

# Comparison of the emission factors measured in real world driving with those of COPERT 4

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## Abstract

The aim of the paper is to compare CO, HC, NO<sub>x</sub>, PM and greenhouse gas emissions for different urban buses regarding the Euro standard. Three buses were tested, two of them covering the range from Euro III to Euro IV emissions standards, and another one meeting the EEV standard. On-board emission measurements in urban buses were conducted in real world driving routes, operated by the Madrid Municipal Transport Company (EMT), in the city of Madrid. Therefore, the paper examines the real-world efficiency of the emission control technologies conducting tests under real-world driving cycles. It also shows a comparison in emissions and fuel consumption regarding the type of fuel used. The fuels analyzed are diesel and Compressed Natural Gas (CNG). Finally, the test results obtained directly from the on-board measurements were compared with those results obtained from the application of the COPERT model and another model developed by INSIA to estimate the fuel consumption and pollutant emissions generated by the urban bus fleet of Madrid.

*Keywords:* on road measurements, emission factors, urban buses.

## 1 Introduction

On road emissions from urban traffic are one of the major environmental problems in large European capitals. In the city of Madrid, and according to the inventories published by the City Council (MCC [1]), road transport is responsible for over 50% of CO<sub>2</sub> emissions, 75% of NO<sub>x</sub> emissions, 90% of CO emissions, and 30% of the emissions from Volatile Organic Compounds (VOC).

Emissions standards for vehicles have included significant emission reduction for many pollutants. Engines from Heavy Duty vehicles are also subject to strict



controls. Global emission limits for mobile heavy-duty diesel engines are becoming increasingly stringent. Due to growing concerns about NO<sub>x</sub> and particulate matter (PM) emissions from diesel engines, stricter regulations are being implemented which require advanced emission control technologies. In response to this trend, diesel vehicle manufacturers have been testing and applying various emission control technologies to mobile applications.

Currently, with regard to the fuel used, the only viable solution for diesel substitution is the Fatty Acid Methyl Esters (FAME), commonly known as biodiesel. Compared to fossil diesel, it is biodegradable and its combustion reduces the most harmful exhaust emissions, including carbon monoxide, unburned hydrocarbon, and particulate matter. However, several approaches showed that the use of biodiesel does not reduce nitrogen oxides emissions (Lopez *et al.* [2], Canakci *et al.* [3], Tzirakis *et al.* [4]).

## 2 Methodology

Although chassis dynamometer drive cycles exist for heavy duty vehicles (Nylund *et al.* [5]), on-road tests are being used to evaluate the development of exhaust after-treatment system under real-world operating conditions in the vehicle (Pelkmans and Debal [6], Frey *et al.* [7]). In this paper, two driving cycles were conducted to evaluate emissions and fuel consumption over conventional urban buses with on-board measurement equipments.

Five tests were run for each vehicle. The five sets of readings were statistically analyzed to assess the validity of the results. Emission data usually vary from test to test, due to the variation in driver performance, external conditions, and engine and after-treatment temperatures.

Test results were compared with the results obtained by applying two different emission models. The first one is the COPERT model (Gkatzoflias *et al.* [8]), the reference model used in Europe (EEA [9]). It was applied for the different Euro buses with a similar driving cycle to the real world conditions regarding speed and distance travelled.

The second model was developed by INSIA (Lopez *et al.* [10]) and allows the estimation of fuel consumption and emissions generated by the urban bus fleet of Madrid. It has been calibrated with on-board emission measurements conducted in real-world driving routes operated by the Madrid Municipal Transport Company (EMT). This model requires a given distance-speed profile. To obtain this input, on-board experimental tests were realized in 8 buses, covering the range from Euro II to Euro IV and EEV (2 buses of each Euro standard). Their behaviour was evaluated taking into account the load, fuel, slope and speed in real operating conditions. Driving cycles were 3 specific driving routes in the city of Madrid, selected in accordance with the EMT in terms of representation and variability (figure 1).

