Real-World Road-Traffic and Fleet Data, Congestion and Pollutant Emissions

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Abstract

Within the framework of MOCoPo research project, an in-situ experiment was conducted during one-month in Grenoble, France (400,000 inhabitants) on a high-capacity road (ring, 2x2 lanes) close to an area of exchanges and frequently under congested conditions. Traffic counting was performed at 6-minutes intervals. Four video-cameras were installed to capture in real-time vehicle license plates. Their identification through the national registrations enabled the characterization of the fleet composition. These data were used to simulate pollutant emissions from the traffic, by the COPCETE calculation plate-form. Based on the COPERT4 (V9) methodology, it enables the computation of around 7000 observations (i.e. two full weeks of valid 6-minutes data), integrated on a distance of 1 km, and described by the real-world traffic data (flow, speed) and fleet composition as observed by the video. These works have first enabled the implementation of the video technique to capture the in-situ fleet composition. 1.7 million of observations and 350,000 French registrations allowed a good and detailed characterization of the local fleet, its specificities and variability with the time-periods. Analyses of pollutant emissions demonstrate that they are mainly linked to the traffic flows, thus to the fleet composition (heavy vehicle share) and then to the traffic conditions. Complementary analyses demonstrate the importance of cold start over-emission.

Nomenclature

COPERT	Computer programme to calculate emissions from road transport
COPCETE	Calculation tool of pollutant emissions due to road traffic
PC	Passenger cars
LCV	Light commercial vehicles
HGV	Heavy goods vehicles

Introduction

Road transport constitutes one of the major sources of pollution in urban environment on regional and global scales. It plays an important role in human health. Fleet composition, traffic flows, and traffic congestion are amongst the main issues in urban areas pollution. It is often considered that decreasing of congestion could improve significantly the air quality, although the mechanisms - real-world fleet composition (vehicle technologies, motorizations and fuel compositions), congestion, real-world pollutant emissions from road traffic under congested conditions, air quality near the road - are complex and not well known. MOCoPo research project aimed at improving the modelling of congestion and nuisances associated on urban motorways. This paper presents main results of MOCoPo project concerning fleet composition and emissions. These works intended to characterize real-world traffic and vehicle fleet composition as well as their variability and to analyse the relation with congestion and pollutant emissions. Usually, emissions are calculated with national estimations of fleet. In this work emissions were estimated using local fleet that enabled to overcome inaccuracy of models. (André et al., 2014)

Method

An in-situ experiment was conducted during one-month in September 2011 in Grenoble, France (400,000 inhabitants) on a high-capacity road (ring, 2x2 lanes, 90km/h speed limit) close to an area of exchanges and frequently under congested conditions.

Traffic counting was performed at 6-minutes intervals by inductive-loop traffic detectors. Besides, vehicle license plates were collected in real-time by four video cameras during 30 days, observing the front of vehicles. Their identification through the national registrations enabled the characterization of the local fleet composition: passenger cars (PC), light commercial vehicles (LCV), Heavy goods vehicles (HGV), coaches and buses, with types of motorization (diesel, petrol, hybrid etc.), weight or size and the European emission standards (in accordance with vehicle age).

These data were used to simulate the pollutant emissions from traffic, by the COPCETE calculation platform, based on the COPERT4 (V9) methodology. COPERT has been built on Guidebook methodology (EMEP/EEA, 2009), and relies on pollutant emissions measured during driving cycle. With vehicle.kilometres and speeds, this calculates:

- Hot emissions for light and heavy vehicles
- Cold over-emissions for light vehicles
- Over-emissions related to road gradient or vehicle load for heavy vehicles
- Evaporation emissions (petrol vehicles)
- Non-exhaust emissions (wear of tires and breaks)

Vehicles are subdivided in 242 types, depending on fuel composition, size of engine, weight, European emission standards. For each vehicle type, necessary input data are:

- Number of vehicles, annual mileage (km/year), and cumulative total (km)
- Distribution of annual mileage according to road type (urban, rural, motorway)
- Travelling speed

Besides, COPERT needs information about:

- Meteorological conditions (ambient temperature, vapour pressure)
- Average trip length
- Road gradient, and load for heavy vehicles

COPERT tool is dedicated to emission inventory at a large scale (large area, country, year) without the potential of spatializing to a road network or an urban area. However, some tools are developed from the COPERT 4 methodology for local applications.

