CO_2 emissions for Euro 5 passenger cars over different driving and load conditions

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Abstract

The targets set in European Union for reducing greenhouse gas emissions from road transport are increasing the need for accurate quantification and projection of passenger car CO_2 emissions. In response to this the Joint Research Centre (JRC) has initiated a series of measurements on various modern passenger cars over various operating conditions. Experimental data of CO_2 emissions were collected and analysed for Euro 5 gasoline and diesel vehicles in order to investigate the CO_2 emitted under different driving conditions and cycles. The results show that on average the Euro 5 passenger cars investigated presented lower CO_2 emissions compared to the Euro 4 emission factors included in the EMEP/EEA emission inventory guidebook. Three different driving cycles were used to test the vehicles, the NEDC, the CADC and the WMTC. Measurements included tests with standard road load, tests with 10% increased road load values and tests with externally imposed electric loads ranging from 0 to 600 W. The highest CO_2 producing phases in all cases were the urban ones, followed by highway phases and lastly the rural phases. The increased road load values resulted in higher CO_2 emissions for all the cycles driven. The impact over NEDC was higher than over the Artemis cycles with a difference of 4.7% to respect to the base case road load. The introduction of electric load resulted in increases in CO_2 emissions. CO_2 increased linearly with the electric load reaching an extra 6.8% over the NEDC cycle, 3.8% over the Artemis cycle and 1.3% for the WMTC cycle for a 600W load.

1. Introduction

The reduction of CO_2 emissions from road transport in the European Union is a major part of the transport policy and legislation put in place. The number of vehicles introduced into the transport fleet in the EU makes the control and reduction of their greenhouse gas emissions an important task for the protection of the environment and climate. Hence the quantification and analysis of the emitted CO_2 from passenger cars, particularly those recently manufactured (2009 – 2011) is important for investigating the level of the current CO_2 emissions and the progress of policy and technical measures adopted in the EU.

In the past decades the EU has introduced a series of regulations and standards aiming at the reduction initially of pollutant emissions and lately also of CO_2. In 1992 the Directive introducing the Euro 1 standards for light duty vehicles was put in place. Until today 6 steps of Euro standards have been adopted in the European legislation. The current emission standard is the Euro 5, introduced in 2009 (Regulation EC No. 715/2007). In addition to emission standards Regulation EC No. 443/2009 foresees also maximum CO_2 emissions limits for new passenger cars which by year 2015 should be less than 130 g/km on average. Different interim targets have also been set in order to steer the transition.

In order to investigate the performance of modern passenger cars and the evolution of CO_2 emissions in view of the current policy, the Joint Research Centre of the European Commission has initiated a series of measurements on various vehicles over different operating conditions. These experiments consist of chassis dyno tests over the European type approval cycle (NEDC), the Common Driving Artemis Cycle (CADC) and the World Motorcycle Test Cycle (WMTC). The scope of this paper is to analyze and present the CO_2 emissions measurement results and attempt to provide CO_2 emission factors for Euro 5 diesel and gasoline passenger vehicles. The emission factors calculated are compared with those of Euro 4 technology vehicles from the EMEP/EEA atmospheric emission inventory guidebook (Ntziachristos, L. and Z. Samaras, 2010), to investigate if and to what extent Euro 5 passengers cars are producing less CO_2 emission than their predecessors. Note that there are no emission factors for Euro 5

vehicles currently available in the Guidebook. In addition a series of measurements were conducted and presented to quantify the CO_2 emissions emitted during different operating and load conditions. These tests included both different road load values associated with parameters that affect the aerodynamic characteristics and the tyres of the vehicle and external electrical loads imposed. The latter aimed to investigate the impact on CO2 emissions of additional electric systems on board of the vehicle.

