Road Transport Emission Inventory in a Regional Area by Using Experimental Two-Wheelers Emission Factors

Paolo Iodice, Adolfo Senatore

Abstract— **Transport activities contribute significantly to air polluting emissions in all the world. In order to estimate the emissions from road transport in Campania (Italy), in this paper the COPERT methodology was employed with a bottom-up approach, focusing at regional level instead of national, then including local parameters relating to fleet, driving pattern, average vehicle speed, fuel consumption and by using experimental two-wheeler emission factors. For this purpose an experimental activity was conducted; information on the emissions of in-use two-wheelers were collected during real driving conditions, contributing significantly to extend knowledge of 2-wheel vehicles emission behaviour, and their emission factors database. This study identified the local critical factors that most affect the pollutant emissions, then it can assist decisions made by air quality management agencies and transportation planners.**

Index Terms—**Cold start extra emission, Copert, emission inventory, moped and motorcycle emission factors.**

I. Introduction

Although the level of emissions from traffic have been reduced with technical developments in the fields of engine and after-treatment technologies, many urban areas around the world still continue to suffer from high concentrations of these emissions. In Europe, the emissions due to road traffic are almost always an important fraction of the total emissions of a territory, despite extensive measures world-wide to reduce emissions during the last one or two decades. In Italy, for example, traffic emissions account for about 67% of carbon monoxide emissions, 51% of nitrogen oxides emissions and 40% of hydrocarbon emissions (UNECE/EMEP). In order to quantify the environmental impact attributable to road transport and to define effective policy to improve air quality, analytical and experimental studies are indispensable for policy makers and researchers. For this reason the emission inventories are becoming more and more important, also in order to accomplish the requirements of the European Directives concerning air quality. Despite their importance, the emissions from road transport with reference to other human and natural activities, are among the most difficult to calculate because they depend on many variables, which are characterized by a particular degree of uncertainty.

The paper describes the road traffic emission inventory estimated for the Campania Region for year 2011 using the COPERT IV, the most complete and accepted software tool available in Europe for calculating emissions from road traffic. In this application COPERT was employed with a bottom-up approach, and by using experimental two-wheeler emission factors. In order to achieve this aim, an experimental investigation on one moped and on two motorcycles (250 cm^3 and 1000 cm^3), belonging to the most recent legislative category, was being performed by the Department of Industrial Engineering (DII) of University of Naples Federico II, in order to characterize the emissive behaviour of 2-wheeler vehicles during different driving cycles.

The results achieved through this activity are extremely meaningful since throughout southern Asia and Europe mopeds and motorcycles are widely used and represent a large proportion of motorized vehicles; because of their prevailing use in urban environments, determination of emissions from 2-wheel vehicles is very important for estimating their relative contribution to total emissions attributable to road transport.

II. COPERT IV Methodology

The COPERT methodology is the collection of algorithms and emission factors suggested at European level for the estimation of emissions from the road transport sector (i.e. the whole SNAP 07 of CORINAIR) [1,2]. It is the most commonly used model in Europe for official national inventories of emissions from road traffic. The current version [3] is a collaborative effort and draws its main elements from several large-scale European activities: the MEET project, the COST 319 action on the Estimation of Emissions from Transport, and the ARTEMIS project. The methodology allows the estimation of the emissions for 230 vehicle categories belonging to the following five main classes: passenger cars, light duty vehicles, heavy duty vehicles, urban buses and coaches, and two wheelers. Vehicles belonging to such main classes are then distinguished according to the fuel type, the EU Directives to which they conform in terms of emissions, the cylinder capacity and other variables. Emissions can be estimated for 36 pollutants, and also for many secondary pollutants like polycyclic aromatics, dioxins and heavy metals contained in the fuel. COPERT calculates the total emissions of exhaust gases by summing emissions from three different sources,

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namely the thermally stabilized engine operation (hot), the warming-up phase (cold start) and due to evaporation. Since vehicle emissions depend on the engine operation (i.e. driving situation), exhaust emissions are calculated as a function of average speed and for three driving conditions: urban, rural and highway.