COPCete is one of these adaptations of COPERT 4, it is developed by the French Ministry of Ecology, Sustainable Development and Energy. It allows working with a series of road sections. (V. Demeules, 2012).To each section is associated its length, gradient, the number of light vehicles, HGV, buses, their mean speed, the rate of light commercial vehicles, the fleet. The IFSTTAR national fleet is integrated into COPCete, but other fleets can be integrated, and it allows adjustment of many parameters (ambient temperature, HGV load, the average trip length, the number of trip per day. That enables the computation of around 7000 observations (i.e. two full weeks of valid 6-minutes traffic data), integrated on a 1 km distance, and described by the real-world traffic data (flow, speed) and fleet composition as observed by video. Results on emissions presented later were calculated with COPCete. Calculations were done with local temperature in September 2011 in Grenoble.

Results

Video technique

These works have first enabled the implementation of the video technique to capture the in-situ fleet composition: dysfunctions, identification errors and inaccuracy can decrease the efficiency of the techniques. Indeed, reliability of observations depends on several factors related to the experimental device or the environment: angle of recording, traffic conditions that might induce a mask effect, meteorological conditions, luminosity etc. Besides, the optical character recognition might be defective. Finally the putting up of cameras has its own limits: in the case of a front view of vehicles, two-wheels won't be detected. Conversely, in a back view of vehicles, trailers would be seen instead of lorries (preventing from the identification of its motorization, age etc.). The work carried out on dysfunctions allowed us to identify and quantify the main issues:

- The identification of vehicle nationality by the optical character recognition algorithm: 53% of observations were associated with French registrations, 20% with Italian, 10% with Belgian, 10% not associated with a country, and 10% associated to other European countries. The high levels of Italian and Belgian observations might be due to wrong identifications because of their similarity with French plates (the difference of shape with Italian plates is just dashes between characters).
- The efficiency of recordings can be observed thanks to traffic counting, the observation rate (observation of plates over traffic per time slot) is on average about 57%. This result hides a high variability depending on cameras and time slot.
- Low rates of observations (about 0 to 10%) were noted during peak hour of mornings for one direction: this can be due to camera positions (overexposure, poor contrast) and heavy road traffic.
- Some observation rates were higher than 100%, by finding the time slot associated, we noted that the same plate could be s recorded many times in a short time interval (lower than 15 hundredth of a second).

Thus, the video device isn't a good technique to assess the whole traffic, however, 1.7 million of observations and 350,000 French registrations is a considerable sample size and enabled a good and detailed characterization of the local fleet, its specificities and variability with time-periods.

Fleet composition

The fleet presented thereafter is composed by the overall of observations that have been identified (i.e. 757000 recordings associated to 270000 plates identified in the national registration). That composition relies on the observations to approach a fleet in circulation.

The observations permitted to build the local fleet, during several time periods: the whole experiment, weekdays, week-end, peak hours, off-peak hours etc. Thereafter, we compared the local fleet to the IFSTTAR national fleet in circulation estimated for the year 2011 (M. André, 2013). Concerning the share according to the type of vehicle (PC, LCV, HGV, coaches, buses), the composition is nearly the same between MOCoPo recordings and national estimation, but we observe slightly more passenger cars in MOCoPo (80% against 77% nationally), to the detriment of LCV (15.9% against 18.8%).

Table 1 outlines the motorization of passenger cars and LCV observed in MOCoPo and nationally estimated in 2011. The local fleet accounts for less diesel cars than the national estimations (-3.7%). Concerning the LCV, the results are similar but the difference between local and national composition shows that petrol LCV are still remaining.

Table 1: Passenger cars and light commercial vehicles motorisations observed locally (MOCOPO) or nationally estimated (IFSTTAR 2011)

Vehicle Categories and types	Number of observations MOCoPo	Local composition of vehicle fleet MOCoPo Per category	Composition of vehicle fleet IFSTTAR 2011 Per category
PC	**598965**	**100,0 %**	**100,0 %**
Diesel		68,5 %	72,2 %
Petrol		30,6 %	27,5 %
Others		0,94 %	0,28 %
Unknown		0,05 %	-
LCV	**118436**	**100,0 %**	**100,0 %**
Diesel		97,2 %	98,7 %
Petrol		2,0 %	1,3 %
Unknown		0,75 %	0,06 %
Total	**717401**		

Figure 1 compares local and national fleet composition according to European emission standards for PC, LCV and HGV. The pre-Euro, Euro-1 and Euro-2 categories are grouped together. It shows that local fleet vehicles are older than national fleet estimation: concerning the passenger cars, the Euro 0-1 and 2 are almost the same for both local and national fleet, but local Euro 3 share are 10% higher locally, at the expense of Euro 4 and 5 categories which are respectively 7.5% and 2.8% lower than nationally. LCV local observations and national estimations show similar proportions as to Euro standards, but all other categories are older locally. We note that for HGV, local share of Euro-0 to 2 is 4% higher, Euro 3 is 6% higher, Euro 4 is slightly lower (2%) and the share of Euro 5 is 8.5% lower than national estimations.

