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Measurement of CO_2- and fuel consumption from cars in the NEDC and in real-world-driving cycles

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Measurement of CO_2- and fuel consumption from cars in the NEDC and in real-world-driving cycles

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1 ZUSAMMENFASSUNG (SUMMARY IN GERMAN)

Um CO_2-Emissionsfaktoren für PKW zu erstellen, wird üblicherweise eine Stichprobe an Kfz in einigen “Real World” Testzyklen vermessen. Um die Testergebnisse in Emissionsfaktoren umzuwandeln werden detaillierte Simulationswerkzeuge verwendet. Die Simulation wird dabei üblicherweise anhand der Ergebnisse aus dem CO_2-Monitoring für jeden Zulassungsjahrgang der PKW kalibriert, da der Stichprobenumfang an gemessenen PKW europaweit klein und damit für die gesamte Flotte nicht ausreichend repräsentativ ist.

Für die Kalibrierung bestehen verschiedene Ansätze, die aber allesamt auf der Grundannahme beruhen, dass im realen Verkehr von einem Modelljahr zum nächsten die selben relativen Änderungen im Kraftstoffverbrauch auftreten wie im CO_2-Monitoring Datensatz, der auf dem Testergebnis im Typprüfzyklus (NEDC) beruht. Diese Annahme wird auch verwendet, um die zukünftigen Verbrauchswerte der PKW in den CO_2-Szenarien abzuschätzen. Detaillierte Analysen, die diese Annahme einer gleichen relativen Verbrauchsänderung in NEDC und in Real World Zyklen bestätigen oder widerlegen waren bisher nicht verfügbar.

In der vorliegenden Studie wurde eine erste Analyse durchgeführt, inwieweit moderne Fahrzeug- und Antriebstechnologien, wie z.B. Motor Start/Stop Funktion, verbesserte Aerodynamik, Bremsenergierückgewinnung etc. den Verbrauch in NEDC und verschiedenen Real World Zyklen (CADC, IATS und IATS mit Kaltstart) beeinflussen.

Für diese Aufgabenstellung wurden folgende Arbeiten durchgeführt:

1. Drei Fahrzeugpaare von drei verschiedenen Herstellern wurden für die Versuchsreihe herangezogen. Dabei wurde je Hersteller ein EURO 4 Modell und das zugehörige EURO 5 Nachfolgermodell mit Verbrauch senkenden Technologien ausgewählt. Jedes der EURO 5 Modelle war also ein PKW mit speziellen Maßnahmen zur Effizienzsteigerung wie etwa Start/Stop System, reduziertem Luftwiderstand, rollwiderstandsarmen Reifen und verbrauchsoptimierten Nebenaggregaten und einem modernen Motorkonzept.
2. Mit jedem der Versuchsfahrzeuge wurden Ausrollversuche gefahren, um die im realen Verkehr auftretenden Fahrwiderstände zu bestimmen.
3. Jedes Versuchsfahrzeug wurde am Rollenprüfstand im NEDC und in den Real World Zyklen gemessen. Dabei wurden am Prüfstand die Fahrwiderstände aus dem Ausrollversuch eingestellt.
4. Die Messergebnisse wurden mit den Typprüfwerten des jeweiligen Kfz verglichen um einen ersten Trend ableiten zu können, inwieweit sich die Daten aus dem CO_2-Monitoring für eine Abschätzung der Entwicklung der real World Verbrauchswerte eignen und ob sich Unterschiede zwischen EURO 4 und der aktuellen Technologie zeigen.

