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PM Emissions in a Urban Context

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Abstract: Within a urban environment, three different sources of particulate matter should be considered: heating plants using different combustibles (natural gas, gas oil, fuel oil, wood), industrial plants placed in the surrounding area, traffic. While the effects of the first two origins can be easily calculated on the basis of existing emission factors, the PM emissions from traffic are of two types, exhaust and non-exhaust. The latter type of emission is due to vehicle components' wear (tyres, brakes), road abrasion and dust re-suspension and its quantification is not straightforward, as the variability of the corresponding emission factors found in literature demonstrates. In this paper we tried to calculate the total PM emission factors due to traffic by means of the measured PM concentrations for a 50,000 inhabitants town in NW Italy. At the same time we tried to assess the different contributions to the air quality of the town due to the other emission sources, namely heating and industrial plants, in order to understand who is the main responsible of the existing critical situation and to get some general information on the positive effect obtainable through different intervention policy.

Keywords: Traffic, PM, non-exhaust emissions, atmospheric model, street canyon, urban area, OSPM

INTRODUCTION

The air pollution situation of many European urban areas doesn't present indications of substantial improvement, in spite of the adoption of technological interventions for emission limitations and processes for source reduction [1]; actually, these actions, without other activities, like clear understanding of emissive and atmospheric phenomena influencing the result, are not able to lead the air quality back to desired standards.

The air quality situation is even more critical in areas like northern Italy, where the pollution levels (in particular PM_{10} and NO_2) are very high because of the low wind conditions of the Po Valley that don't help the dilution of the pollutants. In order to obtain some improvements for air quality, the regional decision makers are trying to define some intervention policies, such as the limitation of old vehicles, in particular diesel cars before EURO II and gasoline cars before EURO I. The present paper deals with PM emissions from traffic, considering exhaust and non-exhaust particles, from civil heating plants and industrial plants. The investigated area is the town of Cuneo, placed in the South of Piedmont, N-W Italy; the town has 50,000 inhabitants and the surrounding area is characterized by the presence of two cement factories, a glass manufacture and a tyre production plant.

In order to deal with the problem in the right way, many subsequent elements are necessary, as follows:

- it is necessary to individuate the principal emission fluxes, taking into account the sources spatial distribution and their capacity to generate fixed quantities of pollutants;
- the correlation between emitted fluxes and environmental concentrations must be evaluated by means of atmospheric models, and the results must be compared with experimental values;
- with reference to different emission scenarios, the different effect on air quality must be established, and the obtained concentrations must be evaluated and compared to the required standards; this way, it will be possible to establish criteria for real time limitation or structural interventions.

RESULTS AND DISCUSSION

Particles emissions from traffic

Data at disposal: In the analyzed town we have at disposal the meteorological data measured by the regional station placed on the roof of the Chamber of Commerce: wind direction, wind speed, solar radiation and ambient temperature. In the analysed area, the winds have a typical bimodal behaviour around 40-60 degrees clockwise from the N: during the night the wind comes from N-E and in the night it blows towards N-E. The mean wind speed in the area is quite low, around 1.4

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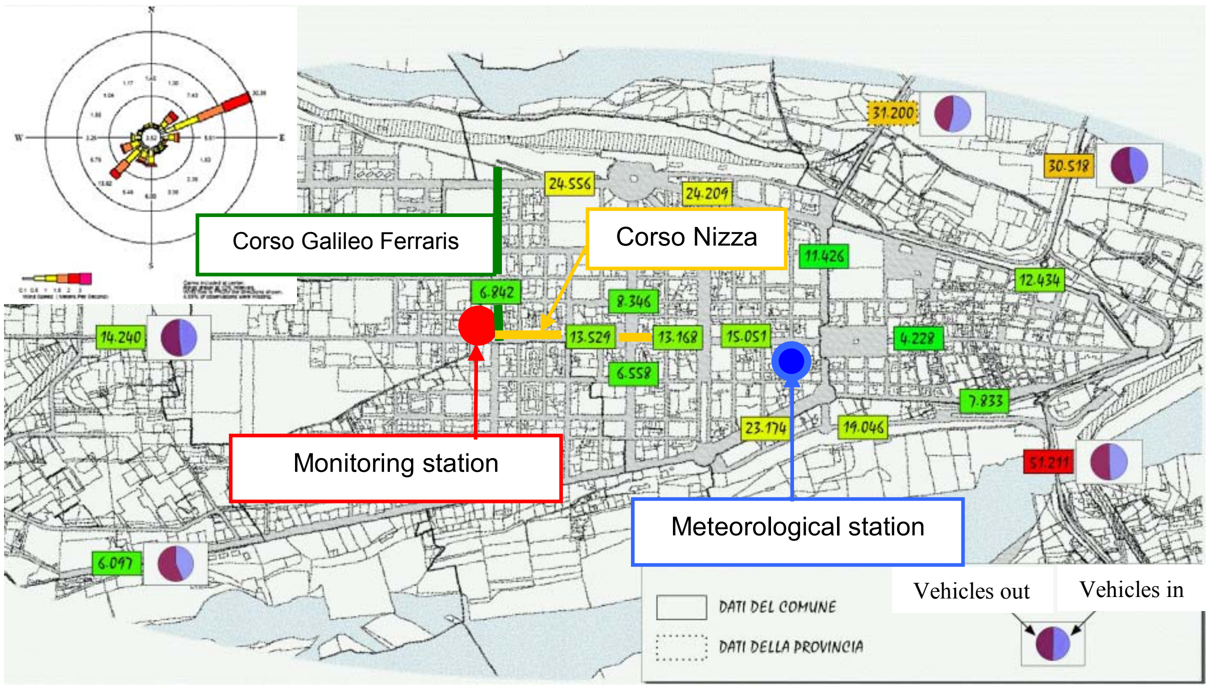