2. Methodology

2.1 Test vehicles and fuels

A total of twelve Euro-5 passenger cars were tested in this study. The pool of vehicles included gasoline cars of a wide range of engine capacities and diesel cars of less than 2000cc (Table 1). A total of 8 gasoline vehicles and 4 diesel vehicles were tested. The mass of the vehicles was close to the reported average for European market (about 1300kg) with the exception of PC9 of 2038kg which was a 4600cc luxury car. The vehicles were tested during the period of 2010-2011 with the exception of PC1 tested on 2009.

Most of the gasoline cars had an engine capacity between 1400 to 2000cc. On the other hand three out of the four diesel cars tested have the same engine capacity of 1590 cc with the exception of PC12 with 1200cc.

Table 1: List of vehicles tested.

Name [text]	Regulation [Euro]	Year Test [yyyy]	Fuel Type [text]	Engine Capacity [cm³]	Reference Mass [kg]
PC1	Euro 5	2009	Diesel	1598	1359
PC2	Euro 5a	2010	Diesel	1598	1132.5
PC3	Euro 5a	2010	Diesel	1598	1132.5
PC4	Euro 5a	2010	Gasoline	1798	1359
PC5	Euro 5a	2010	Gasoline	1490	1245.75
PC6	Euro 5a	2010	Gasoline	1242	1020
PC7	Euro 5a/Euro 5	2010	Gasoline	1995	1245.75
PC8	Euro 5a	2010	Gasoline	1984	1585.5
PC9	Euro 5	2011	Gasoline	4608	2038.5
PC10	Euro 5a	2010/2011	Gasoline	1368	1132.5
PC11	Euro 5a	2011	Gasoline	1984	1585.5
PC12	Euro 5a	2011	Diesel	1248	1245.75

2.2 Test Facilities

The tests were conducted at the JRC Vehicle Emission Laboratories (VELA) located in Ispra (Italy). The emission tests were performed in a test cell complying with the legal requirements for the type approval of passenger cars in Europe.

2.3 Test cycles - Protocol

The cycles used included the certification test cycle (NEDC), and some more dynamic ones (Artemis, WMTC), the latter in hot-start conditions. The NECD (New European Driving Cycle) is the type-approval test used for emissions of all Euro 3 and later light-duty vehicle models in Europe. This cycle has been criticized for being too smooth and underloaded for typical vehicle operation, covering only a small area of the engine operating range (Kågeson, 1998; Mellios et al. 2011; Weiss et al., 2011a). In general, type-approval cycles tend to underestimate real-world emissions because they exhibit low speed dynamics. Although NEDC results have limited value for emission modelling purposes, they were included as a baseline reference, and also to evaluate the compliance with the relevant European emission limits.

The CADC (Common Artemis Driving Cycle) is a so-called real-world driving cycle. From the emissions modelling point of view, these types of driving cycles provide the most valuable emissions data, because they are designed to represent realistic driving conditions. The CADC (or Artemis) cycle (André, 2004) aims to represent real-world driving conditions in Europe. Its

higher dynamicity (as compared to NEDC) makes it more suitable as the basis for the investigation of real-world emissions and emission factor development. The WMTC (Worldwide Motorcycle Test Cycle) was recently developed within the framework of a worldwide regulatory process towards the harmonization of motorcycle emission test procedures. In our experimental campaign, it was applied to the vehicles having a lower engine capacity as a shorter alternative to CADC in terms of test time.

For the baseline tests all vehicles were measured over standard conditions with the road load values provided by the manufacturer or, when those were not available, according to the default road load values foreseen by existing legislation. Additional tests were performed with increased (+10%) road load resistances in order to quantify the impact of higher rolling resistance and/or accessories which affect aerodynamic resistance.

For investigating the impact of electrical loads, different electrical consumptions were applied ranging from 100W to 600W. The application of electric loads was achieved by applying resistors to a standard 12V dashboard power outlet as the vehicle was driven over different cycles. Over the NEDC cycle different electric loads were applied with an interval of 100 to 200W for each test, up to 600W. In these cases the NEDC was run hot in order to limit the variability of the results due to the cold start. Over the Artemis and the WMTC cycle only 600W was used to measure the impact of the electric load to the emitted CO_2.