The COPERT methodology can be used to calculate a traffic emission inventory both with a top-down approach and with a bottom-up approach. For countries for which the required input data are not available at low level, it seems to be more appropriate to start at NUTS level 0 (national level) and to allocate emissions to other NUTS levels with the help of available surrogate data. For countries where the required input is available at smaller NUTS level (including for example traffic counting) it has been proposed to make use of this information and to apply a bottom-up approach, building the national total by summing up emissions from the smaller units. Application of the methodology at higher spatial resolution has to be done only when more detailed data are available from the user. Several input data in applying the methodology can obviously be only estimates and there is a certain degree of uncertainty in estimating these data.

The variables necessary to carry out the calculations are listed in Table I, together with their qualitative uncertainty [4]. The assignment of an initial value from scratch to each variable is difficult, however some of them are suggested by COPERT IV for each country, and others can be found in national transportation studies. Using these variables and the fuel consumption factors of each COPERT IV vehicle category the annual fuel consumption for gasoline, diesel and LPG is estimated. The software estimates the fuel consumption and its percentage difference from the actual consumption; if this difference isn't acceptable some soft variables should be modified. When a reliable result is obtained, all the "soft" variables used for this accepted estimate are used as an input to calculate the emissions using the COPERT IV emission factors.

III. The Road Transport Emission Inventory

A. The collection of the local data

In this study the COPERT methodology has been used with a bottom-up approach focusing at municipal level instead of national, then including local parameters relating to fleet, driving patterns, medium trips, average vehicle speed and the fuel consumption.

The collection of the necessary input data (registered vehicle, average mileage, average speed for vehicle category, etc.) to calculate the emissions in the Campania Region (Italy) has required the contribution of agencies and institutions:

- ISTAT (the Italian Institute of Statistics);
- The Ministry of Transport and Navigation [5];
- ISPRA (the Italian Institute for Environmental Protection and Research) [6];
- ACI (the Italian Automotive Association), that provides the number of registered vehicles and their composition [7];
- The Italian Association of Oil Companies, that reports the fuel sold in each province in annual oil market bulletins [8].

The base year of the emission inventory is 2011. According to the European Directive 98/70/EC fuels must have specific properties in order to protect human health, therefore the fuel typology used for the emission calculation is the Fuel 2009. Data about the number of vehicles regularly registered have been corrected through percentage reductions (suggested by ISPRA) to be applied to vehicles PRE EURO, necessary to represent vehicles actually circulating in Italy. The average length of a trip in Italy is 12 km, as suggested by COPERT. The values of others variables, such as the average speed on each road type and the percentage of mileage traveled on each of road type, have been obtained from ISPRA studies on transportation. The emissions due to cold starts were calculated considering minimum and maximum temperatures for each month in Campania Region.

TABLE I
Variable Needed to Carry out the Emission Estimations and their Uncertainties

Variable	Uncertainty
Actual fuel consumption	L
Traffic on linear sources	M
Annual average mileage for vehicle category	H
Percentage of mileage travelled on each road type	H
Average speed on each road type	H
Average length of a single trip	H
Average temperatures	L
Number of vehicles in each category	L

L = low uncertainty, indicating a variable obtained from continuous measurements; M = medium, indicating a variable obtained from measurements in specific periods extended to the whole year; H = high, indicating estimations

B. The results of the emission inventory

As a result of the elaboration of the acquired data, the composition of circulating vehicle fleet in Campania Region and the average mileage estimates in terms of kilometers covered by each vehicle category [Vehic*Km] for year 2011 are reported in Table II. The estimate of the average mileages, as well as the average speeds, has been validated at the end of the iterative procedure, when the error for the estimation of fuel consumption compared with the fuel sold in Campania Region was been considered acceptable.

As can be seen clearly, the most widespread vehicle category is represented by gasoline and Diesel passenger car. These vehicles are then distinguished (Table III) according to the EU Directives to which they conform. It has been found that in relation to the distribution of the total mileage for the gasoline passenger cars a reasonable percentage (about 5%) is still represented by EURO 0 vehicles, while in relation to the distribution of the registered vehicle the percentage is even higher (about 30%). Indeed in Campania, as in many other areas of southern Italy, the renewal of vehicle fleet is extremely slow compared to other Italian regions, with obvious repercussions on air quality. Instead in relation to diesel passenger cars, much more favorable results have been observed. This vehicle category is on average younger than the gasoline passenger cars, with around 47% of the total mileage represented by EURO 4 cars. Through these obtained results, all the "soft" variables used for this accepted estimate are used as an input to calculate the

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emissions using the COPERT IV emission factors.

