4.15 SENSITIVITY ANALYSIS OF THREE EF METHODOLOGIES FOR PM10 IN USE WITH CLIMATOLOGICAL DISPERSION MODELLING IN URBAN ITALIAN STUDY CASES

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INTRODUCTION

PM10 is among the atmospheric pollutants of main environmental concern in Italy, in particular in the major cities. Both yearly and daily PM10 EU concentration limits are being exceeded for years, due to adverse winter meteorological conditions. Part of these exceedances can be explained by the unfavourable meteo-climatology of a large part of Italy, affected by frequent wind calms and stable situations at ground level, that can prevail especially in winter, during daytime and night time. PM10 is widely emitted from road traffic, house heating and industries, together with other natural and anthropic sources, and it presents also a considerable secondary contribution, in particular in urban contexts. The comprehension of PM10 behaviour and the reproduction of the different source contributions is necessary to define concentration reduction policies to reach air quality standards compliance.

In this work we have focused on the methodologies for PM emission estimation from vehicular traffic. Three widely used methodologies for the related emission factors (EF) have been compared and implemented in a computational chain, also including an air pollution model. This chain, starting from road traffic volumes and characteristics on the main road network of an urban context, will help to assess the different EF methods by calculating the annual PM10 ground level concentration statistics, to be compared eventually with routine measurements.

The studied PM10 EF methods are the followings:

1. the official EU-COPERT;
2. the method used by the IIASA Institute, Laxenburg (Austria), inside the RAINS Europe project;
3. a semi-empirical method proposed by Lohmeyer and co-workers which modifies the US EPA MOBILE5 formula on the basis of observations at some German cities.

The three approaches are discussed in their differences and a sensitivity analysis is performed. Some preliminary results are presented of an application to a test case in an Italian standard urban context.

THE ANALYZED PM10 EF METHODOLOGIES

Methodology 1

The official EU-COPERT methodology (*Ntziachristos L. and Samaras Z., 2000*) is actually dedicated to the estimation of total particulate (TSP) and not only of its coarse fraction (PM10); moreover, it presents EF only due to engine combustion from diesel vehicles, thus only a fraction of the total circulating traffic is intended to contribute to the emissions. The EF formula involved are as follows:

$EF_{TSP} = r(a+bv+cv^2)$ for light vehicles (autos and LDV – Light Duty Vehicles)
$EF_{TSP} = r(a+bv)$ for heavy vehicles (HDV – Heavy Duty Vehicles and busses)

where: EF_{TSP} is the TSP emission factor of a vehicle (g/km); *v* is the mean speed (km/h); *a,b,c* are vehicles type and age depending coefficients; *r* is a reduction coefficients for the most recent vehicles (EURO III and IV) with respect to EURO II vehicles.

Methodology 2
The IIASA method, developed inside the RAINS Europe project (*IIASA, 2001*), takes into account in addition the emissions not only from gasoline engine combustion, but also from the abrasion of mechanical parts, like brakes and tyres, and of road pavement. For each vehicle type, three formula are given for the three major components of TSP (TSP, PM10, PM2.5). The EF formulas are composed by four terms, depending on the vehicle type:

$$EF_{PM10} = E_c + E_t + E_b + E_{rp}$$

where EF_{PM10} (g/km) is the PM10 emission factor of a vehicle and the indices c, t, b and rp identify different sources contributions (c – combustion, t – tyres, b – brakes, rp – road pavement). All involved terms are given in g/km except E_c, which is given in terms of g/GJ, thus involving the fuel consumption, determined here via the COPERT III formulas.

Methodology 3
The method proposed by Lohmeyer and co-workers (*Gámez, A.J., Berkowicz, R., Ketzel, M., Lohmeyer, A. and Reichenbächer, W., 2001*), takes into account also a determinant aspect of the PM10 emission from road traffic: re-suspension of dust deposited on the road surface. It is a semi-empirical method based on direct measurements at German urban sites, the proposed EF formula is a modification of the official EPA one (*EPA, 1993*):

$$EF_{PM10} = \alpha k\, (sL)^{0.52}\, W^{2.14}\, (1-0.5\rho)/0.85$$

where: α is a correction factor varying with the street surface state (0.8 for "good" surface, 2 for "bad" surface); k is the basic EPA emission factor = 0.18g/km; sL is the PM75 fraction of the silt load of the street (g/m^2); W is the vehicle mean weight (t); ρ is the share of rainy days (precipitation > 0.1mm per day) during the year.
The major uncertainty of this formula is in the sL estimation, which shows great variability in the literature (table 1); the method described here considers the latest ones (During et al., 2002).