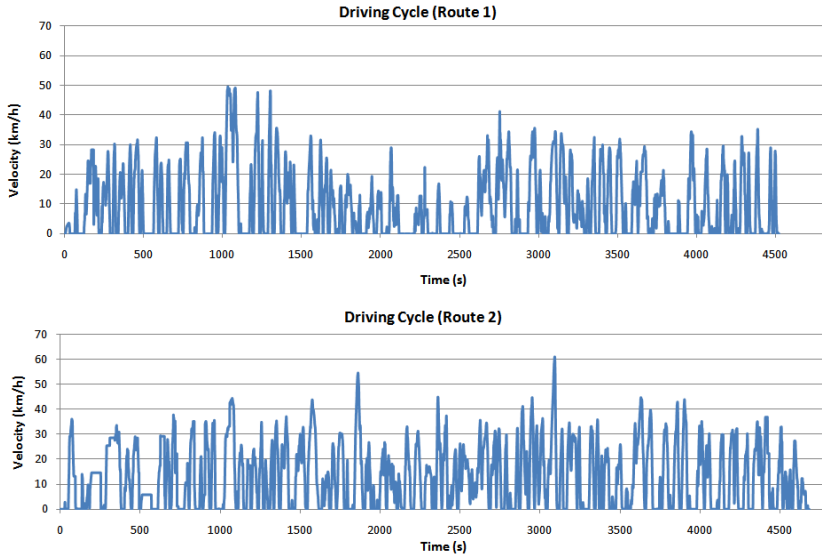


Figure 1: Driving cycles.

## 2.1 Experimental setup

Three urban buses were employed in this study. They were classified in the following groups according to similar behaviour depending on its treatment system (Euro emissions standard) and fuel used:

- Buses with Euro III standard and diesel.
- Buses Euro IV standar and diesel.
- Buses EEV standard and natural gas.

Since there were buses from different manufacturers the most representative were selected. Table 1 shows the technical specifications of the tested vehicles.

Table 1: Technical specifications for test vehicles.

	Vehicle 2	Vehicle 3	Vehicle 4
<b>Euro standard</b>	Euro III	Euro IV	EEV
<b>Come into service</b>	2002	2008	2008
<b>Power (kW)</b>	213	199	228
<b>Cylinders / Displacement</b>	6 / 7,790	6 / 10,518	6 / 11,967
<b>Weight (kg)</b>	12,300	12,180	19,000
<b>Weight / Power</b>	57.75	61.21	83.33
<b>Representativeness (%2009 urban fleet)</b>	42.7%	25.0%	13.8%
<b>Representativeness (%2008 urban fleet)</b>	43.7%	24.5%	16.3%

The experimental tests were conducted along two urban driving routes operated by the Municipal Transport Company (EMT). In both cases, the test procedure consisted of following another EMT bus during working hours and making each bus trip several times a day, on different days at the same hour and with the same driver. The main features of the two driving cycles are described in Table 2.

Table 2: Features of the driving cycles routes.

	Distance (km)	Average Speed	N° bus stops
Route 1	11.9	10.2	38
Route 2	17.3	13.3	64

## 2.2 Measurement equipments

Exhaust emissions have been measured using the Horiba OBS 2200 on board emission measurement system. It measure instantaneous emissions under real driving conditions for CO, CO<sub>2</sub>, THC and NO<sub>x</sub>, fuel consumption and speed. It provides real mass emission results (g/s) and instantaneous emissions (expressed as a % or rpm, depending on the gas involved). The analyzers are:

- Multiple CO, CO<sub>2</sub> and H<sub>2</sub>O analyzer based on the Heated Non-Dispersive Infra-Red method (HNDIR).
- THC analyzer based on the Heated Flame Ionization Detection method (HFID).
- NO<sub>x</sub> analyzer based on the Heated Chemiluminescent Detection method (HCLD).

The equipment also incorporates an exhaust gas flow meter that includes a calibrated pipe with its Pitot tubes, the sample gas outlet and the temperature sensor, as can be seen in figure 2.



Figure 2: Exhaust gas flow meter with its Pitot tubes.

By using the carbon balance method, fuel consumption can be very accurately determined from mass emissions of CO, CO<sub>2</sub> and THC.