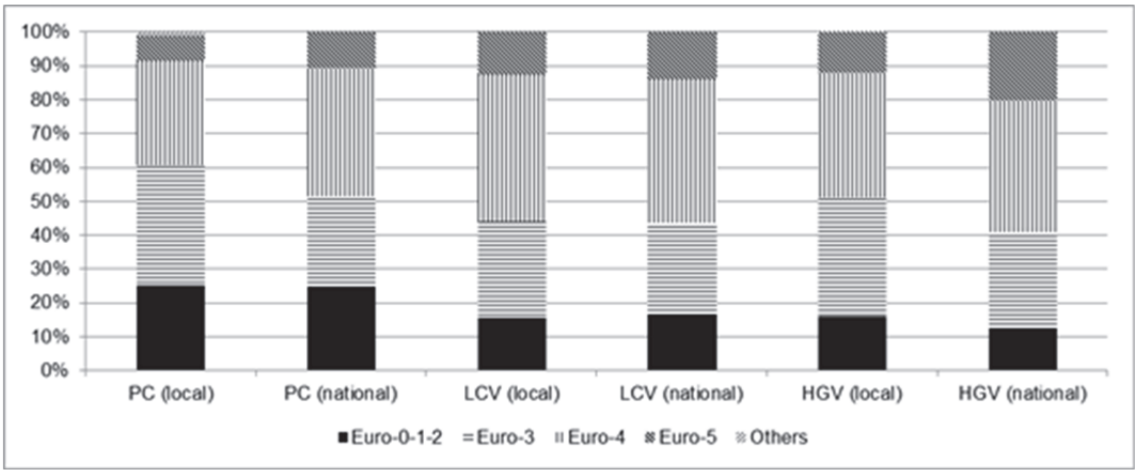

Figure 1: Fleet composition per Euro categories observed locally (MOCoPo) during the whole experiment and during peak hours (7 AM-9AM, 4PM-7PM in weekday) or nationally estimated (IFSTTAR 2011)

The experiment during a whole month, allowed us to compare observations with temporal variability. Thus, a strong variability as regards vehicles categories is observed between week and week-end, in Table 2: while the passenger cars represent about 77% during weekdays, this rate raises up to 89.6% during week-end, indeed HGV and LCV levels are strongly decreasing : -8.5% for LCV, and -3.9% for HGV. And although the variability is weaker between peak hour and off-peak hour, it shows that HGV take advantage of less traffic during off-peak hour.

Table 2: Fleet composition during week-end/week, peak/off-peak hours

	Average	Week-end	Weekdays	Peak hours	Off-peak hours
PC	80,2 %	89,6 %	77,1%	78,9 %	76,1 %
LCV	15,9 %	9,5 %	18,0 %	17,6 %	18,2 %
HGV	3,7 %	0,68 %	4,6 %	3,3 %	5,4 %
Coach	0,16 %	0,16 %	0,15 %	0,16 %	0,15 %
Bus	0,12 %	0,08 %	0,13 %	0,11 %	0,15 %

Peak hours: 7-9 am; 4-7 pm (Monday to Friday)
Off-peak hours: 0-7 am; 10 am - 4 pm; 19-24 pm (Monday to Friday)

Besides, temporal observations and analysis enabled the highlighting of the hourly variability of HGV share, LCV share, diesel passenger cars share and recent passenger cars share (Euro4 and Euro5), when traffic flows are higher than 200 vehicles per hour. Figure 2 depicts the hourly variability of compositions of fleet during the experimentation. The HGV flows vary periodically from 0% to 15% with an average of 4.8%, the LCV flows vary from 0% to 25-35%, and 15.8% on average.