Ein Vergleich der Messwerte in den NEDC Tests mit den Typprüfwerten zeigt etwa 17% höhere CO_2-Emissionen bei den aktuellen Tests. Die höheren Emissionen dürften zum Großteil auf höhere Fahrwiderstände aus den eigenen Ausrollversuchen gegenüber den in der Typprüfung verwendeten Fahrwiderständen zurückzuführen sein. Die Unterschiede zwischen Typprüfwert und NEDC-Messergebnis sind je nach Fahrzeugmodell unterschiedlich und reichen von +9% bis +24%. Für die Typprüfung werden die Fahrwiderstände natürlich eher mit idealer Kombination von Reifen und Fahrbahnbelag bei idealen Umgebungsbedingungen und hohem Reifendruck durchgeführt. Im realen Verkehr sind im Durchschnitt weder Fahrbahn noch Reifen und Reifendruck perfekt. Die erstausgerüsteten Reifen können gegenüber der Typprüfung auch andere Marke und Type sein. Da in den hier durchgeführten Ausrollversuchen jeweils der Reifendruch exakt nach Herstellerangabe verwendet wurde, kann angenommen werden, dass der reale Fahrwiderstand noch etwas höher liegt als hier gemessen, da real nicht immer auf den Reifendruck geachtet wird und zusätzliche Dachaufbauten (Dachboxen, Schiträger, etc.) den Fahrwiderstand weiter erhöhen.

Weiters sind in der Norm auch Unterschätzungen durch die Auswertemethode der Ausrollversuche verankert (Vernachlässigung rotatorischer Trägheiten und Vereinfachungen bei Fahrbahnlängsneigung).

Der Unterschied zwischen CO_2-Typprüfwerten und Messergebnis in einem „Real World Mix“ war im Durchschnitt über alle PKW +21%. Die Ergebnisse der einzelnen PKW reichten von +13% bis +28%.

Die Definition des „Real World Mix" beinhaltet allerdings auch einige Unsicherheiten, da bisher kein Testzyklus verfügbar ist, der beanspruchen kann, die realen Fahrbedingungen moderner PKW abzubilden. Neben dem Geschwindigkeitsverlauf sind auch die Festlegung des durchschnittlichen Schaltverhaltens und die Einbindung von Kalt- und Kühlstarts mit Unsicherheiten behaftet.

Der Schwerpunkt der Studie bestand aus dem Vergleich der EURO 4 Modelle mit dem jeweiligen EURO 5 Nachfolger.

Der EURO 5 Diesel PKW von Hersteller 1 hat laut Typenschein um 18% niedrigere CO_2-Emissionen als sein EURO 4 Vorgänger. Aus den Ausrollversuchen ergab sich bereits ein deutlich geringerer Roll- und Luftwiderstand für die EURO 5 Version. Mit diesen Fahrwiderständen wurden für das EURO 5 Modell im NEDC 18% geringere und im „Real World Mix" 19% geringere CO_2-Emissionen gemessen als mit dem EURO 4 Modell. Die Reduktion gemäß Typprüfwerten passte also sehr gut mit den real gemessenen Daten zusammen. Etwa 12 Prozentpunkte der CO_2-Senkung stammen aus den geringeren Fahrwiderständen, die verbleibende Verbesserung wird durch ein Motor-Start/Stop System eine längere Achsübersetzung und eine neue Motorgeneration dargestellt. Die hohe Motoreffizienz in dem Real World Mix zeigt bei diesem getesteten EURO 5 Modell als Nachteil allerdings relativ hohe NO_x-Emissionen. Für das EURO 5 Modell wurden im Real World Mix beinahe 50% höhere NO_x-Emissionen gemessen als für die EURO 4 Version. Im NEDC mit Kaltstart ergaben sich dagegen für das EURO 5 Modell 31% geringere NO_x. Das zeigt deutlich, dass der NEDC inzwischen völlig unzureichend für den Test moderner Motorkonzepte ist. Alle anderen Abgaskomponenten (PM, PN, HC, CO) waren bei dem EURO 5 Modell auf sehr niedrigem Niveau.

Die Ausrollversuche mit den Modellen der Hersteller 2 und 3 zeigten für die EURO 4 und die EURO 5 Versionen jeweils nahezu identische Fahrwiderstände. Die beworbenen „rollwiderstandsarmen Reifen" waren offensichtlich nicht besser als die Standard-Sommerreifen der EURO 4 Versionen und Änderungen im aerodynamischen Design wurden bei beiden Modellen nicht vorgenommen.