Table 1. Measured (and recommended) silt Load values (g/m^2) proposed in some studies

	URBAN	RURAL	HIGHWAY
EPA	0.54 - 6.82		0.01 - 1.02
EPA (recommended)	0.4 – 3		0.1 - 0.5
Rauteberg - Wulff (2000)	0.13 - 0.27		
During et al. (2001)	0.17 - 0.59		
During et al. (2001)	0.09 - 0.25		
During et al. (2002)	0.2 - 0.4	0.1	0.1

COMPARISON AMONG THE METHODOLOGIES AND SENSITIVITY ANALYSIS

As previously mentioned, the COPERT methodology considers only exhaust pipe emissions for diesel engines and can be significantly lower than IIASA one, though considering the total particulate fraction. The aim of finding a new approach in calculating particulate matter EFs, is to provide tools for a better prevision of re-suspension from paved roads; for this sake,

Lohmeyer methodology is well promising, even if it has no dependence on vehicle speed or vehicle type (only vehicle weight is considered).
In table 2, calculated values of PM10 EFs are presented for different road and vehicle types, and vehicle speeds. These values have been obtained by weighted averages on a test vehicle fleet very close to the Italian national one (referring year: 2000). The test parameter set is completed by the vehicle weights, that we assumed equal to 1.1t, 1.9t, 9.0t, 0.1t and 0.2t, respectively for autos, LDVs, HDVs, 2Ws < 250cc (motorcycles with engine capacity < 250cc), 2Ws > 250cc, and by the annual rainy day fraction, assumed equal to 0.29.
For the Lohmeyer PM10 EFs (PM10Loh), two values are given, “bad” and “good” surface for all surface, but the highway, in which case the surface state can be considered always “good” for the high maintenance state of pavement and the high traffic volumes and speed, which assure a limited value of surface silt load.

Table 2. Calculated PM10 EFs (g/km)

SITE	SPEED	VEHICLE	PMco	PM10	PM10Loh	
					bad surface	good surface
urban	30 km/h	car	0.0108	0.0791	1.5300	0.4280
urban	30 km/h	LDV	0.1730	0.2870	4.9400	1.3800
urban	30 km/h	HDV	0.5910	0.5140	138.0000	38.5000
urban	30 km/h	2-wheels	0.0000	0.0934	0.0091	0.0025
rural	55 km/h	car	0.0169	0.0764	1.8500	0.5160
rural	55 km/h	LDV	0.1740	0.2310	5.5100	1.5400
rural	55 km/h	HDV	0.4190	0.4090	212.0000	59.1000
rural	55 km/h	2-wheels	0.0000	0.0845	0.0091	0.0025
highway	100 km/h	car	0.0213	0.8640		0.6120
highway	100 km/h	LDV	0.2360	0.2990		1.7100
highway	100 km/h	HDV	0.2410	0.5290		84.5000
highway	100 km/h	2-wheels	0.0000	0.0500		0.0025

With respect to IIASA (PM10) and COPERT (PMco) EFs, PM10Loh can be far higher, in particular considering LDVs (more than one order of magnitude) and HDVs (even more than 3 orders of magnitude). PM10Loh EFs for cars are by higher too, with the exception of highways with “good” surface. Due to their low weight, PM10Loh EFs for 2Ws show lower values than IIASA ones (almost two orders of magnitude).
Figure 1 shows schematically the used vehicle fleet composition for the urban context and the relative contributions to the emissions from different vehicle types on urban road. As only diesel engines are considered emitting TSP, in COPERT methodology the most important category is represented by LDV (about 40% of total emissions), while the most represented vehicle category (cars) contributes only by about 30% as the percentage of diesel engines was about 11% among cars (this percentage is suffering a rapid increase as nowadays in Italy half and more new cars have a diesel engine). The PM10 emissions from IIASA methodology show a distribution rather similar to the fleet because of the lower differences in the weighted averaged EFs. The distribution due to Lohmeyer PM10 EFs resulting from PM10Loh calculation tends to “hide” the 2W contributions and to magnify the HDV one (about 50%), because of the great importance given to the vehicle weight.