Fig. 1 : The analyzed area and the daily traffic flows in the main streets

m/s, and there is an high percentage of calm hours (< 1 m/s), almost 30%. Moreover, an air quality station is present in the town, measuring, among other parameters, PM_{10}, CO, NO_x, ozone.
As for the traffic data, magnetic counter measurements provide traffic flows for all the main street of the town, as one can see in Fig. 1. As a matter of fact, in the main street of the town, more than 308,000 vehicles circulate every day.
Moreover, in order to determine the composition of the vehicle park, we used the Automobile Club Italia data referring to the registered vehicles of the town in 2004.
Finally, in order to assess the emissions of the measured traffic flows, we used the emission factors provided by the European model Copert3 [2]: according to this methodology, the vehicle park can be divided into 105 categories depending on the typology, the fuel and the legislation class. The emission factors are speed-dependent functions and they can take into account the transient thermal engine operation (cold start) and the increase of the emissions due to the degradation of the catalytic converters with the mileage of the vehicles.

Particles emission factors
PM emissions from traffic can be divided into three main groups [3]:

- non-exhaust emissions deriving from brakes wear (PM_{10}-$PM_{2.5}$);
- non-exhaust emissions from road abrasion, tyre wear and road dust re-suspension that are found partly in the fine fraction ($PM_{2.5}$) and mostly in the coarse fraction (PM_{10}).

First of all in the present paper, given the dimension of PM emitted by traffic, it will be considered as PM_{10}.
Secondly, PM emissions are strongly influenced by external factors as road condition (wetness, salting, sanding, road material) and use of studded tyres.
The emission factor for PM is a critical parameter for our work. Literature data reports several different model to define in particular non-exhaust emissions:

- The US EPA model [4] based on silt load and the weight of the vehicles,
- The "German method" based on the traffic situation [5],
- The Swedish Empirical Model [6],
- The Danish method [7],
- TNO-CEPMEIP database [8].

Table 1 and Table 2 report the results deriving from some of these methods.
Table 1 : PM emission factors from different methods

Method/ Traffic situation	average Speed [km/h]	Share of constant speed driving[%]	exhaust emiss. factor (fleet-mix) [mg/km veh]	non-exhaust emission factor (fleet-mix) [mg/km veh]	non exhaust emission factor* [mg/km veh]	
					cars / vans	trucks
German method:						
motorways or outside cities	60-130				22	200
tunnel	60-100				10	200
city main road (HVS1)**	56	46	19	29	22	200
city main road (HVS2)**	44	52	20	41	30	300
city main road (HVS3)**	34	44	22	54	40	380
city main road (HVS4)**	28	37	26	66	50	450
city traffic lights (LSA2)**	24	32	28	82	60	600
city slow traffic (IO_Kern)**	17	23	32	118	90	800
Danish method for JGTV	45		66	57	50 / 70	230
Swedish method for HORG	40		37	205***		

* Values for good quality of the road surface, flat terrain and conditions of rain as usual in Germany.
** Speed limit = 50 km/h; ***annual average for the year 2000

Table 2 : Non-exhaust PM emission from TNO-CEPMEIP

	non-exhaust PM emissions (mg/km/vehicle)		
	tyres wear	brakes wear	road abrasion
passenger cars	69	6	145
light duty vehicles	90	8	190
heavy duty vehicles	371	32	738
bus	371	32	738
motorcycles	35	3	73