Die EURO 5 Diesel-Version von Hersteller 2 hat gemäß Typprüfdaten um 19% geringere CO_2-Emissionen als der EURO 4 Vorgänger. Bei den Rollentests ergaben sich mit den gemessenen Fahrwiderständen im NEDC 18% Reduktion, im Real World Mix Zyklus wurde eine Reduktion um 9.3% festgestellt. Das ist ein zwar weniger als im NEDC aber auch ein beachtliches Ergebnis, da Hersteller 2 gleichzeitig die NO_x-Emissionen im Real World Mix noch weiter senkte als im Typprüfzyklus (-40% gegenüber -19%). Alle anderen Abgaskomponenten (PM, PN, HC, CO) waren schon bei der EURO 4 Version auf sehr niederem Niveau. EURO 5 zeigte noch weitere Reduktionen bei diesen Emissionskomponenten.

Für die Diesel-PKW waren die Tendenzen zwischen den beiden getesteten Herstellern also gegenläufig. Ein Hersteller hatte von EURO 4 auf EURO 5 in realen Fahrzyklen etwas höhere CO_2-Minderungen als im Typprüfzyklus, dafür aber deutliche NO_x-Zunahmen im Real World Mix. Der andere Hersteller zeigte im Real World Mix deutlich mehr NO_x-Minderung als im Typprüfzyklus, dafür waren die CO_2-Minderungen in den realen Fahrzyklen geringer als in der Typprüfung.

Von Hersteller 3 wurden zwei PKW mit Ottomotoren ausgewählt. Nach Typprüfdaten hat das neue Modell um 16% geringeren Kraftstoffverbrauch als die EURO 4 Version. Bei den Rollenmessungen mit den real gemessenen Fahrwiderständen ergaben sich im NEDC allerdings nur -4%, im real World Mix -6% CO_2 bzw. Verbrauch von der EURO 4 auf die EURO 5 Version. Das neue Modell hat eine Direkteinspritzung mit Start/Stop Funktion während die EURO 4 Version eine Saugrohreinspritzung hat. Von der neuen Technologie wurde eigentlich ein größeres Verbrauchsminderungspotenzial erwartet. Die gemessenen Reduktionen entspricht etwa dem alleinigen Potenzial einer Motorabschaltung im Leerlauf. Es muss hier allerdings betont werden, dass je Modell nur ein einziger PKW gemessen wurde. Dabei besteht natürlich die Möglichkeit, dass einzelne Kfz wegen der Serienstreuung oder nicht erkannter Schäden nicht repräsentativ für die Gesamtheit des jeweiligen Modells sind.

Jedenfalls hatte das EURO 5 Ottomodell niedrigere NO_x-Emissionen, dafür höhere CO und HC Emissionen als sein EURO 4 Vorgänger. Allerdings sind diese Abgaskomponenten bei beiden Kfz auf sehr niederem Niveau. Die Partikelmasse- und die Partikelanzahlemissionen waren beim EURO 5 Otto-PKW merklich höher als bei seinem EURO 4 Vorgänger, allerdings niedriger als bei dem Diesel-PKW ohne Partikelfilter.

2 EMPFEHLUNGEN (RECOMMENDATIONS IN GERMAN)

Obwohl die Messungen an einer kleinen PKW-Stichprobe erfolgten, ergaben sich einige klare Trends und Empfehlungen.

Eine wesentliche Ursache für die Unterschätzung der realen Verbrauchswerte von PKW in der Typprüfung dürfte der dabei verwendete, zu geringe Fahrwiderstand sein

→ Die in der Typprüfung verwendeten Fahrwiderstände sind in keinem öffentlich zugänglichen Dokument verfügbar. Es wird vorgeschlagen, das Fahrwiderstandspolinom in Zukunft in den Typenschein einzutragen. Damit können die Messungen auch von unabhängigen Labors nachvollzogen werden.

