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ORIGINAL PAPER

Drive-style emissions testing on the latest two Honda hybrid technologies

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Abstract
Introduction Hybrid technology is seen by many as a potential solution to reduce vehicle emissions in cities. However type approval tests of hybrid vehicles measure emission levels comparable to those of conventional cars in the same market segment. It has been argued that type approval tests do not represent the reality of emission in cities therefore, to quantify the real emission of hybrids and to compare them with those of conventional vehicles in the same conditions, an emission measurement campaign was organised.
Acquisition campaign Three Honda cars, one conventional (the Civic 2.0) and two hybrids (the Civic IMA and the Civic Hybrid), equipped to collect emissions as well as the engine and vehicle working parameters were driven three times by twenty drivers on the same urban route. Drivers were asked to drive normally and not requested to do anything special but to scrupulously follow the given itinerary.
Results Two main results were obtained: average and maximum emission levels for the three cars are quantified; the effects of the drivers on such levels assessed. The conventional car (with two people and 250 kg of measurement tools onboard) consumes an average of 12.6 l/100 km, its CO2 emissions range between 200 g/km and 300 g/km with an average of 260 g/km. CO emissions range between 0.25 g/km and 6.25 g/km (Euro IV limit is 1 g/km) with an average of 2 g/km. The most recent of the two tested hybrids consume in average 8.23 l/100 km and emits between 150 and 230 g/km of CO2 with an average of about 180 g/km; it emits virtually no CO in the majority of cases but can reach up to 1.8 g/km and average CO emissions are about 0.2 g/km. The hybrid performs always better than the conventional; in terms of CO2 and consumption it can have up to a 30% reduction and in terms of CO up to 90% reduction.
Conclusions The wideness of the measured ranges depends mostly on the drivers. Women tend to consume and emit less than men. The reason for this is the different way they use the accelerator pedal; they push it less and keep it steadier. In other word the standard deviation of the accelerator position (or throttle) is lower. It is here shown how a correlation exist between the throttle standard deviation and the emissions which justify using such parameter as the indicator of drive-style.

Keywords Hybrids · Onroad emissions measurement · Driving style

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1 Introduction

Over last 10 years hybrid technology reached the necessary maturity to be introduced successfully in the passenger car market. At the end of year 2008 the total number of hybrid cars sold exceeded one million.

Hybrids are seen as intrinsically clean vehicles to save fuel and emissions. To measure whether hybrids do consume and emit less than conventional vehicles several research works have been made. Most of them compare hybrid and conventional powertrains by testing them on the type-approval-procedure-driving-cycles. European type approval tests (on the NEDC—New European Driving Cycle) of hybrid vehicles measure emission levels of the same magnitude of conventional cars in the same market segment; emitting and consuming slightly less but far from the promised halving of consumption and elimination of emissions [1, 2]. It has been argued [1] that type approval tests do not represent the reality of emission in cities and therefore such results do not quantify the real benefits a hybrid vehicle can give.

Other studies measured hybrid performances on dynamometer chassis or on more realistic driving cycles [2, 3]. In that cases better performances than conventional vehicles were observed but could not be used to quantify real benefits of using hybrids.

Simulations and calculations to compare alternative solutions as plug-in [5] or to perform economical and environmental comparison between conventional, electric, hybrid and fuel cell vehicles [4] have been also made.

It is the objective of this paper to make a first step in the direction of quantifying the benefits deriving from substituting conventional vehicles with hybrids in cities and whether such advantages are independent on other external factors such as road, traffic and driver. The paper compares hybrid and conventional vehicles in real urban use and assesses whether and how much drive style influences consumption and emissions. The bases of this work are the experimental campaigns made in October 2006 by the Research Centre for Transport and Logistics of Sapienza University of Rome in the framework of a research agreement with Honda Italia.

The paper presents the acquisition campaign first (Section 2), introducing the three Honda vehicles tested, the data collection tools used and the method for selecting itinerary and drivers. The results obtained for the three vehicles are then compared in Section 3 and finally Section 4 analyses the driver effect on the emissions.

2 Data collection tools and campaigns

2.1 The vehicles tested

Three Honda Civic were tested:

- an Euro IV 2 litres displacement conventional spark ignition, the 2000;
- the Euro III hybrid, the IMA; and
- the Euro IV hybrid, named Hybrid.

The specifications of the three vehicles are reported in Table 1.

The three vehicles were all less than a year old and at the moment of the campaign had less than 10,000 km mileage.

Several tests on a dynamometer chassis were performed on the three vehicles to reproduce the type approval procedures and verify if the emissions standard were respected. The same tests were also used to validate the accuracy of the data collected through the (E)OBD (European On Board Diagnostic) connector by CTL tool described in the next section.

2.2 Data collection tools

Two tools were used to collect data from the vehicles: one, developed by CTL, to collect vehicle data from its control system [2]; the other, the Horiba OBS (On-Board System) 1300, to measure pollution.