3. Results and Discussion

3.1 CO_2 emission results

Figure 1 presents the CO_2 emissions of the Euro 5 gasoline vehicles with respect to the different mean velocities of the driving cycle. In the same figure Euro 4 emission factors are depicted as trend lines by a second order polynomial. It can be observed that the Euro 5 data are following a similar trend. The CO_2 emissions of Euro 5 gasoline vehicles were on average lower than the Euro 4 emission factors, as expected. The vehicle with the highest CO_2 emissions throughout the whole velocity range is PC 9, which is the car with the highest engine capacity and mass. The lowest CO_2 emissions are emitted by PC 10 which has an engine capacity of 1368cc and a mass of 1132.5 kg.

Considering the individual engine capacity classification of the EMEP/EEA emission factors, all vehicles less than 1400cc (PC 6, PC 10) are clearly lower than Euro 4 emission factors. Vehicles around 1400 and 2000cc (PC 5, PC 4, PC 7, PC 8, PC 11) are not all under the emission factor of Euro 4 cars. The vehicle PC11 has higher values of CO_2 emission than Euro 4 emission factors for the lowest and highest velocities. This is mainly due to the fact that it has the highest vehicle mass with respect to the other vehicles in this category. The highest engine capacity vehicle (PC 9) is clearly lower than the Euro 4 emission factor which shows that the technological advances between Euro 4 and Euro 5 cars have made a positive impact especially on the higher engine capacities vehicles.

In Figure 2 the CO_2 emissions of the Euro 5 diesel vehicles are presented versus the different mean cycle velocities. The vehicles tested with diesel fuel were all under 2000cc engine capacity. Most of the CO_2 emissions emitted by those vehicles are on average lower than the emission factor for Euro 4 vehicles. The diesel Euro 4 CO_2 emission trend line is described by a second order polynomial and all the measurement results are following a similar trend. The highest emissions occurred as expected at the lowest and highest velocities.

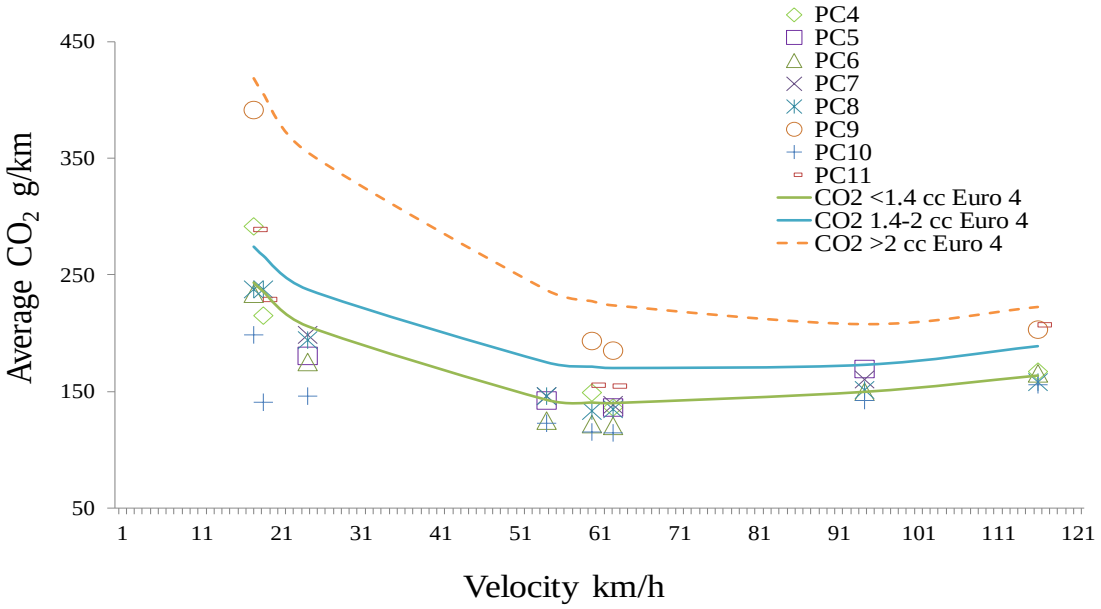

Figure 1: Euro 5 gasoline CO_2 emissions under different velocities.