As one can easily understand, the provided database are quite variable and, most of all, they have been obtained in correspondence to precise conditions of weather and road characteristics that are strongly site specific (see for example the reference to "good quality of the road surface, flat terrain and conditions of rain as usual in Germany", but also take care of the use of studded tyres, the need for road sanding and so on); so the emission factor cannot be easily transported to other context such as northern Italy. A more general and reliable approach could be the so called "tracer method", used within the Swedish Empirical Model [6] in order to obtain the total PM emission factor, including both direct emissions and emissions from the dust layer. The method can be written as follows, using for example CO as tracer:

$$e_f^{PM} = e_f^{CO} \cdot \left(\frac{C_{PM}^{roadside} - C_{PM}^{background}}{C_{CO}^{roadside} - C_{CO}^{background}} \right)$$

where e_f^{CO} is the emission factor for CO, often more well known than the PM one. Table 3 reports the resulting total PM emission factor obtained in Sweden in the year 2000 by using NO_x as tracer. As one can easily observe it is very variable during the year because of different road conditions (sanding and studded tyres).

Table 3 : Total PM emission factors obtained in Sweden by the tracer method

	Winter	Summer
PM_{10} (mg vkm^{-1})	1200	200
$PM_{2.5}$ (mg vkm^{-1})	150	30

Background concentrations and stagnation phenomena

The described tracer method is based on the definition of the background concentrations; in Piedmont, in particular in the analyzed area around Cuneo, the 7 air quality monitoring stations are all placed in urban areas (20,000-50,000 inhabitants) and the measured values are almost the same. So we haven't any background monitoring station at disposal for our purposes. Moreover, on the basis of our experience, the background concentration that can be measured in the countryside is not the same as the one that can be measured in a urban environment, for example when the traffic is totally stopped for sanitary reasons (the so called "no traffic Sundays"). This aspect is quite reasonable if one considers that the background concentration is also due to a stagnation effect of the pollutant emitted in the previous hours only partially dispersed by the wind and the atmospheric turbulence (mechanically and thermally induced); this way the background concentration is strongly dependent on the emission mixture and the dispersion capabilities of the area. For instance, the background concentration measurable in a street canyon would be correlated to traffic emissions as the main emission source and it would be probably higher than that measured in an outside area (or also in a urban background station placed on a rooftop, as indicated by Oemstedt [6]) because of the low dispersion possibilities of a urban canyon if compared to a more open area.

Based on the reported arguments, we tried to define the background concentration for CO by calculating the average concentration from 0:00 am to 5:00 am, because in this period of the day the traffic is low and the heating plants are not working. As we will see in the next chapters, the concentrations at the ground level due to industrial plants are very low, so that we assumed those contributions as negligible in this phase. The described way to define the background concentrations can be considered valid for pollutants such as CO or PM_{10}, that are quite stable in atmosphere (the lifetime is respectively in the order of months and weeks); other pollutants, like NO_x, require a different methodology as they are involved in complex photo-chemical reactions in particular during the summer (in this case the night background tends to be consumed as the sun begins to rise, see also [9])

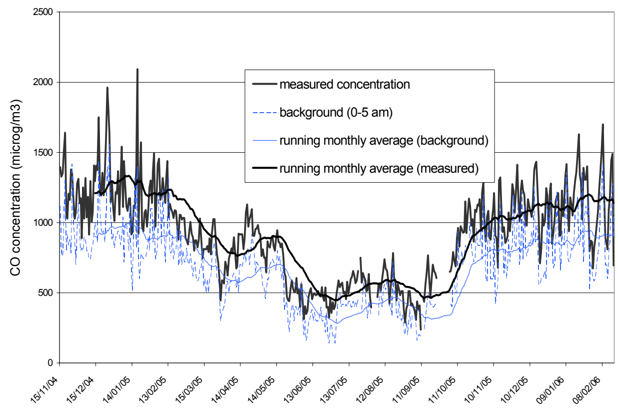


Fig. 2: CO measured and background concentrations in Cuneo

Table 4: CO background concentration as percentage on measured values (monthly average)

month	(background conc/ measured conc)
November 2004	80 %
December 2004	75 %
January 2005	75 %
February 2005	78 %
March 2005	75 %
April 2005	77 %
May 2005	75 %
June 2005	65 %
July 2005	72 %
August 2005	72 %
September 2005	68 %
October 2005	74 %
November 2005	78 %
December 2005	76 %
January 2006	80 %
February 2006	81 %

Fig. 2 reports the results for the monitoring station placed in Corso Galileo Ferraris in Cuneo for the period 15/11/2004 → 17/02/2006; as one can easily observe, the background concentration represents an high percentage of the daily CO average concentration, from 80% during the winter to 60/70% in the summer, due to the higher atmospheric turbulence during the warm season. The reported values (see also Table 4) are confirmed by the same measurements carried out in an other urban monitoring station 120 km far away from the analysed one: in this case, the background percentage is very similar to the reported data with a maximum deviation of 15%.