Total emissions from road traffic in Campania for 2011 are summarized in Table IV. It is important to stress that the reported VOC emissions include evaporative emissions and that the PM emissions include brakes, tyres and road pavement wear. The emissions of CO, NO_x, VOC and PM_{10} are illustrated for each vehicle class in Fig. 1. Gasoline passenger cars contribute more than 46% to the total road traffic emissions of CO, and also the shares from motorcycles and mopeds are considerable (respectively 17% and 13%), as might be expected, since the combustion is incomplete due to lack of oxygen in engines powered by gasoline

About VOC emissions, again a considerable contribution is due to gasoline passenger cars (about 36%), also considering the share of evaporative emissions. The most significant result is the high percentage brought by mopeds, about 28%, despite that the average mileage estimates in terms of kilometers covered by this vehicle category (about 3%) turned out lower, compared to other categories (Tab. II). In fact, two-stroke gasoline engines equipped with carburetor, that characterize mostly old mopeds still circulating in Campania, produce a raised emission factor (about 13 g/km), justifying such results [9].

TABLE II
PERCENTAGE COMPOSITION OF REGISTERED AND CIRCULATING VEHICLE FLEET IN CAMPANIA REGION FOR YEAR 2011

Category	Vehicles	Vehicles [%]	10^6Vehic*Km	Vehic*Km [%]
Gasoline passenger cars	1797962	37,4	10609,8	27,1
Diesel passenger cars	1373837	28,6	18975,4	48,6
GPL passenger cars	187910	3,9	2090,7	5,3
Light duty vehicles	268754	5,6	2852,1	7,3
Heavy duty vehicles	81460	1,7	1673,5	4,3
Buses	10484	0,2	446,0	1,1
Mopeds	506617	10,5	1089,2	2,8
Motorcycles	577307	12,0	1346,3	3,4
Total	*4804331*	*100*	*39082,9*	*100*

TABLE III
PERCENTAGE COMPOSITION OF REGISTERED AND CIRCULATING GASOLINE AND DIESEL PASSENGER CARS ACCORDING TO THE EU DIRECTIVES IN CAMPANIA REGION FOR YEAR 2011

EU Directives	GPC [%]	GPC Veic*km [%]	DPC [%]	DPC Veic*km [%]
Euro 0	29,9	4,4	9,8	2,0
Euro 1	10,2	5,5	3,6	1,8
Euro 2	27,2	26,0	14,8	11,9
Euro 3	14,5	26,1	28,0	28,7
Euro 4	15,8	32,5	37,6	46,6
Euro 5	2,4	5,4	6,2	9,0

TABLE IV
ESTIMATED TOTAL EMISSIONS FROM ROAD TRAFFIC IN CAMPANIA REGION FOR YEAR 2011

Pollutant	Emissions (t/year)
CO	45817
NO_x	32466
VOC	9493
PM_{10}	2122

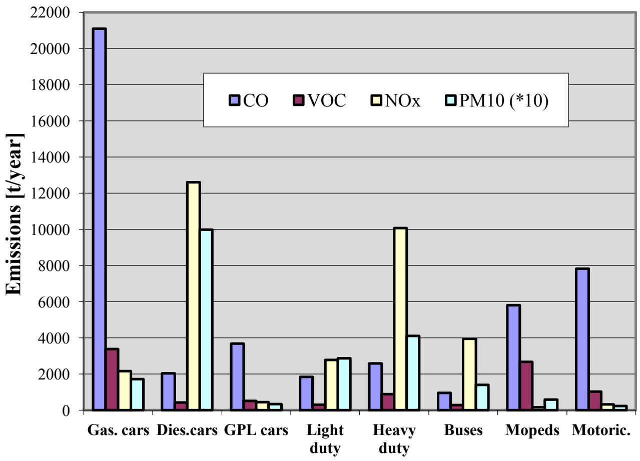

Fig. 1. CO, NO_x, VOC and PM_{10} total emissions in Campania in 2011 from different vehicle classes. (PM_{10} emission are multiplied by 10)

IV. EXPERIMENTAL ACTIVITY

A. The vehicles and the experimental apparatus

The experimental investigation was being performed by the Department of Industrial Engineering (DII) in order to characterize the emissive behaviour of 2-wheeler vehicles during different driving cycles in hot and cold conditions. In the experimental tests one moped and two motorcycles were employed; their technical characteristics are reported in Table V.