The equipment also includes sensors to measure humidity and ambient temperature and a GPS system for measuring speed and position. This speed

measurement has been verified using a Correvit L-CE-non-contact speed sensor finding a deviation lower than 1 km/h.

An EIU (External Input Unit) is also integrated with free analog sports to connect other equipments that allow the connection of a particle measurement device. This device is the MAHA DPMS-04, and provides particle concentration in  $\text{mg}/\text{m}^3$  by laser technology, that can be expressed in  $\text{g}/\text{s}$ . Figure 3 shows an example of the installation of the measurement equipments inside a bus.

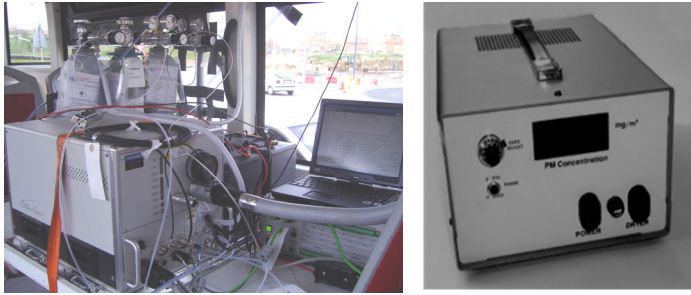


Figure 3: Installation of the measurement equipments: HORIBA OBS 2200 (left) and MAHA DPMS 04 (right).

### 3 Results

Results for CO, HC, NO<sub>x</sub>, PM and CO<sub>2</sub> emissions and fuel consumption for each driving cycle were obtained from three types of engine with two different fuels (diesel and GNC). PM emissions from natural gas vehicles have not been measured because MAHA devices are only applicable to diesel vehicles.

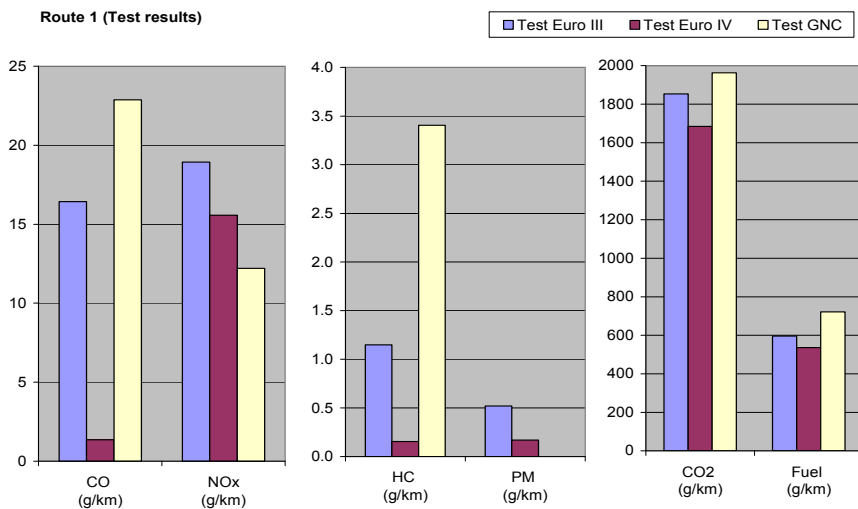


Figure 4: Results of on-board measurement tests (route 1).

Figures 4 to 7 show the comparative results obtained for route 1, and figures 8 to 11 show those obtained for route 2. In both cases, the average results from on-board measurements were compared with corresponding emission factors derived from COPERT 4 calculations for urban, hot stabilized conditions and average speed of 10.2 km/h (route 1) and 13.3 km/h (route 2). It can be shown that results estimated by the model developed by INSIA are consistent with the results obtained from the measurements tests.