The same approach should be followed for PM_{10} concentration in order to define the background contribution to the total measured concentration. In this case, the measurements of the particles are based on a gravimetric method so that only daily values are available (on the contrary, TEOM based monitoring stations provide hourly values but underestimate PM_{10} concentrations); this way it is not possible to calculate the background concentrations as the average night concentration value. In order to overcome this problem we considered the measurements carried out in the period 24/12/2004 → 14/02/2005 with a mobile laboratory equipped with TEOM and placed in the main

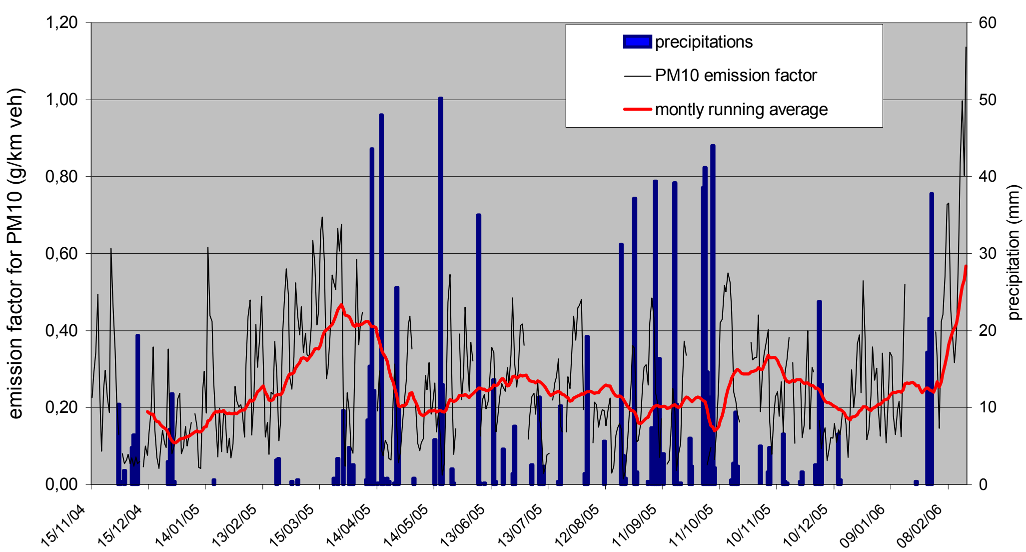


Fig. 3: Calculated PM_{10} emission factor (exhaust + non-exhaust)

street of the town, Corso Nizza, a few hundred meters far from the stationary monitoring station. Here, we obtained a background average percentage for that period of 42% (as a matter of fact PM is less persistent than CO in the atmosphere). Consequently we supposed for PM_{10} the same behaviour of the CO background percentage during the 15 months of analysis and we transferred the obtained values from Corso Nizza to Corso Galileo Ferraris. This choice implies 2 main assumptions. The first one is that the dispersion between different streets is neglected (every urban canyon is considered a box) and the background concentration is directly dependent on the traffic emission in the same street, so that the background percentage with respect to the measurable concentration is the same for different streets (this assumption is partly confirmed by measurements in other towns, as previously cited); the second one is that the seasonal variation of the background concentration is the same for both CO and PM_{10}. In particular the second hypothesis should be confirmed by future in-depth analysis by means of a TEOM station measuring PM for long period.

According to the described tracer method, the daily total PM_{10} emission factor has been calculated; as obvious, the parameter changes according to the season and the wetness of the atmospheric conditions. The emission factor varies around a mean value of 257 mg/km/veh ± 164 mg/km/veh, with a maximum value of 1136 mg/km/veh. It is important to report that the mean CO emission factor for the circulating fleet in Cuneo is 3060 mg/km/veh whereas the mean exhaust PM emission factor is 47 mg/km/veh (we assumed an average vehicle speed of 40 km/h). As one can easily observe, the reported emission factors studied for the analysed area in NW Italy are much higher than the values referred by the "German method" and the "Danish method" while they are quite near to the CEPMEIP-TNO suggested data and most of all to the Swedish values, in particular the described range 200-1200 mg/km/veh.

Fig. 3 reports the trend of the calculated PM emission factors during the 15 analysed months. It is interesting to notice the correlation between rain falls and the monthly running average of the emission factors. As a matter of fact, during the winter, a very dry period in the last years, the emission factor constantly increases till the first spring precipitations. In the analysed area the winter precipitations, even though scarce, are snowy; as a consequence, during the winter, as everyone knows, the practice of road sanding and the use of studded tyres can enhance the PM emissions. During the spring, the precipitations clean the street and consequently the emission factors are more constant at a lower value till a new dry season starts.

In order to simulate the effects of traffic emissions on the urban air quality we used the Operational Street Pollution Model [10].