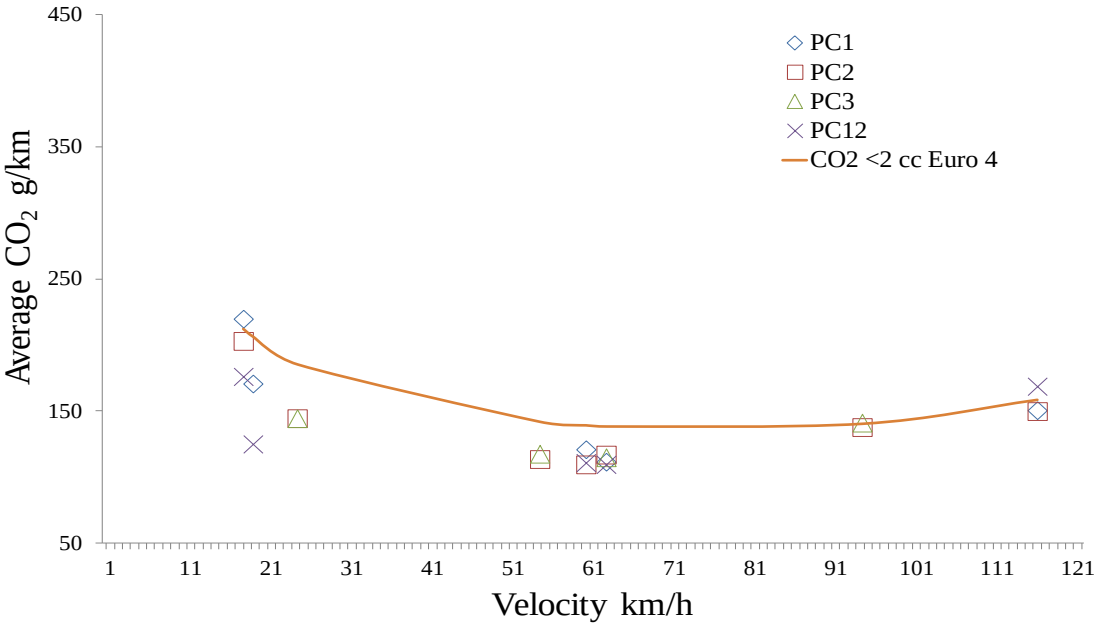

Figure 2: Euro 5 diesel CO_2 emissions under different velocities.

Table 2: Mean difference of CO_2 between Diesel and Gasoline

Cycles	UDC	UDC hot	EUDC	NEDC	NEDC hot	ARTMU	ARTMR	ARTMM	WMTCU	WMTCR	WMTCM
Diesel g/km	158.64	147.77	112.98	129.71	123.92	199.37	113.56	156.21	144.25	115.23	139.29
Gasoline g/km	216.25	182.15	134.41	170.24	147.89	273.53	144.61	175.92	178.96	136.29	154.72
Percentage %	26.6	18.9	15.9	23.8	16.2	27.1	21.5	11.2	19.4	15.5	10.0

As expected the CO_2 emissions of diesel vehicles were lower than those of gasoline vehicles, with a minimum difference of 27.1% in ARTMU and maximum of 10 % in WMTCM (Table 2). It can be observed that diesel emissions of diesel cars lay on the same ranges, fact which can be explained since these vehicles had similar mass and engine capacity characteristics.

3.2 Effect of increases in road load

Figure 3 presents the change of CO_2 emissions compared to the baseline, following a 10% increase in road load values over two different cycles (NEDC, Artemis). As expected the increased road load values resulted in all cases in higher CO_2 emissions. For PC11 and PC12 the average increase over the NEDC cycle is 11%, while the average increase over the Artemis cycle is 6.5%. The highest increase of CO_2 emissions is 14% over the UDC part of NEDC and the lowest 0.4% for the Rural Artemis cycle. The impact over NEDC is higher than over the Artemis cycles with an average difference of 4.72%.

