Michelin approach to measure directly the emission factors of a tire

Tire contribution to atmospheric pollution widely overestimated by current methods

Introduction: the issue at stake

Throughout the past 40 years particulate matter from exhaust emission have been the subject of continuous attention by regulatory authorities. In EU, it is admitted that PM emissions from exhaust has shown a constant decrease during the same period. However the combined effect of these increasingly severized limits on exhaust emission and the progressive conversion of the park to electric power trains mainly driven by climate change challenges sheds light on non-exhaust emission as they could become important if not the main contributors to PM emission from transport in the future. Non-exhaust emission consists of airborne particles from tire, road and brake wear as well as road dust resuspension.

Usually airborne Particulate Matter (PM) are addressed through three classes of size i.e

- Total suspended Particles (TSP)
- Particulate Matter with diameters below 10 mm (PM_{10})
- Particulate Matter with diameters below 2.5 mm ($PM_{2.5}$)

Most of the projections of the tire wear contributions to these three classes of PMs rely on estimations based on Emission Factors reported in the EMEP/EEA Emission Inventory Guidebook.

What are these Emission Factors?

Emission factors are average estimates of the amount matter in mass that a vehicle emits to the air per distance travelled. They depend on the vehicle class and the travelling context through a speed correction factor (increasing the particulate matter at low speed, i.e. urban driving, and decreasing it at high speed, i.e. highway driving). Emission Factors are given in mass of particulate matter below a given size, per distance travelled for one vehicle, typically expressed in mg/V*km (including the 4 tires of a passenger car for instance). These values are feeding a traffic simulation software (COPERT) which considers actual traffic data per vehicle class for a given geographical zone. These computation results are giving the assessment of the contribution of transportation sector to atmospheric pollution which enables a comparison vs other sectors such as housing, industry, trading, agriculture, …

Regarding tires the Emission Factors reported have been set up for the first time in the 2002 EMEP/EEA Emission Inventory Guidebook and they have never been updated since this first publication even in the latest release in 2019. They have been established from a literature review covering publications of the 1995 – 2002 period. See the table 1 below (only figures in blue in table 1 have been kept for computing a mean value).

Table 1: Wear rates, PM_{10} emission factors and TSP emission factors from tyre wear for passenger cars found in the literature

Source	Wear rate (mg/vkm)	EF for PM_{10} (mg/vkm)	EF for TSP (mg/vkm)
Kolliousis (2000)	40,0	4,0	6,7
Gebbe (1997)	53,0	5,3	8,8
Garben (1997)	64,0	6,4	10,7
Lee (1997)	64,0	6,4	10,7
Legret (1999a)	68,0	6,8	11,3
Baumann (1997)	80,0	8,0	13,3
Warner (2002)	97,0	9,7	16,2
CARB (1993)	120,0	12,0	20,0
G ttle (1979)	120,0	12,0	20,0
Malmqvist (1983)	120,0	12,0	20,0
BUWAL (1998)	135,0	13,5	22,5
SENCO (1999)	163,0	16,3	27,2
Baekken (1993)	200,0	20,0	33,3
Dannis (1974), Clark (1988)	300,0	30,0	50,0
Cadle (1979)	400,0	2,4	4,0
USEPA (1995)	50,0	5,0	8,3
Rauterberg-Wulff(1999)	61,0	6,1	10,2

Tire wear calculation methodology by UNECE Task Force on Emissions Inventory and Projections https://www.eng.auth.gr/mech0/lat/PM10/tyre%20wear%20calculation%20methodology.pdf

Most of these publications are based on indirect estimation of the TSP or PM_{10} from tire wear rate which was the most available and known measurement at that time. In this regard, it may be worth noting that some stakeholders and not the least have stressed the need to revise these emission factors.

The potential need for an update in both the methodology and the Emission factor is for example mentioned by the Guidebook itself which states that:

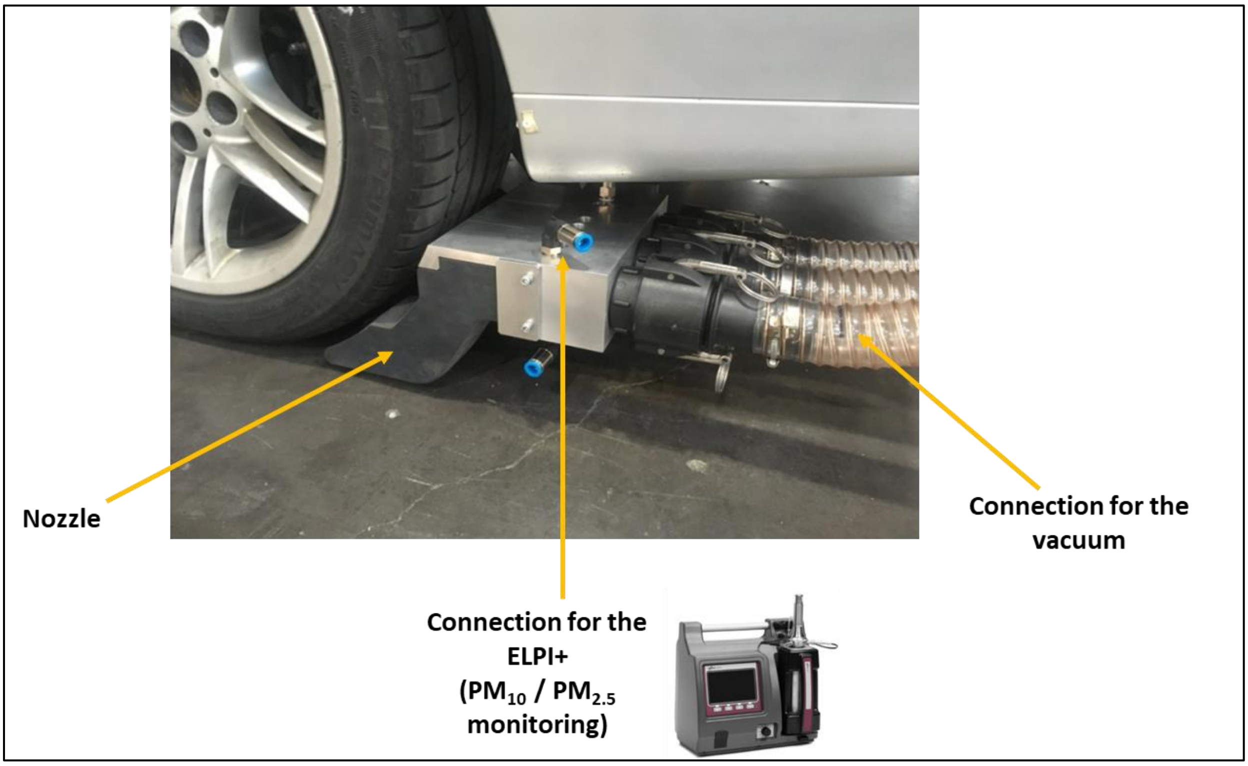
- "The method and emission factors in the Guidebook have not been updated for nearly 15 years and are based on the information available at the time, mostly on wear rates, and a number of assumptions." - *EMEP/EEA Air Pollutant Emissions Inventory Guidebook 2016*

Proposed approach for the direct determination of the emission factors

As no direct determination of the emission factors has been identified in the literature, the following approach has been developed and different tires were tested using this approach to quantify their emission factors.

- ***Description of the collection system***

A rear wheel drive passenger car was equipped with a home-build collection system. The collection system is composed of a nozzle placed behind the rear left tire and close to the contact area between the tire and the road. The nozzle is connected to a vacuum and a known proportion of the total air flow is analyzed continuously using an ELPI+ by Dekati. The ELPI+ is a cascade impactor particle counter which collects particles through 14 size channels between 6 nm and 10 µm.



- ***Driving operating conditions***

Specific driving operating conditions were developed to avoid measurement artefacts for PM_{10} and $PM_{2.5}$ coming from other sources than the tested tire.
The tests were done on Michelin private tracks located in Clermont-Ferrand. The track was systematically cleaned up before each run. This is necessary to minimize the resuspension of particles present on the road surface and to avoid contamination of the tested tire by tread rubbers previously deposited on the track. The track was also privatized for each run to avoid interferences from other vehicles (from tires, brakes, resuspension or exhaust emission). Each run was at least 250 km long in order to be able to accurately determine the mass loss of the rear left tire.

- ***PM_{10} / $PM_{2.5}$ measurement***

The ELPI+ gives information about the number of particles per cm^3 of air sampled behind the tire. The ELPI+ counts particles with an aerodynamic diameter between 6 nm and 10 µm onto 14 size channels. The 14 size channels are added to obtain the number of PM_{10} per cm^3, while only 11 size channels are used to obtain the number of $PM_{2.5}$ per cm^3. These number concentrations are converted into mass concentrations by considering a mean volume for the particles in each channel multiplied by the density of the tire tread. These concentrations are then applied to the total air flow to compute the PM_{10} and $PM_{2.5}$ collected mass. The Emission Factors for PM_{10} and $PM_{2.5}$ are calculated as the ratio between the mass of PM_{10} or $PM_{2.5}$ and the mass loss of the rear left tire.
Three different tires (a winter tire, a summer tire and a sport tire) have been tested following the conditions described above and the Emission Factors for PM_{10} and $PM_{2.5}$ have been calculated.
The Emission Factors are expressed as a percentage of the mass loss of the tire and not in mg/V*km as there was a high variability in usage severity and so in the mass loss rate. The table below summarizes the results:

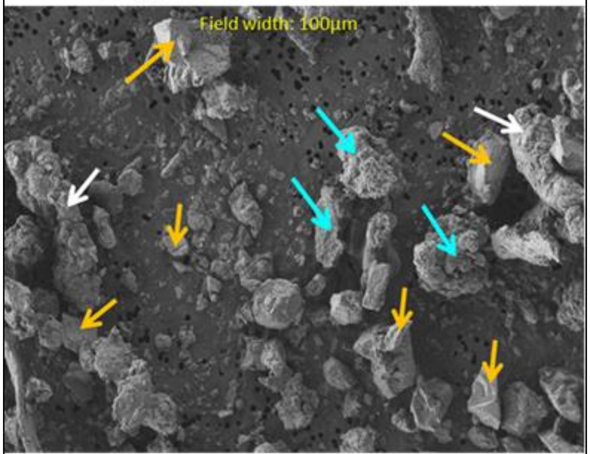
	Tire A	Tire B	Tire C
EF (PM_{10})	4.1 %	1.1 %	1.4 %
EF ($PM_{2.5}$)	0.1 %	0.2 %	0.2 %

Limits of the current methodology

Despite all the precautions (including track cleaning and privatized circuit) taken to avoid interferences, the described methodology does not allow the differentiation between particles emitted directly from the abrasion of the tire and other kind of particles from brakes, exhaust or from resuspension of particles deposited at the surface of the road. This means that all particles are considered as particles coming from the abrasion of the tire, which implies an overestimation of the emission factors.

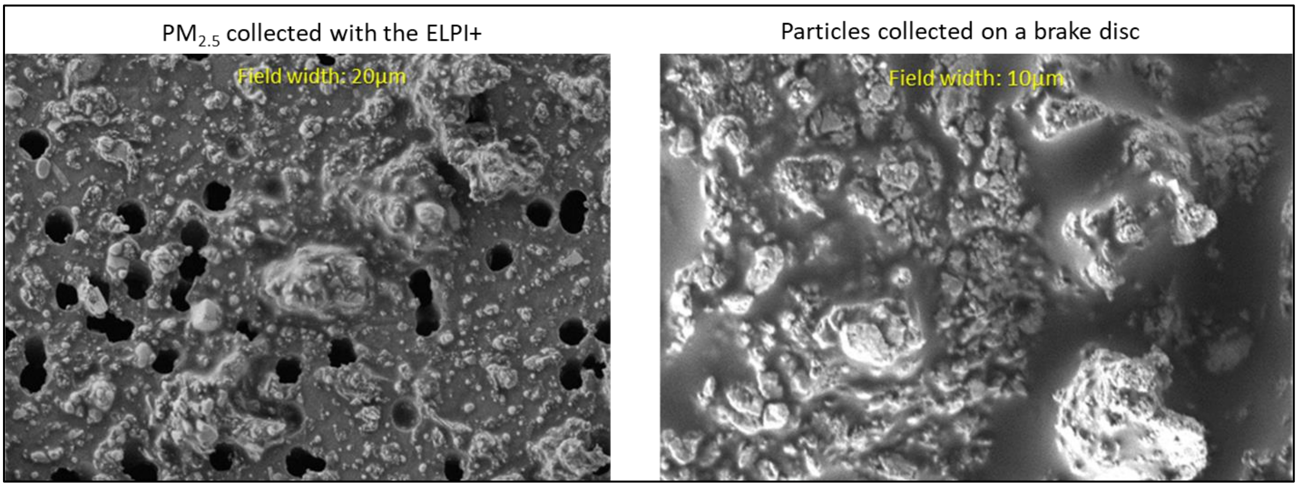
The presence of particles coming from other sources than tires among the PM_{10} / $PM_{2.5}$ collected with the ELPI+ has been confirmed by electron microscopy analyses of the collected particles. For PM_{10}, a significant number of particles seems to be minerals, some particles cannot be identified from their morphology and only few TRWP were identified.

PM$_{10}$ collected with the ELPI+



White arrows: TRWP
Blue arrows: unidentified particles
Orange arrows: minerals

For $PM_{2.5}$, no known morphology has been observed and it was not possible to identify TRWP among the particles collected. Brake particles have been collected directly on the brake disc and observed via microscopy. The morphology of brake particles is different from the one of TRWP and this seems to confirm that most of the $PM_{2.5}$ collected with the ELPI+ come from the brakes.