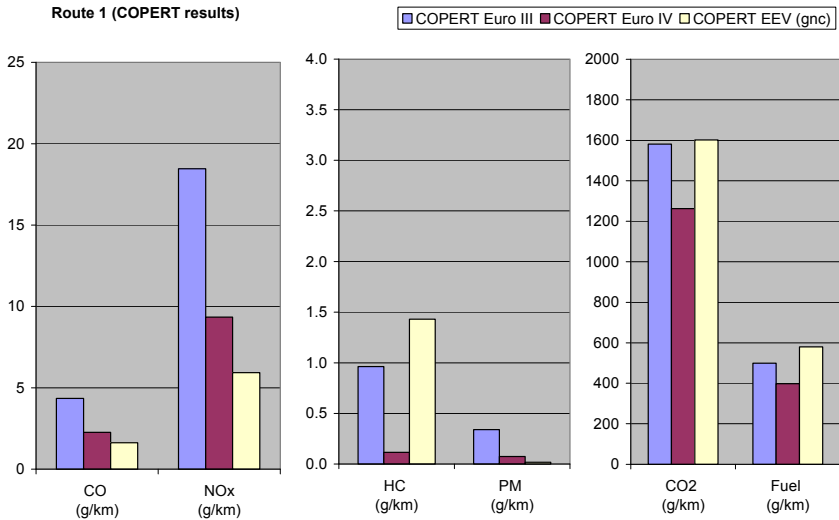


Figure 5: Results by applying the COPERT model (route 1).

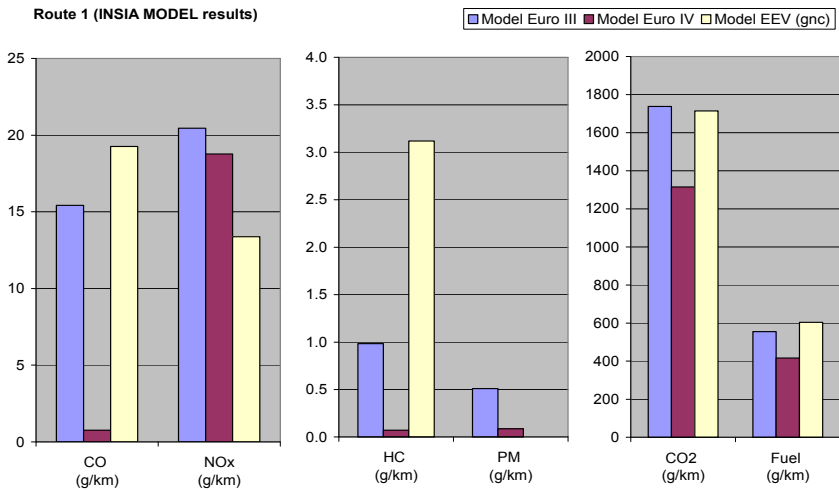


Figure 6: Results by applying the model developed by INSIA (route 1).

**Carbon monoxide (CO):** CO emissions are reduced from Euro III to Euro IV standard vehicle. This reduction is directly related to the introduction of exhaust after-treatment systems. For natural gas vehicles, results are higher mainly due to the work of the spark ignition engine with stoichiometric mixture and in transient conditions most of the driving cycle.

**Nitrogen oxides (NOx):** NOx emissions are also reduced from Euro III to Euro IV standard vehicle, which is related to the exhaust after-treatment systems. Values with natural gas engines have a lower value.

**Unburned Hydrocarbons (HC):** HC emissions are also reduced due to the introduction of exhaust after-treatment systems. For natural gas vehicles, the values of HC emission are higher for being a spark ignition engine with stoichiometric mixture. These emissions are primarily methane.

**Particulate Matter (PM):** PM emissions have the same trend. The reduction is also directly related to the improvements in exhaust after-treatment systems. For natural gas values are not shown because the measurement device cannot be applied to this kind of engines. However, PM concentrations are much lower and caused by the combustion of oil dilution.

**Fuel consumption and CO<sub>2</sub>:** It is observed a reduction of fuel consumption and CO<sub>2</sub> emissions in Euro IV standard vehicles respect to Euro III standard vehicles, despite the increase of exhaust back pressure as a result of after-treatment systems installed in the exhaust pipe. Natural gas vehicles gave higher fuel consumption due to its lower volumetric efficiency, quantitative load regulation, very unfavorable in urban traffic, and stoichiometric mixture.