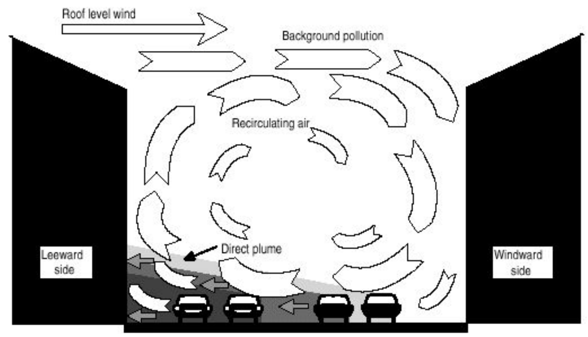


Fig. 4 : Conceptual scheme of the OSPM model

Atmospheric dispersion modelling

OSPM has its main focus on the physical processes governing the dispersion of pollutants in urban streets: as a matter of fact, the most characteristic feature of the street canyon wind flow is the formation of a wind vortex so that the direction of the wind at street level is opposite to the flow above roof level (Berkowicz et al., [11]). OSPM calculates concentrations of exhaust gases using a combination of a plume model for the direct contribution and a box model for the recirculating part of the pollutants in the street (see Fig. 4).

We applied the OSPM model both for CO and PM_{10} at the monitoring station location (Corso Galileo Ferraris), taking into account the background contribution obtained as described in the previous chapter.

Fig. 5 reports the comparison of measured and modelled CO daily concentrations. As one can easily observe, the modelled values reproduce the measured one in a satisfactory way, the correlation coefficient is very high (r=0.977), so that the model and the approach can be considered reliable for our purposes.

In the same way, based on the PM_{10} emission factors calculated by means of the tracer method, we calculated the PM_{10} concentrations, as reported in Fig. 6.

Also in this case the correlation is very good (r=0.959), even though the model lightly underestimate the measured concentration. The mean deviation D, defined as follows:

$$D = \sum_{i=1}^{n} \frac{|Cm_i - Cc_i|}{n} \cdot \frac{1}{\overline{\overline{Cm}}} \cdot 100$$

where Cm is the measured concentration and Cc is the calculated concentration, is less than 17%.

It is important to observe that the reported results could be even better if one considers that the concentrations are calculated on the basis of traffic flows measured in a few working days, without information about the size distribution of the traffic (data that could improve the definition of the circulating fleet and consequently the

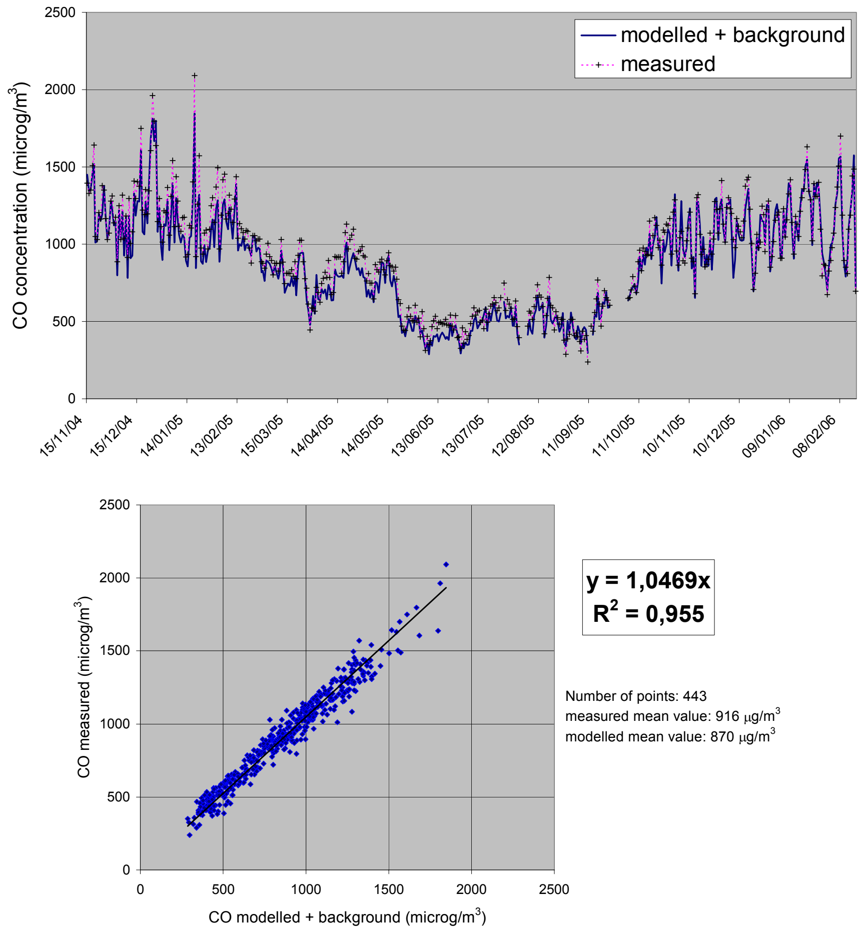


Fig. 5 : Comparison of measured and modelled CO daily mean concentrations

description of emission fluxes); if one excludes the weekend days and the main festivities, when we surely overestimate the traffic flows, the correlations get better.