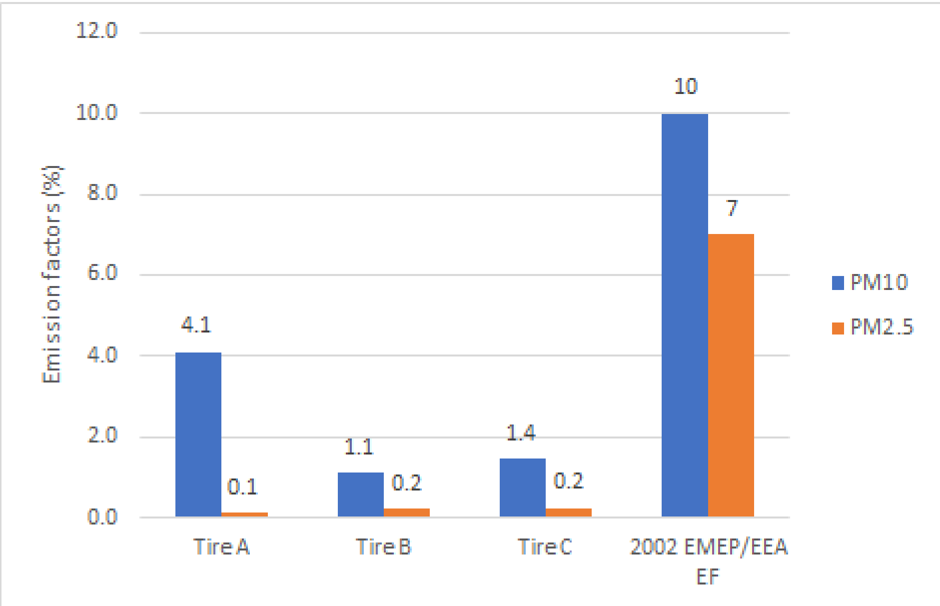


How do these values compare to historical Emission Factors?

From table 1, one can see that Emission Factors for PM_{10} is set at a ratio of 10 % of total tire wear rate. The mean values that have been retained in the Inventory Guidebook for tire Emission Factors were:

- EF PM_{10} = 6.42 mg/V*km ~ 10% of tire wear rate
- EF $PM_{2.5}$ = 4.5 mg/V*km ~ 7 % of tire wear rate

From our direct measurements, we found mean values (average of tires A, B and C) for the ratio between PM_{10} and $PM_{2.5}$ emitted mass vs tire mass loss respectively of 2 % and 0.13 % (see graph below) and as mentioned above, these values are by far upper bonds of the said ratio since we considered all the counted particles as being rubber from the tested tire which is obviously an overestimate. This overestimation is even more important for PM2.5 due to the low contribution of the tire wear particles to the finer size fractions.



Conclusion

The Emission Factors for PM_{10} / $PM_{2.5}$ for tires have been established from a literature review covering publications of the 1995 – 2002 period and based on indirect determination of the TSP or PM_{10} from tire wear rate. This is also stated by the "Non-Exhaust Emissions from Road Traffic" report to DEFRA by the UK AIR QUALITY EXPERT GROUP 2019, which summarizes the State of Art:

"What is clearly apparent is that all the emission factors for these non-exhaust sources come from the same era and have not been updated in the EMEP/EEA Inventory Guidebook in over 15 years, yet they are still used in national inventories by most countries in Europe, including the UK […] These factors were based on analysis of data available at the time the review for the TFEIP was undertaken. […] Changes in tire […] materials, […] could mean that current emission factors are outside the ranges indicated above. There is an urgent need for further direct measurements of emission factors for current vehicles and technologies to test this and update the factors for use in emission inventories."

In this work, an approach for the direct determination of the emission factors has been developed. State-of-the-art instruments available on the market were used to monitor the emission of PM_{10} and $PM_{2.5}$ and the methodology was set-up to minimize the possible interferences (i.e. to reduce the collection of exogenous particles for instance) in order to collect PM_{10} and $PM_{2.5}$ coming as much as possible from the tested tire. Despite all the precautions taken the electron microscopy analyses of the collected samples evidenced a significant amount of non tire wear particles, meaning that the emission factors determined in this work are overestimated.

Nevertheless, upper bonds emission factors were estimated for 3 different tires (summer, winter and sport tires), showing a lower contribution to the emission of PM_{10} and $PM_{2.5}$ than the one currently reported in the 2019 EMEP/EEA Emission Inventory Guidebook (2% and 0.13% of the wear rate respectively vs 10% and 7% of the wear rate reported in the Guidebook).

Although our direct experimental protocol delivers upper bound assessments, we found values far below the value reported in the 2019 version of the EMEP/EEA air pollutant emission inventory Guidebook. This work suggests that a revision of the emission factors is necessary to better estimate the contribution of tires into the emission of PM_{10} and $PM_{2.5}$. To do so, the methodology presented here can be applied to a large panel of tires representative of the current market to obtain more accurate emission factors from direct measurements.