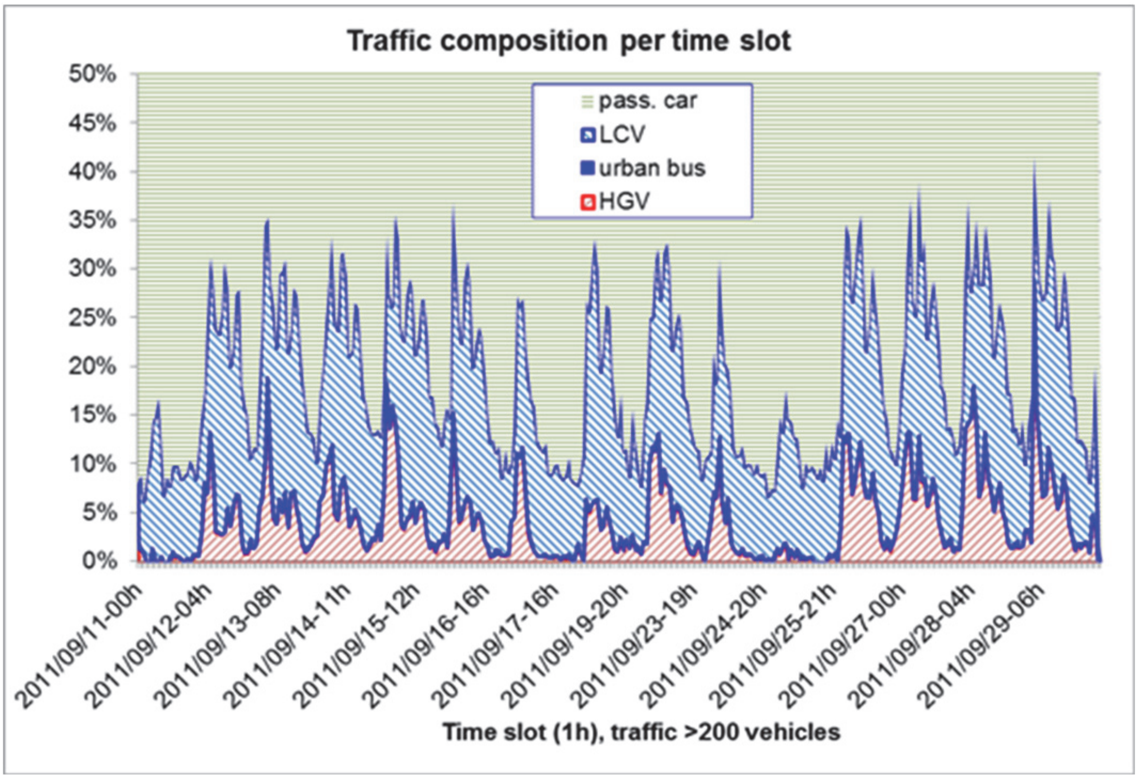

Figure 2: Composition of traffic according to vehicle types during MOCoPo experiment

Concerning the rate of diesel passenger cars, it fluctuates between 60% and 80%. As for the European emission standards, the rate of older vehicles (Euro 3 included) varies between 55% and 65%, and sometimes reaches 70%.

For each case, we have considered two contrasted fleet compositions: the first one has low rates of HGV (or low rate of diesel PC, or low rate of recent cars) that represents 25% of the traffic (vehicule.km), and the second one has high rates of HGV which represents 25% of the traffic.

The vehicle fleet can strongly vary from one hour-interval to the next one as regards the share of HGV (0 to 8%), LCV (9-22%), diesel cars (60-70%) or recent cars (35-45%). This observed variability can be an issue when calculating air pollution, and questions the use of a uniform fleet composition.

Impacts of traffic flow, fleet composition and cold start on emissions

- Emissions depending on week-ends or weekdays

Table 3 shows the traffic volume for the two weeks experiment (overall), its share according to vehicle types, speeds and emission factors, these results are shown for weekdays and week-end too. The analysis of Table 3 reveals that the traffic of heavy vehicles, buses and LCV is weaker during week-ends, thus the traffic includes less diesel vehicles. Besides, the traffic conditions are easier during week-ends, with higher speed range: 82km/h against 66km/h during weekdays. Although, the distribution during a week is almost homogeneous (in proportion over a week, a week-day is about 15% of traffic and a day of week-end represents12% of the traffic), the consequences of the previous conditions (less heavy vehicles, and diesel vehicle, higher speed range) are that CO_2, NOx, VOC and PM emission factors are weaker during week-end than weekday (from -10 to -30%). But there are slight rises of CO and Benzene emission factors due to a higher proportion of petrol vehicles during week-end.