The CTL tool [2] communicates with the engine ECU (Electronic Control Unit) of last vehicle generation (gasoline cars homologated in Europe since 2001 and Diesel ones since 2003) through the (E)OBD (European On Board Diagnostic) diagnostic connector and with every CAN (Controller Area Network) BUS equipped vehicle. The tool used for IMA and 2000 is exactly the one described in [6] and collects up to 5 engine and vehicle working parameters contemporary with a sampling frequency of 1 Hz; while for Hybrid the tool was updated to the CAN communication protocol and was able to collect any available parameters at 5 Hz sampling rate. In addition to the data collected from the (E)OBD connector, a GPS receiver contemporarily

Table 1 Specifications of the three examined vehicles

Technical specs[a]	Honda Civic IMA	Honda Civic 2.0	Honda Civic Hybrid
Displacement [cc]	1339	1998	1339
Thermal Engine max Power [kW]	63 @5,700 Rpm	118 @6500 Rpm	70 @6,000 Rpm
Electrical Engine max Power [kW]	6.5 @1,000 Rpm		15 @ 2,000 Rpm
Gearbox	Manual	Manual	CVT (automatic)
Weight [kg]	1190	1264	1324
Consumption 99/100/CE [l/100 km]	4.9	7.8	4.6
CO_2 99/100/CE [g/km]	116	185	109
Emission standard	Euro 3	Euro 4	Euro 4

[a] This are the official data declared by Honda

reads the position every second and through map-matching in the post-processing procedure all data are associated with the road links.

In parallel the Horiba OBS analyzer allow to measure CO_2, CO, HC and NO_x emissions with the sampling rate set to 2 Hz.

By contemporarily using CTL and Horiba tools it was possible to assess how the engine functioning conditions and the specific driver behaviour influenced both fuel consumption and instantaneous emissions.

The weight of the tools installed onboard was 250 kg, therefore not negligible. This is a bias for the measurements but it is the same for the three tested vehicles. The weight of people and tools on board (one driver, one measurement technician and 250 kg of tools) configure the tested vehicles as fully loaded.

2.3 Testing route

In order to characterize the driving style during the real world usage of the vehicles, measurements were made on a given urban itinerary in Rome. The itinerary was selected around the Engineering faculty of the University of Rome, in order to facilitate recharging and calibration of the