→ Beim nächsten Update der Typprüfnorm sollte darauf geachtet werden, eindeutig definierte und eventuell auch realitätsnähere Randbedingungen vorzuschreiben. Es sollte vorgeschrieben werden, beim Ausrollversuch die Reifenmarke und –type zu verwenden, die in der Erstausrüstung verbaut wird. Die Default-Fahrwiderstände gemäß 70/220/ECE sollten den Luftdruck der Reifen vorschreiben und eventuell den Rollwiderstand aus dem Reifenlabelling-Test nach ISO 8767 verwenden.

Das Verhältnis von Verbrauch und CO_2-Emissionen in der Typprüfung zu denen in realen Testzyklen schwankt stark zwischen den getesteten Marken und Typen. Das gilt auch für die NO_x-Emissionen die eine wichtige Abgaskomponente für die aktuelle Luftgütesituation darstellen.

→ Der nächste Typprüfzyklus (WLTP) sollte unbedingt darauf hin überprüft werden, dass er einen größeren Kennfeld- und Abgastemperaturbereich abdeckt und deutlich mehr verschieden dynamische Laständerungsprofile aufweist als der NEDC. Damit wird in der Entwicklung die Emissionsoptimierung über eine größere Einsatzprofilbreite notwendig.

Die realen CO_2-Emissionen liegen etwa 20% höher als die Typprüfwerte. Da derzeit europaweit keine verlässlichen Daten über das durchschnittliche Fahrverhalten von PKW verfügbar sind und auch die gemessene Stichprobe an PKW klein ist, kann dazu im Moment keine genauere Aussage getroffen werden.

→ Es sollte eine bessere Datengrundlage zum realen Fahrverhalten geschaffen werden

Die Abschätzung der Real World CO_2-Emissionsniveaus von Fahrzeug-Neuwagenflotten anhand der Typprüf-CO_2-Werte und zukünftiger CO_2-Zielwerte in der Typprüfung beinhalten einige Unsicherheiten, sind derzeit aber die beste verfügbare Option. Die drei getesteten PKW-Paare deuten allerdings darauf hin, dass eine direkte Übernahme der Reduktionsraten aus der Typprüfung für Voraussagen des Real World Verbrauchesentwicklung zu optimistisch sein dürfte.

→In den zukünftigen Testprogrammen der an ERMES beteiligten Staaten sollten die PKW Marken und Typen viel systematischer ausgesucht werden, um aus dieser europäischen Kooperation eine bessere Übersicht über die Entwicklung der Verbrauchswerte der Neuwagen zu erhalten. Insbesondere sind weitere systematische Tests an Modellpaaren sinnvoll um die Entwicklung von Typprüfverbrauch bzw. CO_2 gegenüber dem Trend im realen Verkehr zu überwachen.

3 SUMMARY

To compute CO_2 emission factors for passenger cars typically a large set of vehicles is tested in different real world cycles. Then simulation tools are used to calculate emission factors from the test results. Since the sample of vehicles tested is limited, the actual data from CO_2 monitoring is used to calibrate fuel consumption and CO_2 emission factors of the new registered car fleet for each year of registration.

Although there are different options for this calibration, the basic assumption is that the relative change of the specific fuel consumption from one model year to another is similar in real world driving as in the CO_2 monitoring data. This assumption is also used for predicting future CO_2 and fuel consumption values but no detailed analysis on this assumption is available yet.

In this work a first analysis was done if the influence of modern vehicle technologies like Start/Stop-function, improved aerodynamic etc. on fuel consumption is different in the NEDC and in real world cycles (CADC, IATS and IATS cold start).