In the emission laboratory the motorcycles were tested on a chassis dynamometer (AVL Zollner 20" - single roller) that enables simulation of vehicle weights from small mopeds up to heavy two-wheel vehicles (range 80-450 kg) [10]. This bench is designed to simulate the road load, including vehicle inertia, and to measure the exhaust emissions during dynamic cycles. A variable speed cooling blower was positioned in front of the vehicles so as to direct the cooling air in a manner which simulates operating conditions. During the tests the exhaust gases were diluted with purified ambient air by a Mixing Unit connected to a Constant Volume Sampling with Critical Flow Venturi (AVL CFV-CVS) unit; a continuous sample flow of the mixture filled one or more bags so that concentrations (average test values) of CO, HC, NO_X and CO_2 were determined. Average test values and continuous diluted emissions were measured with an exhaust gas analysis system (AVL AMA 4000), according to the procedures laid down in the Directive 97/24/EC. Fig. 2 shows a scheme of the experimental apparatus, while Fig. 3 portrays the motorcycle *C* on the bench.

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TABLE V
TECHNICAL SPECIFICATIONS OF THE TESTED VEHICLES

Vehicle	*Vehicle A(Moped)*	*Vehicle B(Motorcycle)*	*Vehicle C(Motorcycle)*
Engine principle	4-stroke	4-stroke	4-stroke
Cubic capacity [cm^3]	50	244	982
Compression ratio	12:1	11.0:1	12.2:1
Power system	carburettor	electronic injection	electronic injection
Cooling system	air forced	liquid	liquid and oil
Max power [kw]	3.2@8250rpm	16.2@8250rpm	104@10900rpm
Maximum speed [km/h]	45	125	265
After-treatment system	catalytic conv.	catalytic conv.	catalytic conv.
Legislative category	Euro 2 (for mopeds)	Euro 3 (for motorcycles)	Euro 3 (for motorcycles)

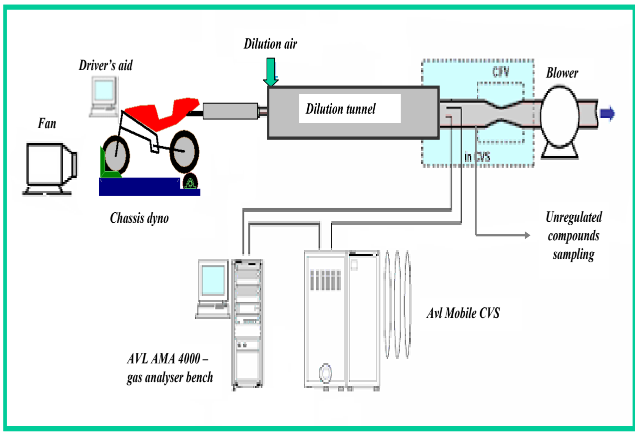

Fig. 2. The experimental apparatus

Fig. 3. The motorcycle *C* on the bench

B. Emissive behavior under real urban conditions

Mean emission factors from two-wheeler vehicles measured during the Type-Approval test cycles have been extensively documented, but not much is known about the emissions in real-world situations. It's evident that application of the Type-Approval driving cycle to motorcycles has the shortcoming of underestimating cycle dynamics. Consequently, such emission factors might not be sufficiently representative of real-world motorcycle riding, significantly different from the speed-time pattern of the test cycle on which they were measured. Besides, while there are many data published on emissions factors from motorcycles belonging to old standards approval, little is known about the emissions of new motorcycles in real-world situations. It is thus very interesting to assess the development of motorcycle emissions in these conditions.

For this purpose, measurements during real-world test cycles were therefore indispensable in order to evaluate motorcycle performance under real driving conditions. In this study three real urban driving cycles were considered: the WMTC, the Urban Cold, and the Road Cold.

Mean experimental emission factors of all driving cycles considered (for the three vehicles) are shown in Table VI, Table VII and in Table VIII [9,11,12]. The reported emission factors are calculated in thermally stabilized engine operation (hot), for the typical driving conditions: urban, rural and highway. These tables also show the COPERT emission factors, calculated as a function of speed values equal to the mean speeds of the considered cycles.