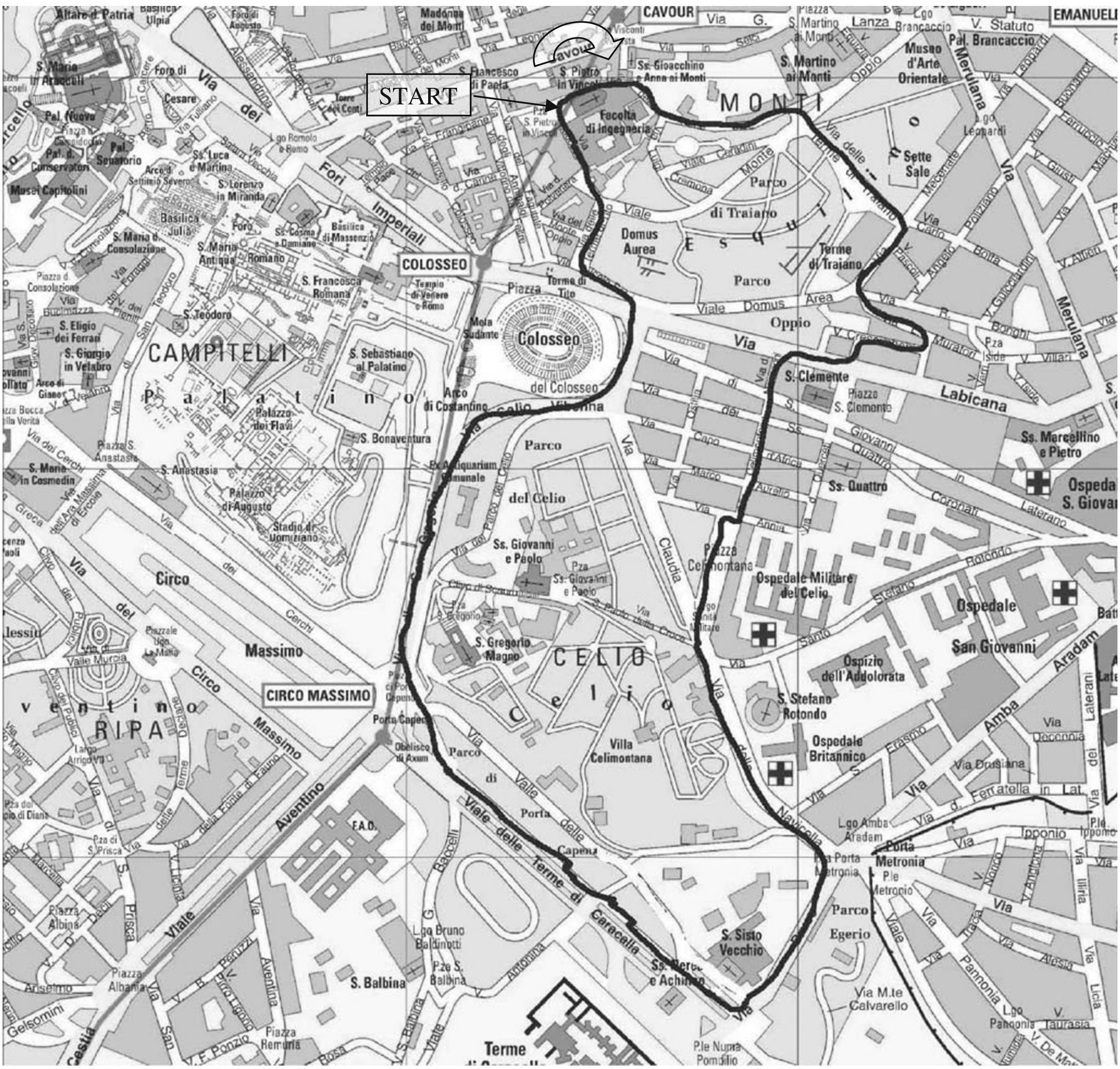


Fig. 1 Testing route map

Horiba tools, being this necessary three times a day. The itinerary is shown in Fig. 1.

The total itinerary is 4.6 km long and well represents of an average urban trip, being constituted by a mix of main and minor roads with an alternation of slopes (downhill and uphill) starting and ending at the same geodetic altitude.

For analyses purposes data were aggregated by "mission"; where mission is a trip on the given itinerary. Each time any car was driven by any driver for the full itinerary data for one mission where gathered.

All missions were driven in weekdays on two off-peak hours (10.30–12.30 morning and 14.30 16.30 afternoon).

The average speed of all the missions is 18.3 km/h with a standard deviation is 2.1 km/h. Despite no traffic measurement have been done nor measures to control traffic adopted no big differences in traffic have been observed during tests. It is left however to future investigations to quantify the relevance of traffic on the emissions and which is the combined effect of driver and traffic.

2.4 Selection of the drivers sample

The drivers sample for Hybrid has been selected through the following approach. The population has been divided in two categories (men and women) and again in 2 (over and under 30 years old, as the insurance companies do). The 4 obtained categories have been represented by five drivers each for a total of 20 drivers and 60 missions (three missions each). For technical reasons the acquisitions of two drivers were considered invalid, thus at the end the same route was used for each test with the Hybrid by 18 drivers (nine women, nine men). Although such a sample is not fully representative of the drivers population, it allowed to carry out a differentiate analysis among men and women. On the other hand age group analyses were not performed because, despite half of the drivers were over 30 and half under, all where between 25 and 45 and the sample did not represent correctly age distribution.

The acquisitions made with the two other vehicles (IMA and 2000) had not the same structured samples therefore a similar gender analysis was not performed.

3 Energy-emission comparison

Each mission has its fuel consumption and emissions of CO_2, CO and NO_x. Such measured values differ significantly from mission to mission. To compare consumption and emission levels of the three vehicles it was therefore necessary to compare the relative frequency distributions. Figures 2, 3 and 4 are the relative frequency distribution charts respectively of CO_2, CO and NO_x for the three vehicles. A chart for fuel consumption was omitted as it is substantially overlapping with the CO_2 one.

The measured average consumptions are: 8.23 l/100 km for Hybrid, 9.95 l/100 km for IMA and 12.66 l/100 km for 2000. The averages consumption of IMA and 2000 are different from Hybrid's one with a statistical significance (measured doing the t-Student tests) higher than 99%; while the measured average consumptions of IMA and 2000 differ with a statistical significance of 92%. In percent IMA consumes 21% more fuel than Hybrid, and 2000 54% more than Hybrid. Such differences show how hybrid vehicles tend to consume less than conventional vehicles and Hybrid, the hybrid vehicle of the latest generation which features a more powerful electric motor and a continuously variable transmission, performs better than older IMA.

CO_2 emissions, being closely related to fuel consumption show similar percent and statistical results. Figure 2 is the relative frequency distribution chart of CO_2 [g/km]. The chart shows how the three frequency distributions overlap

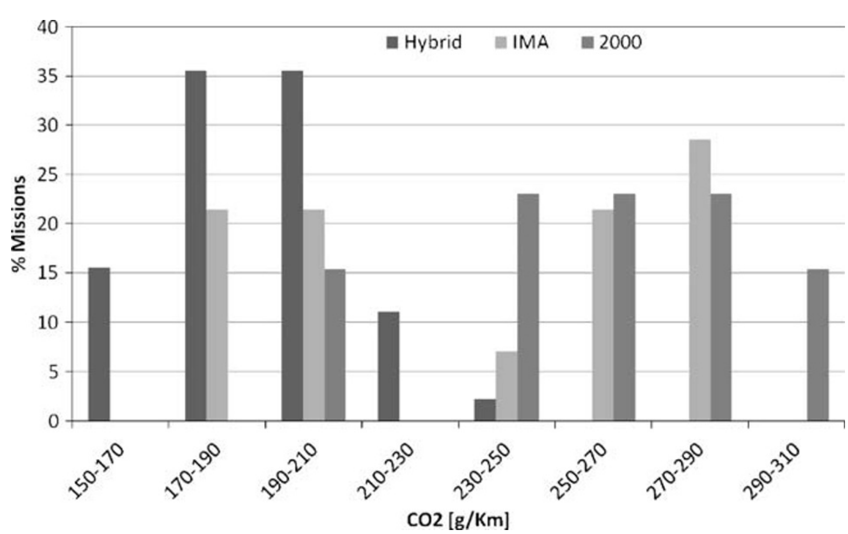


Fig. 2 Comparison of CO_2 emissions [g/km] of the three cars: Hybrid, IMA and 2000