For this task following work was done:

1. Three vehicle pairs from three different manufacturers each with one EURO 4 model and one EURO 5 follow-up model were selected. Each EURO 5 model was a car with special fuel efficient features like engine start-stop system, improved air resistance and tires with low rolling resistance, reduced energy consumption of auxiliaries and modern engine concept.
2. With each vehicle coast down tests were performed to determine the real world air and rolling resistance values.
3. Each vehicle was measured on the roller test bed in the type approval cycle and in different real world driving cycles with the driving resistance values gained from the coast down tests.
4. Then the results were compared to the type approval data to obtain first trends how data from the CO_2 monitoring can be used to assess fuel consumption and CO_2 emissions of modern cars in real world traffic conditions.

A comparison of the results from the NEDC tests run in this study with the type approval data shows that the driving resistance values gained from the real world coast down tests are on average approx. 17% higher than the values applied in type approval. The trends are different between the single models and range from +9% to +24%. In type approval certainly the optimum combination of tire and road surface as well as high tire pressures are applied at best ambient conditions. In the reality the road surface is not perfect and most likely the tires are different. Since the coast down tests here always used the tire pressure suggested by the manufacturer and no additional load, roof racks or other equipment which increases driving resistances was applied to the vehicles we can assume that in the real “real world driving” the discrepancy in the driving resistance values to type approval can be even larger. Furthermore the official procedure for the evaluation neglects the inertia of rotating masses and includes simplifications in the evaluation for roads with road gradients which both tend to lead to lower driving resistances compared to the real situation.

The difference between CO_2 in the type approval data to CO_2 in a “real world cycle mix” was found to be on average +21% ranging from +13% to +28%. The real world mix includes reasonable uncertainties since no test cycle is available which reliably depictures real world driving. Beside the speed curves also the gear shift behaviour and depicting the influence of cold starts includes uncertainties.

The main focus of this study was the comparison between the emissions of the EURO 4 model and the EURO 5 follow-up model.

The EURO 5 diesel model from manufacturer 1 has 18% less CO_2 emissions in the type approval data compared to the EURO 4 version. The driving resistance data from the coast down tests showed already an impressive reduction of the air and rolling resistance values for the EURO 5 model. Applying this data in the roller tests lead to -18% in the NEDC test and -19% CO_2 in the real world cycle mix. This means the real world data met the type approval data quite exactly. 12% of the CO_2 reduction is due to lower driving resistances, the remaining reduction comes from an engine start-stop system a longer axis transmission and an improved engine technology. Unfortunately the high fuel efficiency of the engine in real world cycles takes as a loss reasonable increasing NO_x emissions. The EURO 5 model had nearly 50% higher NO_x emissions in the real world mix than the EURO 4 model while it had -31% NO_x in the NEDC with cold start. This shows clearly that the NEDC is outdated as test procedure for modern engine concepts. All other pollutant emissions (PM, PN, HC, CO) were impressively low from this EURO 5 diesel vehicle.

The coast down tests with the models from manufacturer 2 and 3 gave nearly identical driving resistance values for the EURO 4 and EURO 5 vehicles. The “low rolling resistance tires” obviously did not behave better than the standard summer tires used on the EURO 4 version. Changes in the aerodynamic design were not made from these manufacturers.

The EURO 5 diesel model from manufacturer 2 had -19% CO_2 emissions compared to the EURO 4 version according to the type approval data. In the roller tests with the real world driving resistances a CO_2 reduction by 18% was measured in the NEDC test. In the real world cycle mix the change between EURO 4 and EURO 5 was 9.3% for CO_2. This still is an impressive result, especially since manufacturer 2 reduced the NO_x emissions in the real world test cycles even more than in the type approval cycle (-40% compared to -19%). All other relevant pollutants (PM, PN, HC and CO) were on very low levels for EURO 4 and even lower for the EURO 5 model.

For the two diesel cars thus the trends were quite contrary. One manufacturer had slightly higher CO_2 reductions from EURO 4 to EURO 5 in real world driving than in type approval but with clearly increased NO_x emissions. The other manufacturer had lower CO_2 reductions from EURO 4 to EURO 5 in real world driving than in type approval but with a clear reduction of the NO_x emissions in parallel.