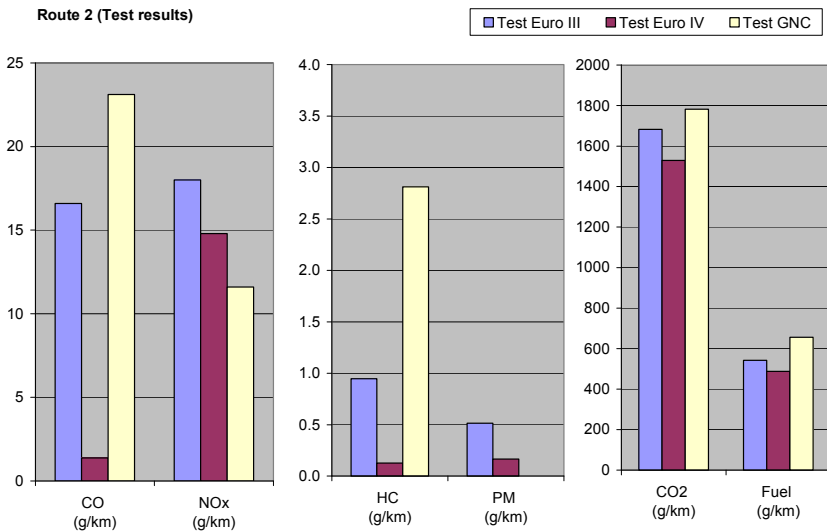


Figure 7: Results of on-board measurement tests (route 2).

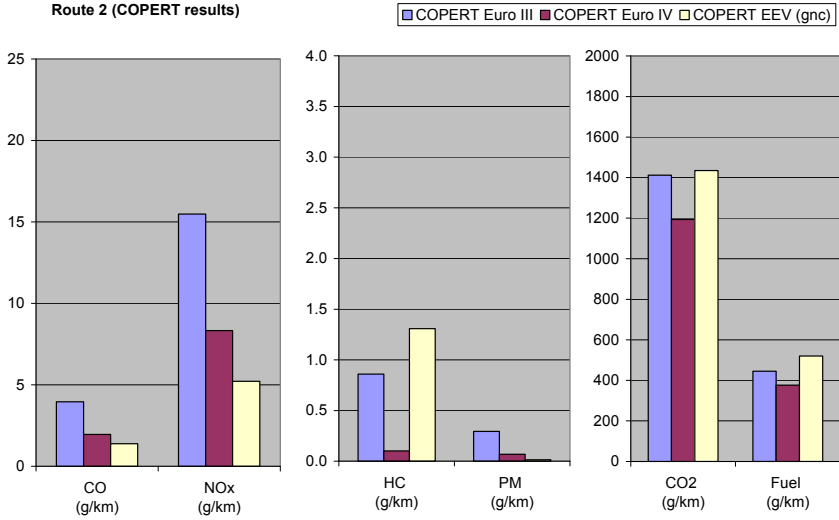


Figure 8: Results by applying the COPERT model (route 2).

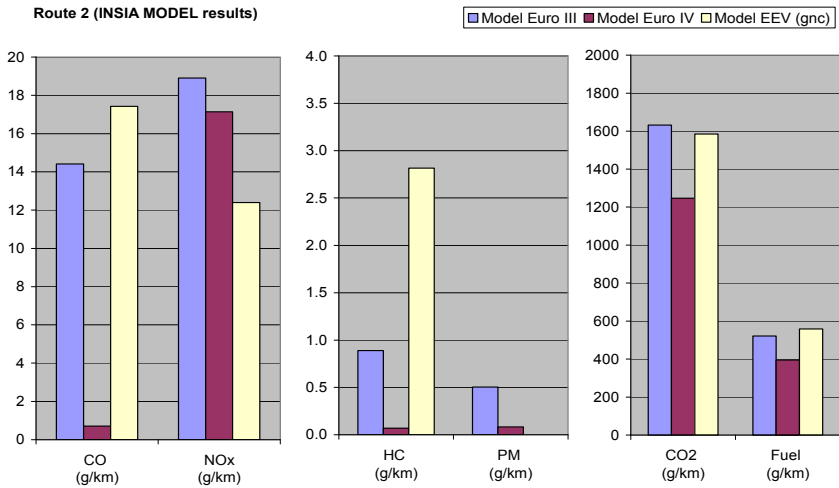


Figure 9: Results by applying the model developed by INSIA (route 2).