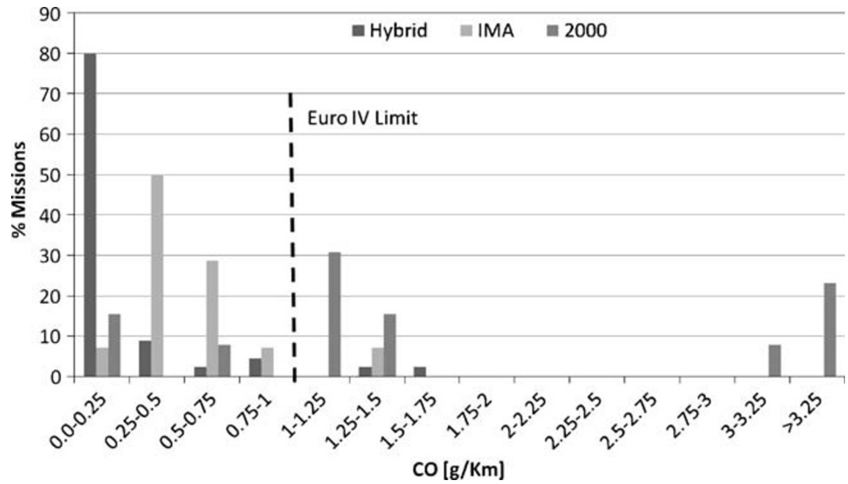


Fig. 3 Comparison of CO emissions [g/km] of the three cars: Hybrid, IMA and 2000 (EURO 4 limit 1.0 [g/km])

despite Hybrid emits on average less CO_2 than the other two vehicles. In other words there are situations in which one of the two vehicles emitting (and consuming) more than Hybrid on average emits (and consumes) the same or less. This means that there are other things, beside the vehicles, which have an influence on the mission CO_2 emission (and fuel consumption). Three factors, beside the vehicles, can have an influence: road, driver and traffic. However the missions were all on the same itinerary and in off-peek traffic periods, as explained in Section 2, and the only reaming factor is driving style. Section 4 of this paper deals with drive-style relevance on emissions. Another interesting fact emerges looking at Fig. 2: the relative frequency distribution of IMA CO_2 emission is divided in two main zones one between 170 g/km and 210 g/km and the other between 250 g/km and 290 g/km. The first zone is in the range of Hybrid results and the other nearer to the 2000. IMA is a hybrid vehicle but has a manual gearbox and the control system does not have the same degrees of freedom to optimise engine and motor performances as in Hybrid. No further conclusions can be drawn at this stage from this fact but it would be interesting, in future further investigations, to check whether this peculiar form of the frequency distribution chart might be caused by driving style too.

Figure 3 is the relative frequency distribution chart of CO [g/km]. Both Hybrid and IMA have CO emission almost always under the EURO 4 limit (more than 90% of the missions for both). Two thousand results show two peaks, one just above the limit and the other in the right end of the chart for emission levels three times higher than the limit. The average CO emissions of the three cars are respectively 0.194 g/km, 0.529 g/km and 1.951 g/km and are all different with statistical significance over 99%. It is striking to notice how 2000 emits ten times more CO than Hybrid and nearly four times more than IMA on average. However it is even more important to see how huge differences can exist between the lowest and the highest CO emission missions of each car. The highest CO emission measured for the 2000 is 6.33 g/km and the lowest 0.23 g/km (25 times) and a similar spread, though on lower figures, was measured for Hybrid: maximum 1.526 g/km and minimum 0.009 g/km. Such spreads show how if the driving style is of

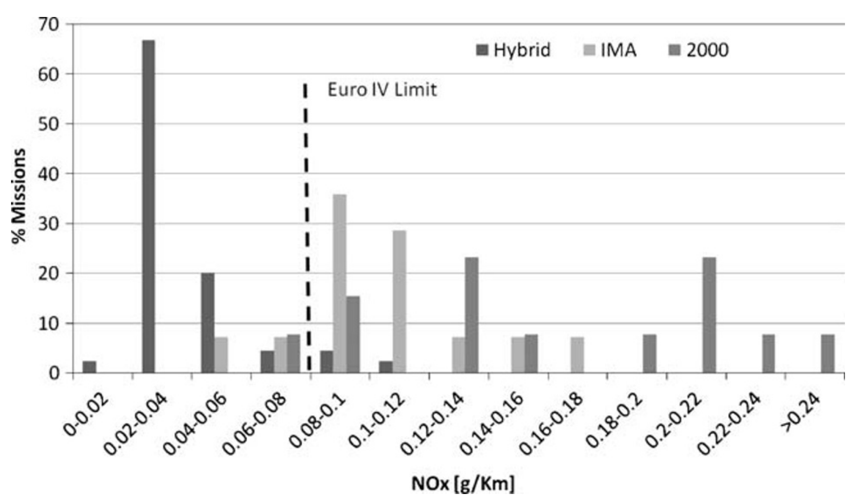


Fig. 4 Comparison of NO_x emissions [g/km] of the three cars Hybrid, IMA and 2000 (EURO 4 limit 0.08 [g/km])