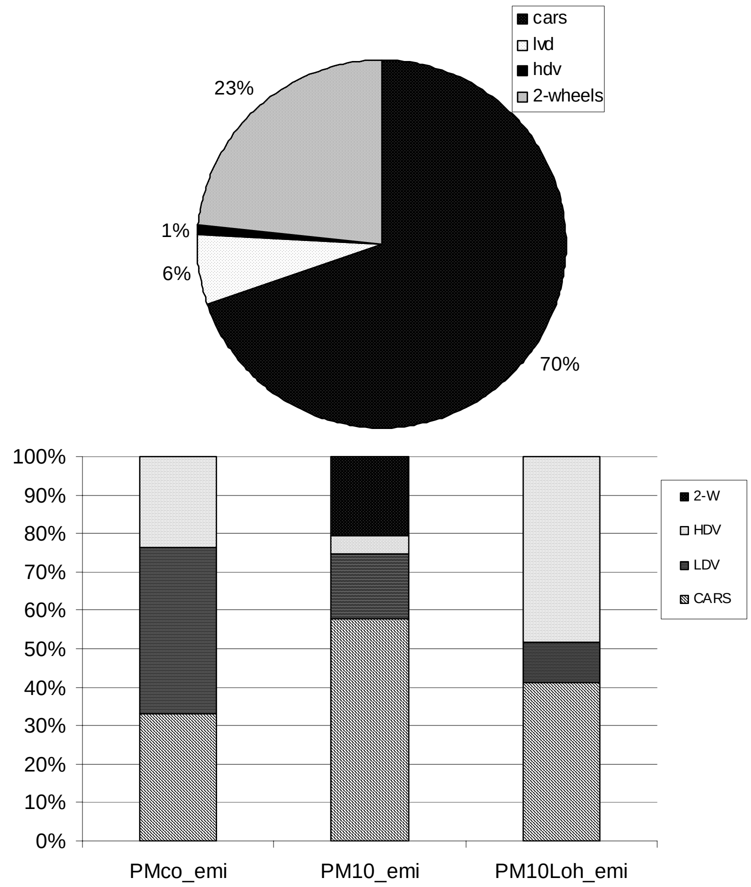

Figure 1. Composition of vehicle fleet and relative PM10 emission in urban context

As far as the Lohmeyer method is concerned, other parameters assume importance: annual rainy day fraction and silt load. Figure 2 shows its EF trend vs. annual rainy day fraction for cars and in urban context. A reduction 15% is observed between 0.1 and 0.4 rainy day fraction.

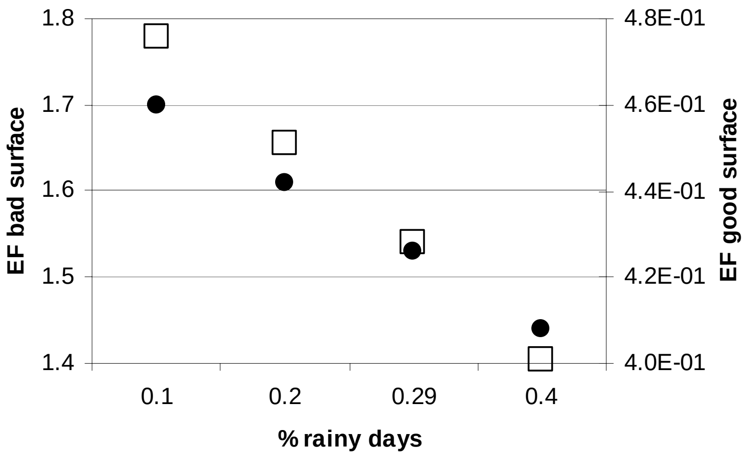

Figure 2. PM10Loh EFs (g/km) vs. annual rainy days fraction - good (□) and bad (●) street surface (cars, urban site).