Once the described approach is validated, the calculated PM_{10} emission factors can be applied to other main streets interested by different traffic flows. In this case we implicitly assume that the physical mechanisms that lead to PM release from vehicles are the same in the whole area and that the background concentration represents the same percentage of the total measurable concentration in every street. Fig. 7 shows the calculated average PM_{10} concentrations due to traffic in 28 streets of the town for the analysed period. The mean value for all the streets is around 42 µg/m^3, lightly above the air quality limit for PM_{10}.

Emissions from other sources

Within the analysed area, four important factories are placed, namely two cement factories, a glass manufacture and a tyre production plant. The PM emissions deriving from these industrial activities (mainly PM_{10}) have been assessed for the Integrated Pollution Prevention and Control (IPPC) authorization procedure and are reported in Table 5.

As far as the heating plants of the town area concerned, Table 6 reports all the data at disposal for Cuneo, in particular the heating plants power divided for different fuels, the energy consumptions and finally the PM_{10} emissions.

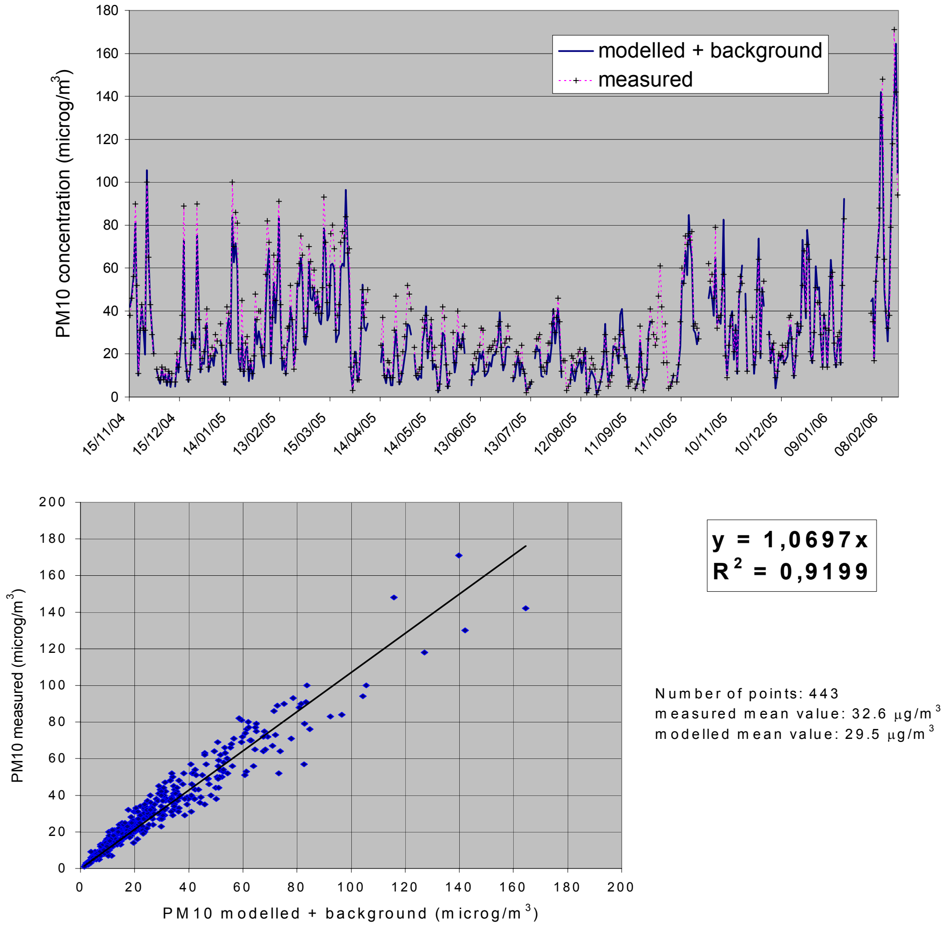


Fig. 6 : Comparison of measured and modelled PM_{10} daily mean concentrations

Table 5: PM emissions from industrial activities in the studied area

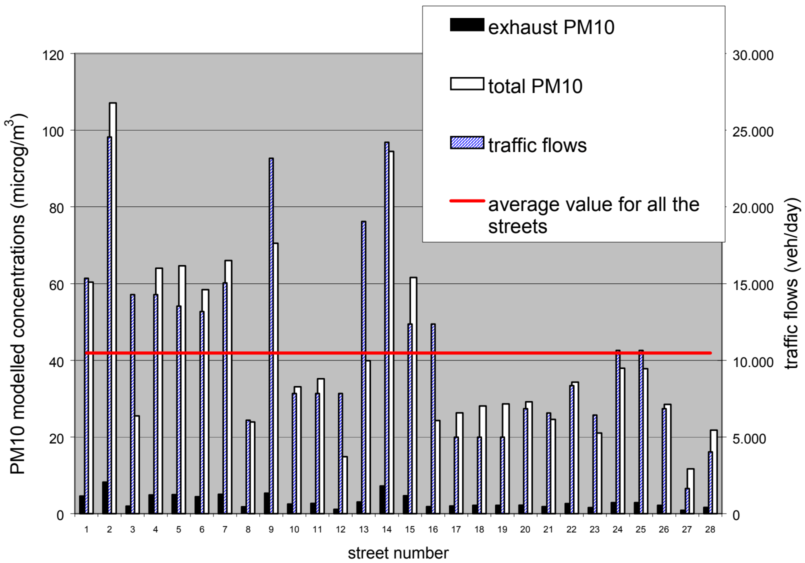
	PM emissions (t/y)
Glass factory	19
Cement factory n.1	25.7
Tyre factory	15.8
Cement factory n.2	111.8
total	172.3

In order to build an emission inventory of the analysed area, we have to determine also the PM_{10} emissions from the traffic on the basis of the calculated emission factor (257 mg/km/veh as a mean value of exhaust + non-exhaust releases), the daily traffic flows (308,000 vehicle per day) and the length of the main streets (almost 16 km). The resulting PM_{10} emissions from traffic in the town are around 16.8 t/y.

Table 6: PM emissions from heating plants in the studied area