Table 3 shows the comparison between results obtained from the experimental test, COPERT model and the model developed by INSIA.

### 4 Conclusions

The aim of the paper is to compare CO, HC, NOx, PM and greenhouse gas emissions for different urban buses regarding the Euro standard. Three buses



Table 3: Emission and fuel consumption results in g/km.

	<b>CO<sub>2</sub></b> <b>(g/km)</b>	<b>CO</b> <b>(g/km)</b>	<b>HC</b> <b>(g/km)</b>	<b>NO<sub>x</sub></b> <b>(g/km)</b>	<b>PM</b> <b>(g/km)</b>	<b>Fuel</b> <b>(g/km)</b>
<b>TEST RESULTS</b>						
<b>Route 1</b>						
Euro II	1695.13	23.71	0.61	16.10	0.32	548.94
Euro III	1852.76	16.43	1.15	18.93	0.52	596.22
Euro IV	1683.77	1.36	0.15	15.56	0.17	536.34
GNC	1962.11	22.87	3.41	12.20	-	721.30
<b>Route 2</b>						
Euro II	1539.43	23.96	0.50	15.31	0.31	499.30
Euro III	1682.58	16.60	0.95	18.00	0.51	542.30
Euro IV	1529.12	1.37	0.13	14.80	0.17	487.84
GNC	1781.89	23.11	2.81	11.60	0.00	656.08
<b>COPERT 4 RESULTS</b>						
<b>Route 1</b>						
Euro II	1497.98	4.22	1.12	17.49	0.31	472.63
Euro III	1580.62	4.35	0.96	18.46	0.34	498.70
Euro IV	1262.29	2.26	0.11	9.34	0.07	398.26
GNC	1602.15	1.62	1.43	5.93	0.02	580.35
<b>Route 2</b>						
Euro II	1340.02	3.72	0.98	15.51	0.27	422.79
Euro III	1412.63	3.97	0.86	15.48	0.29	445.70
Euro IV	1193.33	1.96	0.10	8.33	0.07	376.51
GNC	1435.16	1.39	1.31	5.22	0.01	519.86
<b>MODEL RESULTS developed by INSIA</b>						
<b>Route 1</b>						
Euro II	1405.14	15.41	0.38	15.65	0.16	454.42
Euro III	1737.60	15.42	0.99	20.45	0.51	555.49
Euro IV	1314.81	0.76	0.07	18.77	0.09	416.46
GNC	1713.99	19.26	3.12	13.38	0.00	604.21
<b>Route 2</b>						
Euro II	1318.94	14.68	0.34	14.54	0.15	426.41
Euro III	1631.55	14.41	0.89	18.90	0.50	521.52
Euro IV	1246.53	0.71	0.07	17.14	0.08	394.83
GNC	1584.24	17.42	2.82	12.40	-	558.04

were tested, two of them covering the range from Euro III to Euro IV emissions standards, and another one meeting the EEV standard.

Test results show a similar trend for HC, NO<sub>x</sub>, PM, CO<sub>2</sub> and fuel consumption for the technology classes (from Euro III to Euro IV, and EEV). In this respect, there was a good agreement between the two methods, although values given by COPERT were systematically lower than those from

experimental tests (as in Ekström *et al.* [11]). Despite this good agreement, the largest discrepancies were found in natural gas vehicles, especially in CO and HC emissions, but also in NO<sub>x</sub> emissions.

As for CO emissions, the agreement was less favorable, being overestimated by experimental tests. This trend was found in all technologies classes except in Euro 4 standard bus. This difference may be due to the dispersion of this pollutant in these engines. Therefore, it is necessary to analyze the methodology used in the INSIA model for estimating CO emissions in order to study in greater depth the spread and variability of this component in test measurements.

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