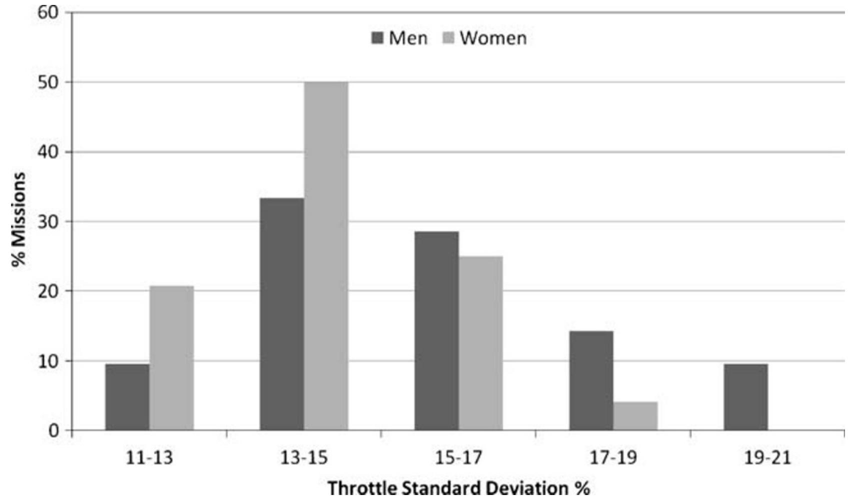


Fig. 5 Throttle Standard deviation % values for men and women for the 3 vehicles tested

importance consumption and CO_2 wise it is of even greater importance for CO emission. Most CO emissions are produced because the air-fuel mixture is not stoichiometric: at cold start (not included in these tests) at full load and in transient conditions [1]. Hybrid has lower CO emissions because it limits full loads using the electric motor and smoothes transients through the CVT transmission. IMA limits CO emissions with respect to a conventional car but having no CVT and less electric power is less effective than Hybrid.

Last chart in this section is the relative frequency distribution chart of NO_x [g/km] in Fig. 4. The average emissions of the three vehicles are; 0.04 g/km for Hybrid, 0.1 g/km for IMA, and 0.16 g/km for 2000. The three averages are all different with statistical significance over 99%. Figure 4 shows the EURO 4 limit for NO_x (0.08 g/km) and only Hybrid is below such limit on average. 90% of Hybrid NO_x emissions are under the EURO 4 limit while only 10% of IMA NO_x emissions are. 2000 has the highest average value, four times the average of Hybrid and twice the limit, NO_x emissions.

The HC emissions were neglected because during the whole testing with all vehicles (in hot conditions) this value was always very low and below the measurability threshold of the measurement equipment.

4 Drive style relevance on emissions

4.1 Drive style relevance on honda civic hybrid emissions

Drive-style is the peculiar behaviour of each person while driving. The scientific definition of drive-style through a single indicator is not straightforward. Literature tends to use driving cycle characteristics in attempting such definition ([7–13]). This study introduces however a new indicator to measure driving style not directly related to the driving cycle but to the use the driver makes of the accelerator pedal (throttle): the throttle position standard deviation. Such indicator was chosen because, neglecting lateral movements of the vehicle which do not have an influence on emissions, the driver has normally three controls on the longitudinal vehicle motion: accelerator, brake and gearshift. Being brake mostly used in decelerations, when emissions are at their lowest, and having Hybrid an automated transmission the main control remaining for the driver is the accelerator pedal. A synthetic indicator of the pedal movements could not be simply the average and the standard deviation was preferred. The definition of standard deviation of a sample N of data x_i is the following:

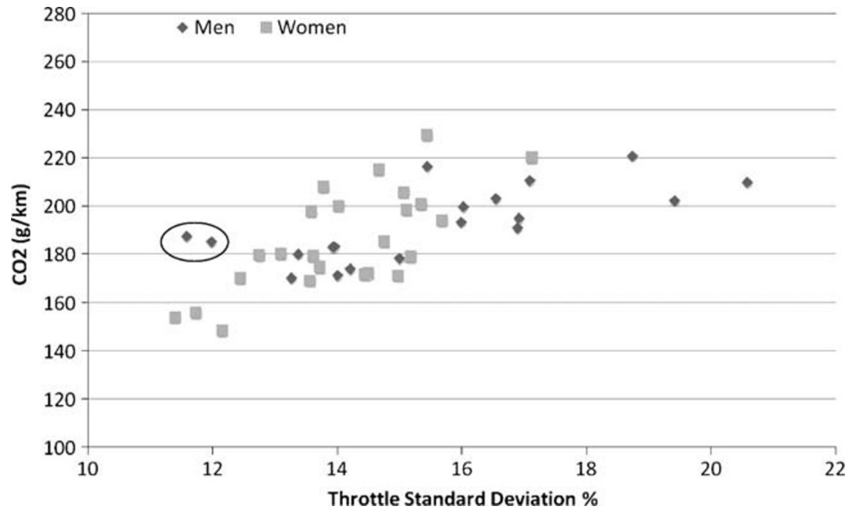
$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \overline{x})^2}{N}}$$

in which $\overline{x}$ is the average.