	heating plants power (kW)	energy balance (MWh/y)	PM_{10} emission factors (mg/kWh)	PM_{10} emissions (t/y)
natural gas	294,608	229,000	13	3.0
gas oil	159,011	79,979	22	1.7
LPG	381	742	10	0.0
wood	221	2,325	2,716	6.3
fuel oil	38,782	15,555	73	1.1
total	493,002	327,601		12.2

The effect of the heating plants and the industrial activities on the air quality of the town can be calculated by means of a model such as ISCST3 (US EPA, [12]), in account of its capacity as a conventional steady-state plume Gaussian model to describe a transport and turbulent dispersion condition. In the case



ID	CORSO/VIA
1	CORSO DE GASPERI – da ll'esterno fino a Corso Ferra
2	CORSO MONVISO
3	CORSO FRANCIA –dall'esterno a Corso Gramsci
4	CORSO FRANCIA – da Corso Gramsci a Corso Ferraris
5	CORSO NIZZA – da Corso Ferraris a Corso Giolitti
6	CORSO NIZZA – da Corso Dante a Corso Giolitti
7	CORSO NIZZA – da Corso Dante a Piazza Galimberti
8	VIALE DEGLI ANGELI – dall'esterno a Corso Dante
9	VIALE DEGLI ANGELI – da Corso Dante a Corso Gariba
10	LUNGOGESSO GIOVANNI XXIII – da Corso Garibaldi a
11	LUNGOGESSO GIOVANNI XXIII – da Via Chiusa Pesio
12	LUNGOGESSO GIOVANNI XXIII– da Via teatro a Piazza
13	CORSO MARCONI
14	CORSO IV NOVEMBRE
15	CORSO KENNEDY – da Largo De Amicis a Via Leutrum
16	CORSO KENNEDY – da Via Leutrum a Piazza Torino
17	VIA ROMA : da Piazza Galimberti all'altezza di Via Cac
18	VIA ROMA : da Via Cacciatori delle Alpia a Largo Audi
19	VIA ROMA : da Largo Audiffredi a Piazza Torino
20	CORSO VITTORIO EMANUELE II
21	CORSO CARLO BRUNET
22	CORSO GIOVANNI GIOLITTI
23	CORSO DANTE
24	CORSO SOLERI
25	CORSO GARIBALDI
26	CORSO GALILEO FERRARIS
27	VIA BERSEZIO – da Corso Carlo Brunet a Via Massimo
28	VIA BERSEZIO – da Corso Vittorio Emanuele II a Corso

Fig. 7: PM_{10} average concentrations calculated for 28 different streets in the period between 15/11/2004 and 17/02/2006

of the heating plants the description of the sources has been carried out by means of a very detailed definition of the fuel mix and the installed power for every street, and then we decided to consider 504 equivalent point sources.