Figure 2 shows the relationship between Lohmeyer EF values and silt load (sL); sL values plotted are the ones recommended by different studies (*see Table 2*).It can be observed that in "good" surface conditions the trend of the two groups of data (with rainy days fraction = 0.29 and 0.40) is similar, while in "bad" conditions, the EFs tend to grow faster in more rainy conditions.

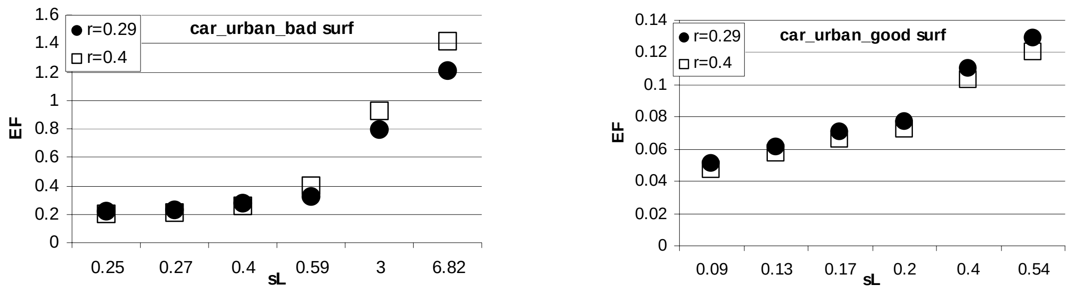

Figure 3. PM10Loh EFs (g/km) vs. silt Load – 0.40 (□) and 0.29 (●) rainy days fraction.

SETTING UP A MODELLING CHAIN TO PERFORM TRAFFIC PM10 DISPERSION SIMULATION

All the three described PM10 EF methods are included in the commercial software TREFIC (Traffic Emission Factor Improved Calculation), developed by ARIANET, developed to estimate road traffic emissions for both inventory and modelling purposes. In order to study the performances of the methods with respect to real urban air quality levels, a modelling system has been set up, to assess air quality impact of a complex road network (with thousands of road segments) starting from spot traffic measurements at specific sections. The model chain includes a simple and very light traffic assignment model CARUSO (CAR Usage System Optimisation), TREFIC (both developed by ARIANET) and ARIA Impact^{TM}, developed by ARIA Technologies and ARIANET, a modelling suite which includes a classic gaussian model for advective conditions and an advective puff model for wind calm conditions.

A test application of the chain has been set up for an urban domain of 100m grid step. Preliminary results of the application of this modelling chain to a rather standard Italian urban network, show that Lohmeyer EFs bring to more realistic PM10 concentration levels as they reach close to the roads an annual mean concentration of 20µg/m^3 and a 98° percentile of daily average concentrations of 40µg/m^3 which are about one half of observations in analogous Italian urban sites. These results, though obtained by means of a first modelling application, are quite interesting considering we simulated only the traffic sources, neglecting other important ones like industries, house heating and agriculture (for suburban sites only), the background emissions from the domain boundaries and also the secondary fraction of PM10, which can be very relevant in urban sites.

CONCLUSIONS AND FINAL REMARKS

The study showed how a new approach to the calculation of PM10 EF, including the re-suspension term, behaves against more traditional approaches. In particular, the methodology proposed by Lohmeyer and co-workers, which is anyway affected by uncertainties in the parameter setting and shows some limitations in the description of the end-of pipe emission term, seems to be promising in the search of a better reproduction of measured PM10 concentration.

The use of this approach is currently being tested in a test dispersion modelling application,involving a traffic model, an emission model and a dispersion model. The preliminary results seems promising, and a more detailed description of this part of the work, with an extensive analysis and comparison between calculated and observed concentrations at a real urban site in Italy will be published later, considering a more complete emission inventory as well as the background and secondary fractions of PM10.

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