The standard deviation is expressed as a percentage because the position of the accelerator pedal is expressed in percentage; 0% is the accelerator fully up and 100% fully down.

Figure 5 is the relative frequency distribution chart of the throttle standard deviations of men and women. On average men move the accelerator pedal more than women; 15.6% is the average standard deviation for men and 14.1% for women. The “t-student” test performed on the two populations gave a result of 0.0131 which given the sample size confirmed the two averages are different with statistical significance over 95%. Men and women behaviour differs also because men were measured to have standard deviations ranging from 11 to 21 while women only from 11 to 19. Furthermore 50% of women missions had a standard deviation between 13–15% while men behaviour is less homogenous.

Fig. 6 Hybrid CO_2 production as a function of Throttle Standard Deviation



The standard deviation of the throttle position has been calculated on each mission. Every mission is a dot in Figs. from 6, 7, 8, 9, 10 and 11; in Figs. from 6, 7 and 8 the dot is a square when the driver is a woman and a rhombus when the driver is a man.

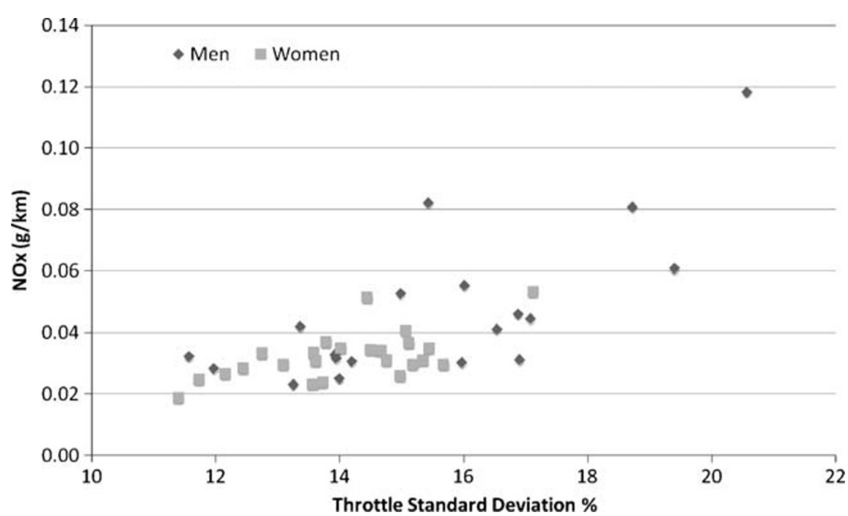
CO_2 emission is shown in Fig. 6 versus throttle standard deviation. A correlation between CO_2 emission and throttle standard deviation can be seen. The correlation coefficient for men is 0.72, for women is 0.73 and the overall correlation (men + women) is 0.69.

Dots in Fig. 6 are grouped in three areas. First in the left lower part (below 13%) is a "women only" area with the exception of two “men” points; second is a common area up to 18 % and the third, over 18% is men only. Investigating the two men missions in the women only area more in detail longer stop times were observed; the two missions were in fact influenced by longer times in idle with the accelerator pedal at 0%. It might be interesting for future studies to try to exclude idle from the calculations. The other option is to find a way to include traffic influence in the analyses.

The same three zones of Fig. 6 are visible (although less clearly) in Fig. 7, in which NO_x show an even greater dependence on throttle standard deviation. Those drivers who move more the accelerator pedal emit more NO_x; three missions, of three men, have even scored a NO_x level out of the 0.08 g/km EURO 4 limit, being uncommon for such a clean car. The correlation coefficients are: 0.73 for men missions, 0.6 for women missions and 0.75 overall.

CO emissions (Fig. 8) are extremely low for most of the drivers; however when throttle standard deviation grows CO emission grows more than linearly. "Dirty" drivers are all men; two of whom emit more CO than the EURO 4 limit (1.0 g/km). The correlation coefficients are: 0.66 for men, 0.63 for women and overall.