About mopeds, they are mostly driven under "urban" driving conditions and therefore only an urban emission factor value is proposed. For this vehicle category (Table VI) the COPERT emissions factors are pertinent only to the 2-stroke engine, while the tested vehicle is a 4-stroke moped. Moped experimental CO emission factors were greater than emission factors reported in COPERT, and measured HC emission factors were lower than COPERT values regarding emissions from 2-S engines that originate primarily from "scavenging losses".

With regard to motorcycles (Table VII, Table VIII), the COPERT emission factors provide CO and HC emission factors higher than those measured on two tested motorcycles in real-urban situations, for the effect of improved engines, in combination with very efficient catalytic technology used on the tested vehicles.

Since mopeds and motorcycles are mostly driven in residential areas, evaluation of their emissive behaviour should take into account the cold-start influence in assessing CO and HC emissions from this vehicle categories. Although COPERT methodology is lacking in data regarding the 2-wheeler cold-start emissions, the experimental activity examined this phenomenon, evaluating the differences between emissions measured during the cold-start and the hot phase of the type-approval driving cycles. Table IX shows for the tested vehicles the cold-start extra emission factors and the share of cold-start emissions in the type-approval driving cycle [13,14]. As evidenced in the Table IX, for newly sold 2-wheeler vehicles equipped with a catalytic converter and electronic mixture control, cold-start emissions represent an important proportion of total emissions, with an obvious repercussion on air quality.

TABLE VI
VEHICLE A EXPERIMENTAL EMISSION FACTORS AND *COPERT* DATA

Emission factors	CO		HC		NOx	
	Exper. data	Copert data	Exper. data	Copert data	Exper. data	Copert data
Urban [g/km]	4.11	1.15	0,74	1.42	0,21	0.24

TABLE VII
VEHICLE B EXPERIMENTAL EMISSION FACTORS AND *COPERT* DATA

Emission factors	CO		HC		NOx	
	Exper. data	Copert data	Exper. data	Copert data	Exper. data	Copert data
Urban [g/km]	1.63	2.26	0.07	0.34	0.08	0.21
Rural [g/km]	0.44	2.20	0.05	0.27	0.11	0.24
Highway [g/km]	1.55	3.09	0.06	0.27	0.19	0.31

TABLE VIII
VEHICLE C EXPERIMENTAL EMISSION FACTORS AND *COPERT* DATA

Emission factors	CO		HC		NOx	
	Exper. data	Copert data	Exper. data	Copert data	Exper. data	Copert data
Urban [g/km]	0.61	1.88	0.06	0.37	0.08	0.06
Rural [g/km]	0.22	1.06	0.01	0.20	0.09	0.06
Highway [g/km]	0.35	1.48	0.02	0.19	0.13	0.12

TABLE IX
INCIDENCE OF COLD-START EXTRA EMISSIONS FOR THE TESTED VEHICLES

Vehicle	Pollutant	Cold-start additional emission factors [g/km]	Share of cold-start emissions [%]
Vehicle A	CO	12.57	45.9
	HC	0.97	43.0
Vehicle B	CO	4.28	22.4
	HC	0.51	51.8
Vehicle C	CO	8.95	83.4
	HC	0.72	57.8

V. FINAL RESULTS AND CONCLUSIONS

Atmospheric emission inventories are fundamental tools for studying air quality and to set up possible remediation plans in areas characterized by nonattainment of the limit values established by legislation. In order to estimate the emissions from road transport in Campania (Italy), the COPERT model was employed with a bottom-up approach, focusing at regional level, then including local parameters.

The second aim of the study was to collect information on the emissions of in-use 2-wheeler during real driving conditions, due to high contribution to total emissions attributable to this vehicle category. CO, HC and NO_X emissions were evaluated in the exhaust of three 2-wheeler belonging to the last legislative category. Sampling was performed on a dynamometer bench on a type approval cycles and on real-world cycles, both during cold-start and hot phases.

By using emission factors measured in the activity test, afterwards the same COPERT algorithms estimated the emissions in Campania for the specific vehicle classes to which the tested vehicles belong. These results, summarized and shown in Table X, can be used to study future scenarios that include the impacts of the renewal of the vehicle fleet and of new traffic conditions. Therefore, such information is very helpful for prescribing mitigation measures, and designing and developing environmental management plans and monitoring programs to provide a healthier environment for future generations.