Table 3: Emission factors calculated depending on week or week-end

		Overall	Week	Week-end	Difference %
Traffic	(veh.km)				
CO_2	FE (g/veh.km)	192	200	165	-17,6
CO	FE (g/veh.km)	0,806	0,798	0,829	3,9
NOx	FE (g/veh.km)	0,808	0,866	0,620	-28,5
VOC	FE (g/veh.km)	0,078	0,080	0,072	-10,6
Benzene	FE (g/veh.km)	0,003	0,003	0,003	4,4
PM	FE (g/veh.km)	0,098	0,106	0,075	-29,3
Traffic	%PL + Bus	4,8	6,0	1,0	-82,9
Traffic	%VP	79,2	76,2	89,1	17,0
Traffic	%VUL	15,9	17,8	9,9	-44,6
Traffic	%Diesel (VP, VUL, PL)	74,9	75,8	72,0	-5,1
Speed	All vehicles	69,5	66,4	82,1	
(km/h)	Light vehicles	66,6	66,4	82,2	
	HGV + bus	69,8	66,5	72,4	

- Emissions regarding on congestion events

In the following time, we analyse emissions with regard to time slot with traffic congestion or no traffic congestion. Although the traffic conditions were quite severe, the congestion events represent about 8% of the overall time for a 70km/h threshold (5.4% of the 6 minutes time slots for 40km/h threshold), 15% of the total traffic (9% for 40km/h) and 14% (for PM) to 20% (for VOC and Benzene) of the emissions. The congestion contribution to the overall air pollution is thus significant but not predominant.

Table 4 shows that due to strongly contrasted traffic conditions (average speeds ranging from 30 to 80 km/h), emission factors (g/veh.km) are higher in congestion. However, although average speeds are strongly different (37km/h during congestion, 80km/h without congestion) the emission factors differences remain limited (4 to 30%) for these speed ranges. Part of these low differences might be explained by emission functions depending on speeds: between these speed ranges, they are almost flat.

Table 4: Emission factors calculated during traffic congestion (beyond a threshold of 70km/h)

		Overall	Congestion	No congestion	Difference %
Traffic	(veh.km)	1215273	180844	1034429	472,0
CO_2	EF (g/veh.km)	192	217	188	-13,3
CO	EF (g/veh.km)	0,806	0,846	0,799	-5,6
NOx	EF (g/veh.km)	0,808	0,866	0,798	-7,9
VOC	EF (g/veh.km)	0,078	0,105	0,073	-30,0
Benzene	EF (g/veh.km)	0,003	0,004	0,003	-30,3
PM	EF (g/veh.km)	0,098	0,095	0,099	3,9
Traffic	%HGV + Bus	4,8	4,1	5,0	20,0
Traffic	%PC	79,2	78,2	79,4	1,5
Traffic	%LCV	15,9	17,6	15,6	-11,4
Traffic	%Diesel (PC, LCV, HGV)	74,9	75,2	74,9	-0,4
Speed	All vehicles	69,5	37,2	81,7	
(km/h)	Light vehicles	69,6	37,2	82,1	
	HGV + bus	66,8	37,3	75,3	

Congestion events represent about 50% of traffic during peak-hours, and around 47-57% of emissions. But, emission factors differences between congestion events and no congestion are limited to 13-14% for CO and CO2, 9% for NOx, 4% for PM, and 30% for VOC. The congestion decrease during peak-hours would thus provide limited gains in air quality. Considering the only congested events, the gains in emissions that would results from the congestion removal, would be limited to 2-4% for NOx and PM, 7% for CO2, 15% for VOC.

- Global emissions depending on vehicle categories

Previous analyses showed that week, week-end and overall fleets induce large differences between emission factors. Consequently, we analyse emissions regarding vehicle types and fleet compositions.

Table 5 shows the emission factors of CO_2, NOx and PM depending on vehicle categories, motorization for passenger cars and LCV. We note that diesel passenger cars represent more than the half of the traffic and 44% of CO_2 emissions. Indeed, the average CO_2 emission factor is 192 g/km and 156 g/km for the passenger cars, 221 g/km for LCV and 694 g/km for heavy vehicles.

Thus, the heavy vehicles that are less than 5% of the traffic represent 17% of CO_2 emissions. Besides, the heavy vehicles have a strong influence on particulate matter and nitrogen oxide emissions, since they emit up to 30% of PM and NOx (for less than 5% of traffic). Their CO_2 and NOx emission factors are 10 times higher than passenger cars emission factors. Passenger cars emit up to 53% of NOx and PM, 39-41% of which due to diesel cars.