Fig. 7 Hybrid NOx emissions as a function of Throttle Standard Deviation



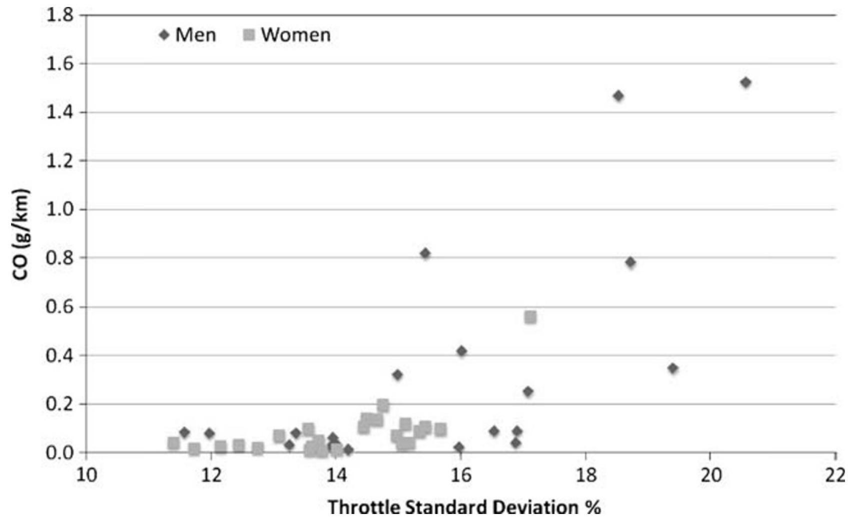


Fig. 8 Hybrid CO emissions as a function of Throttle Standard Deviation

This analysis shows how the vehicle is cleaner when driven by women. Consumption and emissions rise with the throttle standard deviation and women keep the right foot steadier.

4.2 Comparison of drive-style relevance on the emissions of the three vehicles

Using the same indicator, the throttle standard deviation, for the other two vehicles it is possible to appreciate whether such parameter is again a valid indicator of drive-style and whether emission and consumption are still dependent on it.

Figures from 9, 10 and 11 compare the dependence of CO_2, NO_x and CO emissions of the three cars on the throttle standard deviations. First thing to notice in the figures is that the samples of IMA and 2000 are much more spread. As anticipated in Section 4.1 introducing the throttle standard deviation as indicator of the driving style, the driver, when driving a manual gearbox vehicle, can control it also with the gear shift. He/she can influence the engine working speed selecting the gear. Hybrid has a CVT automatically actuated while IMA and 2000 have manual gearboxes and on these two vehicles similar throttle standard deviations may correspond to different average engine rotational speed and therefore different emissions levels can occur.

Second difference is that, although Hybrid has a much lower environmental impact than the other two, its throttle standard deviation tends to be higher. Again the difference can be due to the fact that, when driving the Hybrid, the drivers have just the accelerator to control it and therefore they tend to use it more. In other words with a manual gearbox the driver can decide to shift to a lower gear to have high acceleration while with an automated gearbox he/she can only kick down the accelerator.

Lower throttle standard deviations were recorded for the 2000 in four cases. This is however the most powerful car

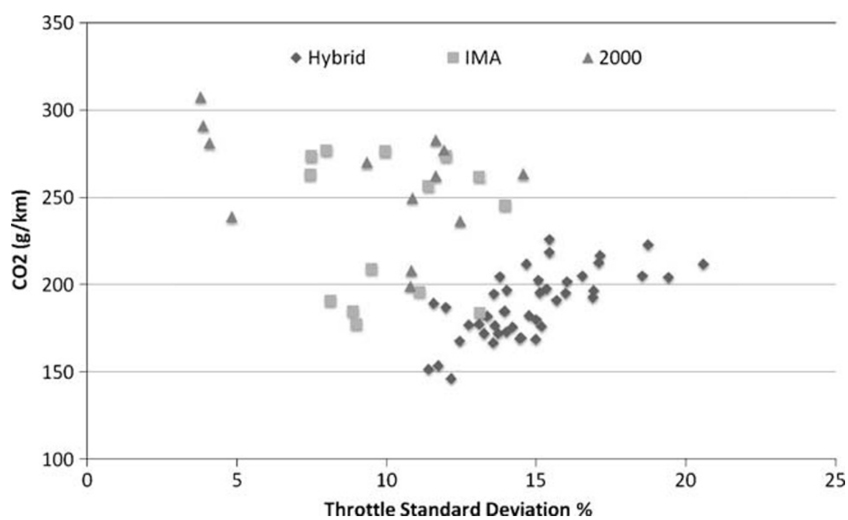


Fig. 9 Fuel consumption as a function of Throttle Standard Deviation

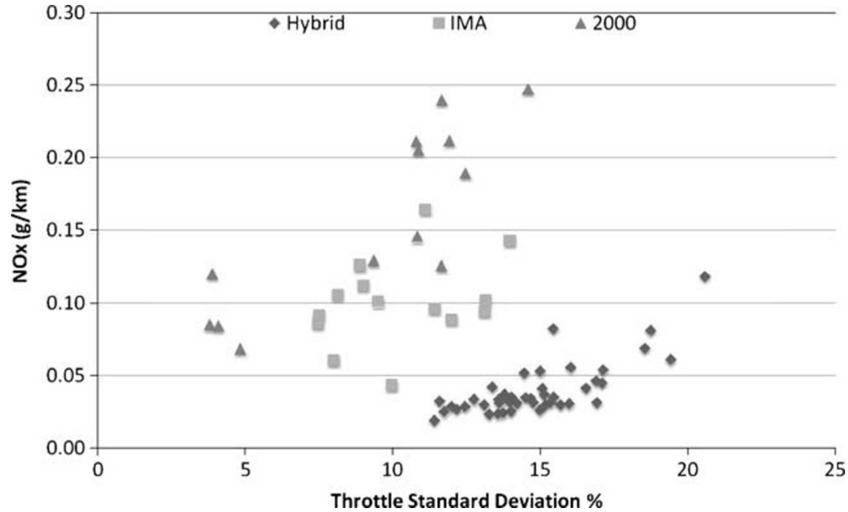


Fig. 10 NO_x emissions as a function of Throttle Standard Deviation

of the lot and it is possible for some of the less aggressive drivers to push the accelerator less when driving a car which can accelerate more.