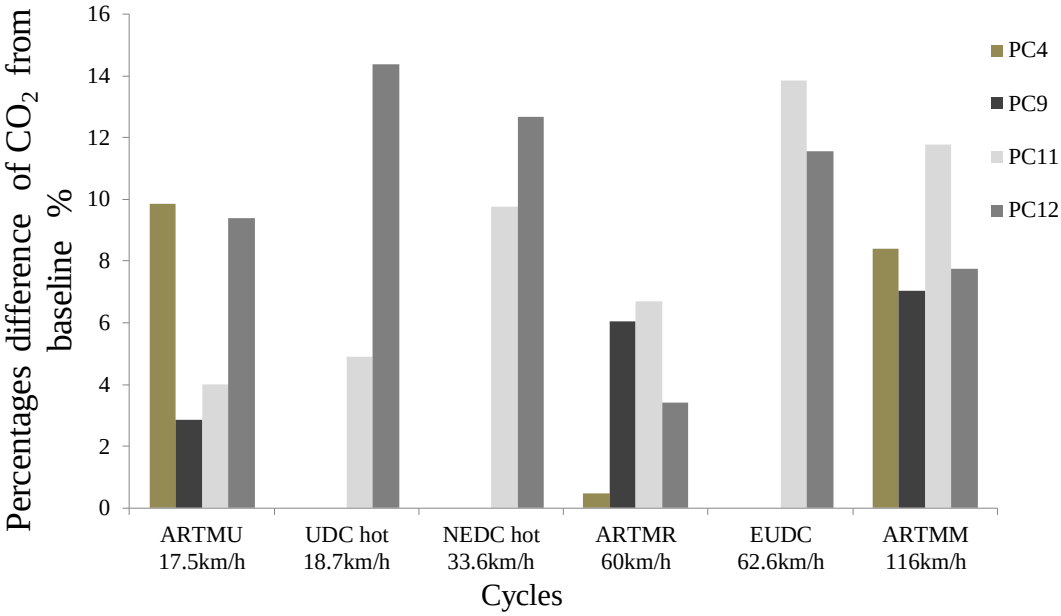

Figure 3: CO_2 increase caused by 10% increase in road load values (Diff. from baseline).

For PC4 and PC9 that with increased road load were tested only over the Artemis cycle, the mean average CO2 increase is about 6.5% for the urban cycle, 4% for the road cycle and 8% for the motorway. Lower increases are observed in the Artemis cycles despite that Artemis urban and Udc and Artemis road and EUDC have similar average speed. This is explained by the fact that Artemis cycles are more transient thus vehicles resistances contribute less in CO_2 emissions over these cycles.

3.3 Effect of increasing electric load values on CO_2 emissions

Regarding the impact of increasing electric load on CO_2 a linear pattern was observed over NEDC in all cases (Figure 4), with higher electric loads proportionally leading to higher CO_2 values. Figure 5 presents the impact on CO_2 emissions of the application of a 600W electrical load on 3 different vehicles over NEDC.