Table 5: Vehicle categories contribution to traffic, CO_2, NOx and PM emissions

	% traffic	CO_2 % emission	Emission factor (g/km) Global	NOx % emission	Emission factor (g/km) Global	PM % emission	Emission Factor (g/km) Global
PC Diesel	54,5	43,8	154	38,6	0,572	41,3	0,074
PC Petrol	24,1	20,0	159	14,6	0,489	11,2	0,046
PC Hybrid	0,1	0,1	107	0,0	0,017	0,1	0,044
VP GPL	0,5	0,4	158	0,1	0,142	0,2	0,045
LCV Diesel	15,6	17,9	220	15,5	0,804	14,6	0,092
LCV Gasoline	0,4	0,5	248	0,3	0,641	0,2	0,052
LCV elec	0,0	0,0	0	0,0	0,000	0,0	0,050
HGV	4,7	16,9	691	30,0	5,145	31,6	0,659
Bus	0,1	0,6	823	1,0	6,250	0,9	0,653
PC	79,2	64,2	156	53,3	0,543	52,7	0,065
LCV	15,9	18,3	221	15,8	0,800	14,8	0,091
HGV+Bus	4,8	17,5	694	31,0	5,175	32,4	0,659
Diesel (All)	74,9	79,1	203	85,0	0,917	88,3	0,116
All vehicles	100,0	100,0	192	100,0	0,808	100,0	0,098

- Variability of emissions depending on hourly variability of fleet

To study the sensitivity of emissions with the HGV share, LCV share, Diesel share or European emission standards shares that are hourly-variable, we considered each time two contrasted fleets that represent 25% of the traffic.

Figure 3 highlights that the hourly-variability linked to the HGV share, has a strong effect on emissions, although the variability has a limited range. NOx and PM emissions from high rates of HGV and LCV can reach 65% higher comparing to low rates of HGV and LCV fleet, and 30% higher for CO_2 emissions.

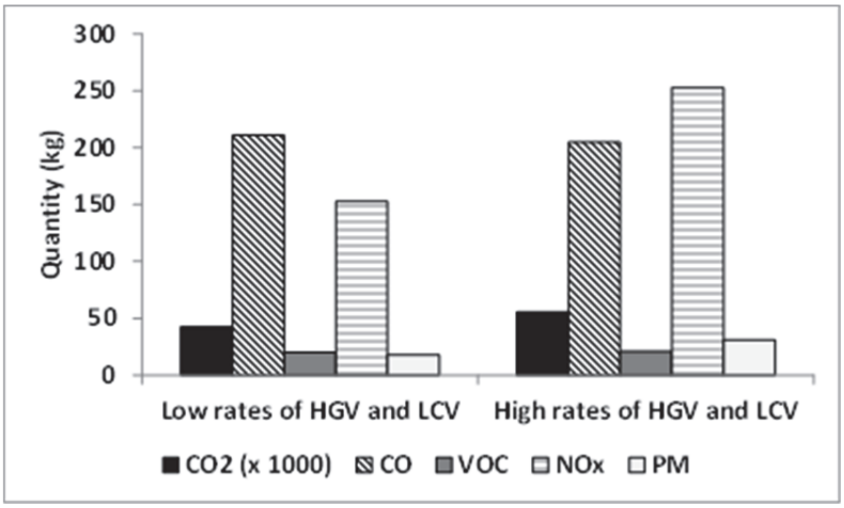

Figure 3 : Effect of the HGV and LCV traffic rates on overall emissions of traffic flows. Low rates: HGV=0.4% and LCV=9.2%; High rates: HGV=8.1% and LCV=22%

A similar study was done with the diesel car rate with two contrasted fleets: low rates of diesel PC with 66% of diesel vehicles and high rates of diesel PC with 70% of diesel vehicles. Differences between the rates are low (4%). Thus, differences between diverse pollutant emissions are weaker than previously (Figure 4), but pollutants linked to petrol combustion (CO and VOC) are about 10% lower with a strong dieselization. For the pollutants more specifically related to Diesel (NOx, PM), variations are weak because the fleet remains strongly diesel and heavy vehicles highly contributes to those emissions.