Correlations between throttle standard deviation and emissions for the three cars change with the emission considered. CO_2 emission of the three cars are shown in Figure 9 versus throttle standard deviation; while for the Hybrid there is a correlation between the two parameters (correlation coefficient 0.69), for the other two vehicles it does not seem to be one (2000 0.18 and IMA 0.039).

NO_x emissions versus throttle standard deviation are shown in Fig. 10. 2000 and Hybrid have correlation coefficients of respectively 0.84 and 0.75 while IMA has just 0.32.

CO emission versus throttle standard deviation is shown in Fig. 11. Correlation coefficients are 0.69 for Hybrid, 0.60 for IMA and 0.56 for 2000.

Consumption and emissions of the three cars were shown in Section 3 to be influenced by the driver. Despite the two vehicles with manual gearbox have lower correlation coefficients than Hybrid between emissions and the throttle standard deviation such indicator can still be seen, especially for CO emission, as an indication of the driving style; it will probably need to be complemented, in future investigations of vehicles with manual gearboxes, by some other indicator to consider the gear shifting behaviour like average engine rotational speed.

5 Conclusions and future developments

This paper reported on the results of an experimental campaign to compare consumption and emissions of conventional and hybrid vehicles on urban roads.

The campaign was made with samples of drivers asked to drive three Honda Civic, one conventional (Honda Civic 2000 16v, EURO 4) and two hybrids (Honda Civic IMA EURO 3 and Honda Civic Hybrid EURO 4) on the same urban itinerary. For analyses purposes data were aggregat-

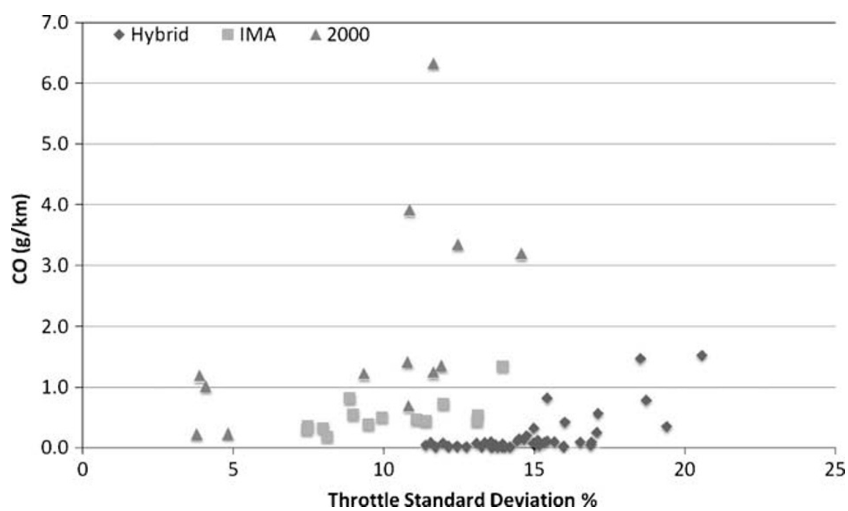


Fig. 11 CO emissions as a function of Throttle Standard Deviation

ed by "mission"; where mission is a trip on the given itinerary.

The conventional vehicle was measured to consume 54% more than Hybrid and to emit twice as much CO and NO_x than the EURO 4 limit.

The IMA, despite being certified EURO 3 emits and consume less than the conventional EURO 4. It consumes 21% more than Hybrid and emits on average half the EURO 3 limit of CO and 25% more than EURO 4 limit of NO_x.

Hybrid performed best; it emitted a fifth of the EURO 4 limit of CO and half the EURO 4 limit of NO_x.

HC were very low for the three vehicles, below the measurability threshold of the used tool.

Beside the measured averages of consumption and emissions the main result presented in this paper is the difference between missions with the same vehicles. Emission can differ up to 25 times from the least to the most polluting mission. Since all missions were all on the same itinerary and in off-peek traffic periods such differences can only be due to driving style.

A new indicator to measure driving style was here introduced: the throttle standard deviation. This parameter shows high correlations with consumption and emissions of Hybrid. It further showed how women, who tend to move less the accelerator pedal, do emit and consume less than men.

Applying the same indicator to the other vehicles lower correlations were found. Hybrid has a CVT automatically actuated while IMA and 2000 have manual gearboxes and on these two vehicles similar throttle standard deviations may correspond to different average engine rotational speed and therefore different emissions levels can occur. This is probably the reason for lower correlation coefficients.

This paper demonstrates that a conventional vehicle can emit more on the road than during type approval tests while the reverse can be true for hybrids. However the driver has a great influence on all vehicles.

While throttle standard deviations is a good indicator for the drive style of the tested car featuring an automated transmission a further indicator might be required to better classify drive style of vehicles featuring manual gearboxes.

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