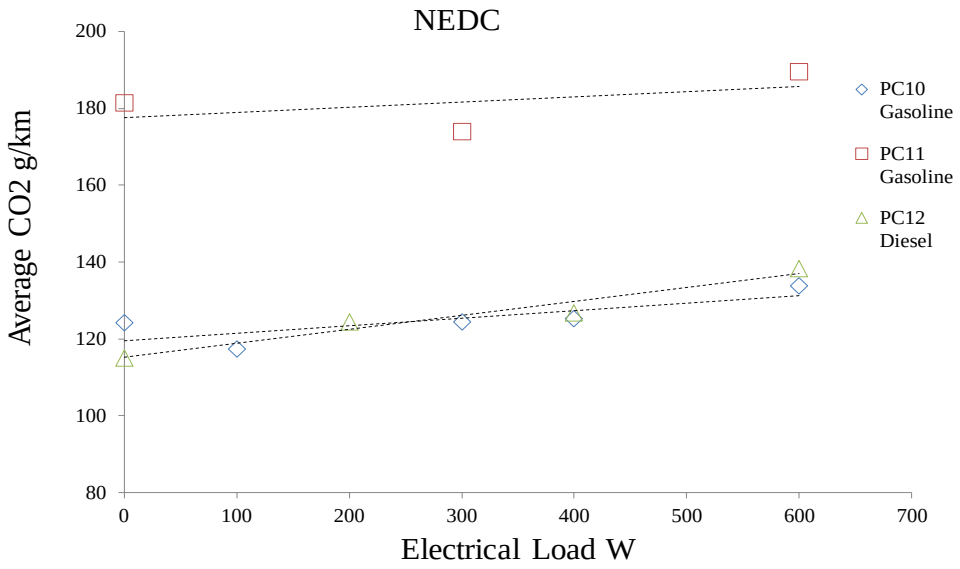

Figure 4: CO_2 emitted for different electric loads under NEDC

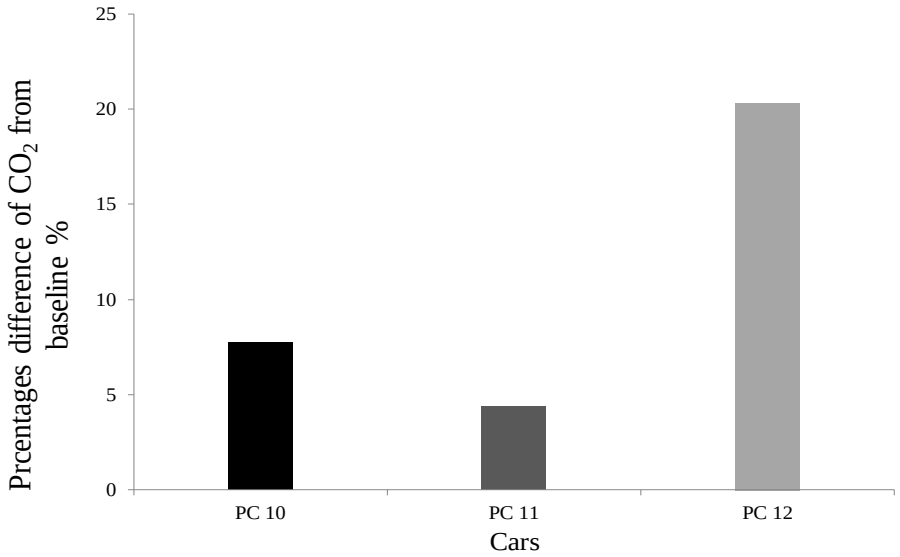

Figure 5: Percentage difference from 0 W to 600 W of CO_2 emissions for the NEDC cycle

The highest increase in CO_2 emissions for a 600W electric load was observed in the case of the diesel vehicle (PC 12) leading to a 20% excess emissions. For the two gasoline fueled vehicles a lower impact on CO_2 emissions was measured. PC 10 presented an increase of 7.7% and PC 11 presented an increase of 4.4%.

Vehicles PC12 and PC8 were also tested with different electric loads under other driving cycles (Artemis and WMTC, respectively). In figure 6 the percentage differences in CO_2 emissions are presented in comparison to the baseline of 0W when a 600 W electric load is applied.

For PC12 the highest increase in CO_2 emissions (17%) was observed under the urban sub-cycle of Artemis and the lowest under the road sub-cycle (4%). We can observe a difference in the percentage of CO_2 increase between the NEDC and the Artemis cycles under different electric loads on a magnitude of 3% by taking the average emission calculated during the cycles for all the vehicles tested.