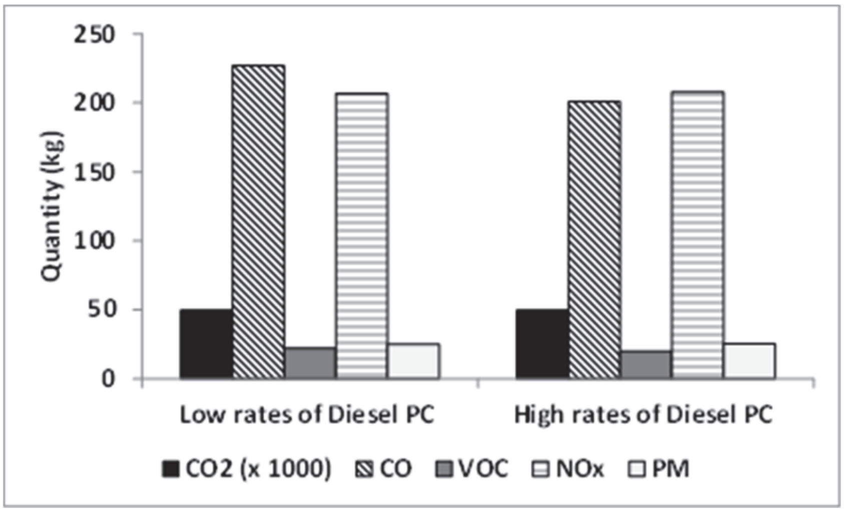

Figure 4: Effect of the Diesel car traffic rate on overall emissions of traffic flows. Low rates of diesel PC: Diesel=66%, Petrol=34%; High rates of Diesel PC: Diesel=70%, Petrol=30%

Finally, concerning the recent car rates, the differences observed in Figure 5 are low, due to a weak variability of recent car share, and because the age variability of heavy vehicles and LCV were not considered.

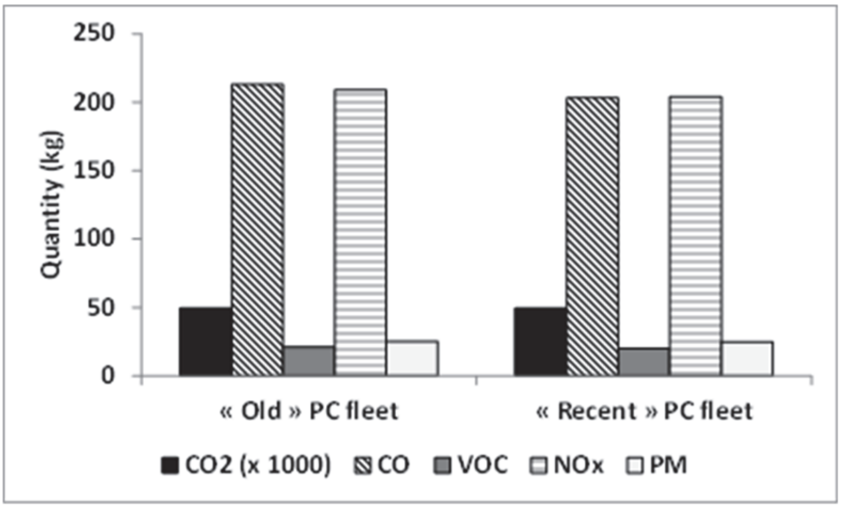

Figure 5: Effect of European emission standards traffic rate on overall emissions of traffic flows. Old PC fleet: Pre-Euro to Euro 3=65%, Euro 4=29%, Euro 5=6%, Recent PC fleet: Pre-Euro to Euro 3=57%, Euro 4=32%, Euro 5=11%

- Other phenomena

Cold-start might be predominant for the emission of CO and VOC (M. Weilenmann, 2009), thus we assessed the contribution of cold start emissions on overall emissions (we remind that experiment and calculations were done for the month of September).

Figure 6 gives us the part of cold start emissions (for passenger cars) and the total emissions (the whole traffic) calculated with the reference case. Cold start emissions are about 5% of CO_2 emissions (and consumption and GHG emissions), and is also limited for NOx, PM, SO_2. But, the cold start emissions represent 40% of the CO, VOC, VOCNM, nearly 50% of Benzene and Methane emissions and about 15 to 30% of other organic compounds emissions.