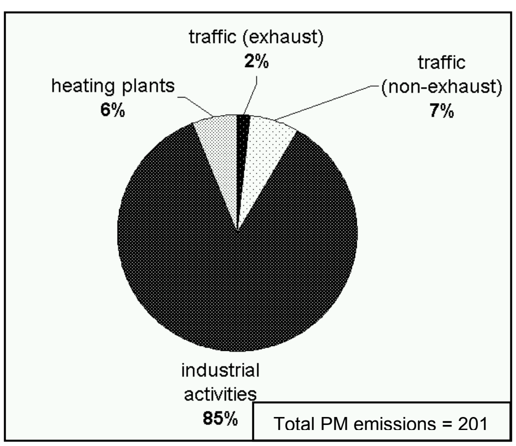


Fig. 8: PM_{10} emission inventory for the studied area

The results of the atmospheric modelling were that the maximum daily mean concentration of PM_{10} calculated at the monitoring station due to the heating plants is around 1 $\mu g/m^3$, whereas the industrial contributions are even smaller, with a maximum concentration of 0.5 $\mu g/m^3$. It is important to remember that in this case we are talking about direct instantaneous contributions, since a part of the calculated amounts takes part to the formation of the background concentrations of the street; anyway, the an important contribution to the background concentration seems to be the secondary inorganic aerosols deriving from NO_x, NH_3 and SO_x emissions, mostly due to traffic, industrial and agricultural activities.

As far as the CO emissions deriving from the heating plants and the industrial activities are concerned, their effect can be considered around 5 $\mu g/m^3$, as maximum daily concentrations at the ground level; the reported levels is negligible if compared to the CO concentrations measured in the analysed area (300-2000 $\mu g/m^3$).

As a consequence, we may say that the direct effect of sources, other than traffic, is very low on the air quality of the analysed area and so it is acceptable to neglect them when applying the tracer method, as we assumed in the present paper.

By taking into account the different sources, it was possible to calculate the fraction of the total PM_{10} concentration due to each of them. These estimations are reported in Fig. 9 for the month of January 2005; it is possible to observe that the traffic contribution to the determined concentration has an influence of 54% on the whole. In any case it is necessary to take into account that the background contribution (42% of the total) may be strongly related to the instantaneous direct emissions in the same street, i.e. mainly to traffic, and to the secondary particulates, due to traffic and industries; anyway, traffic can be considered the main responsible for the bad quality of urban air.

The main focus of the present paper was the definition of PM_{10} emission factors due to traffic exhaust and non-exhaust emissions in a medium town in N-W Italy. By applying the so-called tracer method, based on the parameter CO, we obtained total PM_{10} emission factors

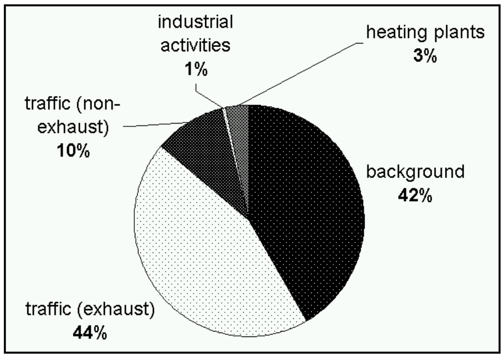


Fig. 9: Contributions of different sources to the calculated PM_{10} concentrations (January 2005)

varying around a mean value of 257 mg/km/veh ± 164 mg/km/veh, with a maximum value of 1136 mg/km/veh, while the mean exhaust PM emission factor calculated by means of the Copert3 model is 47 mg/km/veh. The calculated data confirm the emission factors suggested by CEPMEIP-TNO and most of all some Swedish values, in particular the reported range 200-1200 mg/km/veh. The described methodology indicates that 80% of the total emitted PM_{10} originates from non-exhaust emissions and so it is evident that policies reducing the exhaust releases of the park or limiting diesel vehicles without particle traps can have a limited effect on the air quality; anyway, it must be said that improvements of the exhaust emissions or old vehicles' restrictions can reduce NO_x releases, the main source of secondary PM, and then can achieve positive results.

Another important analysis carried out in the present paper concerns the definition of the background concentration that, in our experience, can be different if one consider the countryside, a street canyon or a urban rooftop. In our analysis we used the night measured concentration as background concentration for a urban street canyon but we need more detailed studies in order to understand the background behaviour during the year for different pollutants (CO, PM_{10}, NO_x) and to compare it in different streets of the same town or for different areas.

The main conclusion of the paper is that traffic, as we already know, is the main responsible for the direct instantaneous contributions to the air quality in a urban area; the other sources (heating plants and industrial activities), that can be larger than traffic if absolute emission values are considered, are probably very important in determining the PM_{10} background concentration, chiefly as secondary particulates precursor.

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