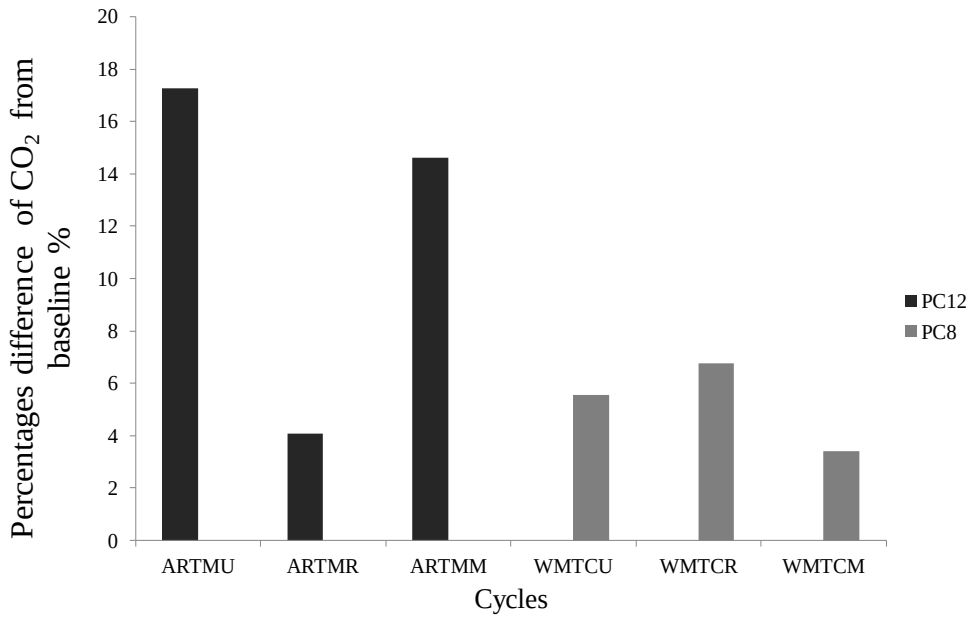

Figure 6: CO_2 increase caused by different electric loads under Artemis and WMTC driving cycles (Diff. from baseline).

For PC8, tested under WMTC driving cycle, we can observe a pattern different from the one observed with PC12 under the Artemis cycle. The highest increase of CO_2 emissions applying the 600 W electric load is related to the rural sub-cycle (6.7%). The increase over the urban sub-cycle is 5.5% and over the motorway sub-cycle is 3.4%. From figure 5 and figure 6 we can conclude that diesel vehicles (PC12) are affected more by electric load and emitted higher CO_2 emissions than gasoline vehicles (PC8, PC10, PC11).

It is apparent that applying different electric loads to a vehicle the CO_2 emissions increase whatever the characteristics of the engine, vehicle mass and fuel used, although the correlation is not the same for all vehicles. The average increase of the CO_2 emitted when a 600W electric load is applied is in the order of 5 – 15 %. The increasing use of electric and electronic application in modern vehicles (e.g. dvd, game stations, sound systems) may have a substantial impact on CO2 emissions.

4 Conclusion

In this study 12 passenger cars in the Euro 5 category were tested for CO_2 emissions under different driving conditions and vehicle loading. Three different driving cycles (NEDC, Artemis, WMTC) were used in the experiments, under normal, 10% increase road load values and different electrical load conditions.

CO_2 emissions emitted from Euro 5 cars remained under the current Guidebook's CO_2 emission factors for Euro 4 vehicles. This was observed, for all technologies, engine capacities and fuels used during this study. It was observed that especially for vehicles with high engine capacity and mass the difference from Euro 4 emission factors was quite substantial.

Increasing the road load values has led to an increase in the CO_2 emissions. The Artemis urban and highway sub-cycles presented the highest emitted CO_2 with the increased road load values.

Electric loads from 0 W to 600 W were applied over various driving cycles for gasoline and diesel vehicles. It was observed that the application of a 600W electric load on the vehicle results in an increase of CO_2 in the order of 5 to 15%.

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