However, additional experimental investigations on other 2-wheel vehicles, belonging to other legislative categories (with different after-treatment systems and different technical specifications), will be indispensable. In this way, the output of the emission models will improve significantly and then the emission factors, so obtained, will be more representative of the general 2-wheel vehicles fleet under real driving conditions. The road transport emission inventories, in fact, must be considered as dynamic instruments since both updating of information as well as data reliability and details are in continuous evolution and improvement.

TABLE X
CO, NO_X AND VOC TOTAL EMISSIONS IN CAMPANIA IN 2011 FROM THE VEHICLE CLASSES EXAMINED IN THE EXPERIMENTAL ACTIVITY

Vehicle classes	CO [t/year]	VOC [t/year]	NOx [t/year]
Mopeds Euro II	2186.3	450.8	111.7
Motorcycles <250 cm³ Euro III	350.5	64.6	31.5
Motorcycles >750 cm³ Euro III	19.8	8.2	5.5

REFERENCES

[1] CORINAIR (1988), "European Inventory of emissions of pollutants into the atmosphere", Commission of the EC– CORINAIR project, DG XI, 30/3/1988
[2] Leon Ntziachristos, Zissis Samaras, "Methodology for the calculation of exhaust emissions", SNAPs 070100-070500, NFRs 1A3bi-iv.- EMEP/EEA (European Environment Agency) Emission inventory guidebook 2009, updated May 2012.
[3] D. Gkatzoflias, C. Kouridis, L. Ntziachristos, Z. Samaras, "COPERT 4 Computer programme to calculate emissions from road transport", http://www.emisia.com/copert/ - ETC-ACC (European Topic Centre on Air Air and Climate Change)
[4] Bellasio R, Bianconi R, Corda G, Cucca P (2006), "Emission inventory for the road transport sector in Sardinia" Atmospheric Environment 41 (2007) 677-691
[5] Ministero Dei Trasporti (2011): "Conto Nazionale dei Trasporti"
[6] ISPRA, "Trasporto su strada – Inventario nazionale delle emissioni e disaggregazione provinciale", © ISPRA, Rapporti 124/2010, ISBN 978-88-448-0466-4
[7] ACI "Annuario Statistico - Automobilismo e Trasporti", Ufficio Statistica, Roma, 2011
[8] Ministero dell'Industria - "Bollettino Petrolifero – vari anni"
[9] P. Iodice, "Metodologie teorico-sperimentali per la determinazione del comportamento emissivo dei motoveicoli e per la valutazione dell'impatto dei trasporti stradali sui valori di qualità dell'aria", Tesi di Dottorato - Dottorato di Ricerca in Ingegneria dei Sistemi Meccanici – XXII Ciclo
[10] S. Pagano, R. Russo, S. Strano, M. Terzo, "Modelling and Control of a Hydraulically Actuated Shaking Table Employed for Vibration Absorber Testing" (ESDA2012-82118), in *Proc. of the ASME 11th Biennial Conference on Engineering Systems Design and Analysis (ESDA2012)*, vol. 1, pp. 651 – 660, 2012.
[11] P. Iodice and A. Senatore, "Analysis of a Scooter Emission Behavior in Cold and Hot Conditions: Modelling and Experimental Investigations", SAE Technical Paper 2012-01-0881, 2012, doi:10.4271/2012-01-0881, Emissions Measurement and Testing, ISSN 0148-7191, ISBN: 978-0-7680-7607-3 - SAE 2012 World Congress & Exhibition
[12] P. Iodice, M. V. Prati and A. Senatore, "Emissive behaviour of two-wheeler vehicle category. Methodologies and results", Urban Environment, Springer; Series: "Alliance for Global Sustainability Bookseries", Vol. 19 (2012), X, 448 p., ISSN: 1571-4780, ISBN: 978-94-007-2539-3, DOI: 10.1007/978-94-007-2540-9_17, © Springer Science+Business Media B.V. 2012
[13] P. Iodice, A. Senatore, G. Meccariello and M. V. Prati, "Methodology for the analysis of a 4-stroke moped emission behaviour", SAE International Journal of Engines, March 2010, vol. 2 no. 2, pages 617-626, ISSN 1946-3936, DOI: 10.4271/2009-24-0142
[14] P. Iodice, M. V. Prati and A. Senatore, "A calculation procedure for the evaluation of cold emissive behavior of high-performance motorcycles", SAE Technical Paper 2011-24-0200, 2011, ISSN: 0148-7191, doi:10.4271/2011-24-0200 - 10° SAE ICE Conference