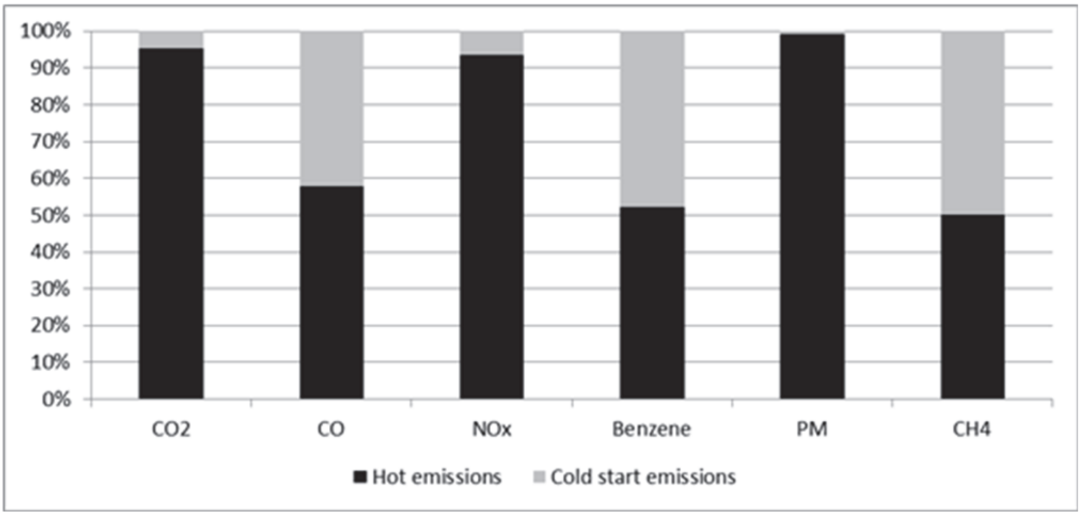

Figure 6: Hot emissions and cold start over emissions

However, those emissions were calculated for the month of September 2011, with summer temperatures, thus the over emissions were limited. But a simulation using wintry temperatures shows that cold-start emissions are significant particularly for CO (80%), volatile organic compounds including benzene (from 70 to 80%). Besides the cold start over emission are limited to few kilometres after starts, and are not shared out uniformly over the land. Thus, the quantification of cold start emissions on a local scale and in accordance with the variability of flow conditions is limited.

Such phenomena - together with evaporative emission, heavy duty vehicle load rate influence and non-exhaust emissions - are poorly approached in particular as regards spatial and temporal distribution. They limit thus significantly the assessment of the properly local emissions and air pollution. Finally, beyond non-exhaust phenomenon, neither road abrasion nor the resuspension of particles are taken into account in COPCete methodology, whereas those quantities may be as significant as exhaust sources of particles (EMEP/EEA, 2013).

Conclusion

The MOCoPo research project enabled an experiment to characterize local fleet and traffic on the south bypass of Grenoble. The plate video recording device permitted to identify issues related to this technique and above all, with a sample of 270000 recognised plates, to characterize the local fleet and its temporal variability.

The local fleet is different of the national estimations as to the share of vehicle types (PC, LCV), concerning the Diesel share (less Diesel in Grenoble), and as to the emission standards (local fleet has less recent vehicles). Besides, we've been able to characterize the variability of the fleet of weekdays, week-end (less LCV and HGV during week-end), peak hours and off-peak hours. Finally, we observed the hourly variability of several parameters: the share of HGV, the share of Diesel passenger cars, and the share of old passenger cars.

The assessment of emissions due to traffic in the south bypass of Grenoble was implemented thanks to the local observation of the fleet. Indeed this fleet was used as input data in the COPCete tool derived from COPERT 4 methodology. The analysis of congestion events (70 and 40HM/h threshold) shows that they represent 5 to 8% of time, 9 to 15% of the traffic and 13 to 20% of the overall emissions. Besides, the improvement of circulation conditions during peak hours would provide limited improvements in emissions (although average speeds are very different with or without congestion, because emission functions are slightly changeable at these speed ranges). Emissions are strongly variable with the type pf vehicle, thus, HGV which are 5% of traffic represent 30% of NOx and PM emissions.

The hourly variability of the fleet might be important as to the HGV-LCV, the Diesel passenger cars and European emission standards shares. Thus, the study of sensitivity of emissions with contrasted fleets shows that the gap for HGV-LCV is significant (30 to 70%), but the gaps are lower for Diesel share or recent car share. Finally, the analysis of cold-start emissions for some pollutants highlights the stake this phenomenon.

Acknowledgements

The MOCoPo research project was funded by the PREDIT G06. We thank also CEREMA for providing COPCete tools.

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