* toxicity and epidemiological studies focused specifically on non-exhaust sources, the data that are starting to emerge indicate that non-exhaust PM can be as hazardous as tailpipe PM depending on the nature of the health effect studied.

Particle mass, size and (surface) chemistry all affect PM toxicity. One of the biological mechanisms causing toxicity is oxidative stress which is often related to transition metals and/or redox active organics such as quinone [9–11]. Brake and tyre wear particles have higher oxidative potential than other traffic-related sources and their effect is very local (50–100 m from the source) [12] yielding more oxidant PM (per $\mu g/m^3$) at road sites rather than at urban background sites. Tyre wear particles have been shown to induce Reactive Oxygen Species (ROS) formation and inflammatory reaction in human alveolar cells [13,14] as well as inflammatory response in mouse lungs [15,16]. Other important factors to be investigated are PM size and size distribution, particle number, composition (including coating and surface modifications), shape, surface area/specific surface area, surface chemistry, and charge and solubility/dispersibility.

Happo et al. [17] found significant inflammatory response in rats lungs exposed to coarse PM in Helsinki and correlated this with Fe and Cu content. A recent assessment of using ascorbic acid depletion (marker for presence of redox active metals), electron spin resonance (marker for $OH^\bullet$ radical) as well as DTT consumption (marker for redox active organics), showed a clear much higher oxidation potential of brake pad particles compared to diesel engine exhaust and tyre or road dust (F. R. Cassee, personal communication). Gustafsson et al. [18] showed at least as high inflammatory potential from road wear PM10 compared to diesel engine exhaust particles. Brake wear particles damage have been linked to oxidative stress and inflammatory responses in the lung using incubations of lung cells with brake wear particles [19].

Epidemiological studies related specifically to non-exhaust sources are still very few, again due to the difficult task of obtaining long time series of specific tracers and the lack of personal exposure data for risk assessment studies. Perez et al. [20] analyzed the respiratory, cardiovascular and cerebrovascular mortality risk associated with different PM size fractions in Barcelona, and found a significantly increased risk ratio (for coarse PM) of 5.9% and 9.8% for cardiovascular and cerebrovascular causes, respectively. Similarly, in Stockholm, Meister et al. [21] found that coarse particles (PM10–2.5) had a significant effect on daily mortality (1.7% per 10 $\mu g/m^3$ increase), while, across the Mediterranean region, Stafoggia et al. [22] reported associations between PM2.5–10 (and PM2.5) levels with cardiovascular and respiratory admissions. Source apportionment studies help identify the source-related health effects: Ostro et al. [23] identified a 4% increase of all-causes mortality risk for an interquartile range increase of road dust contributions only (in PM2.5), which was larger than the risk from vehicle exhaust emissions. Unpublished results from the MED-PARTICLES project, suggest an association between Fe and cardiovascular disease in Rome and Barcelona (J. Sunyer, personal communication), as well as for other non-exhaust tracers (Mn, Ti and Cu), supporting similar findings in the literature [24–26]. Although more research is necessary, especially that implementing source apportionment methods, there is already enough clear evidence to demonstrate the need for stricter PM10 guidelines.

3. Measurements and source contributions

There is no doubt about the serious environmental impact of non-exhaust emissions. Ambient air measurements across Europe have revealed a total non-exhaust contribution (wear emissions + resuspension) to PM10 comparable to that of tailpipe emissions, with a clear exacerbation in Scandinavian and Mediterranean countries due to winter tyres and drier climate, respectively [2,27–29]. Ketzel et al. [30] estimated that in several European countries a large part (about 50–85% depending on the location) of the total traffic PM10 emissions originates from non-exhaust sources. Moreover the lack of abatement measures for non-exhaust emissions has led to their increasing contribution to the PM airshed. In Southern Spain for example, from 2004 to 2011 road