From manufacturer 3 gasoline vehicles were selected. According to the type approval data the new model consumes 16% less fuel than the old model. In the NEDC test with real world driving resistance values only -4% were measured, in the real world mix the result was -6%. The new model is a direct injection engine with start/stop function while the predecessor used a port injection. From a combination of these technologies a larger CO_2 reduction potential was assumed. However, it has to be pointed out that testing just one vehicle per model includes the risk of taking single vehicles which do not represent the entire series due to spreads for standard factory models or malfunctions which were not detected in the inspection before the tests. The EURO 5 gasoline direct injection engine had lower NOx than the EURO 4 model but higher CO and HC emissions. However, all of these components were on a very low level for the EURO 4 and EURO 5 model. The particle mass and number emissions from the EURO 5 gasoline vehicle were found to be clearly higher than from the EURO 4 model but still lower than from the one EURO 4 diesel car tested without particle filter.

4 RECOMMENDATIONS

Although the tests performed cover only a very small sample of vehicles the test result indicates clear trends and recommendations.

- A main parameter for underestimation of real world fuel consumption values by the type approval data seems to be the lower driving resistance values used at type approval.

→ The driving resistance values of the vehicle models applied in the TA are not available in any document of the vehicle registration. It is suggested to make the driving resistance equation in future available in the approval certificate to be able to reproduce the TA procedure at independent labs. Additionally in a future update of the test procedure more realistic settings could be prescribed for TA coast down testing. Also the tire model could be prescribed which is used as original equipment of the vehicle. The default resistance values defined according to 70/220/ECE should define a tire pressure and a suitable default rolling resistance value (e.g. from the tire labelling tests according to ISO 8767).

- The ratio between type approval data and real world mix fuel consumption and CO_2 emissions varies strongly between makes and models. This is also true fro the NO_x emissions which are an important exhaust gas component with the actual air quality situation in Europe.

→ The next test cycle (WLTP) shall therefore be checked to cover more load points and exhaust gas temperature ranges as well as to include more different transient load changes than the NEDC to enforce the optimisation towards low emissions over a broader range of operation conditions.

- The real world CO_2 emissions are in the range of +20% compared to the type approval data. Since the actual real world driving behaviour is not well known and the tested vehicle sample is quite small a more exact statement for the tested vehicles is not possible.

→ Obtain better data on real world driving (see above)

- A prediction of future trends of real world CO_2-emissions from new vehicle registrations based on the CO_2 targets for the manufacturers in the type approval test will include reasonable uncertainties but seems to be at least the best available indication. The three tested vehicles suggest that applying the reduction rates from type approval data to real world may be too optimistic in future.

→Select vehicles and test cycles in future national test programs more systematically to get a better picture from an European cooperation (e.g. in the ERMES group). Especially further tests on pairs of models shall be performed to get an overview how the average trends in real world CO_2 reduction compared to the CO_2 monitoring data evolves.

5 ABBREVIATIONS

CADC......... Common ARTEMIS Driving Cycle
CO .... Carbon monoxide
CO_2............. Carbon dioxide
CVS .... Constant Volume Sample
C_W............... Air Resistance Coefficient [-]
DOC .... Diesel Oxidation Catalyst
DPF .... Diesel particulate filter
EGR............ Exhaust gas recirculation
EUDC......... Extra Urban Driving Cycle (part of the NEDC)
EURO......... European emission type approval level
FC............... Fuel consumption
GPS .... Global Positioning System
HC .... Hydrocarbon emissions
HDV .... Heavy duty vehicle
IATS........... Integrated Austrian Traffic Situations (test cycle)
IVT .... Institute for Internal Combustion Engines and Thermodynamics
LCV............ Light commercial vehicle
NEDC......... New European Driving Cycle
NO_x............. Nitrogen oxide
OEM........... Original Equipment Manufacturer
PC............... Passenger car
PHEM......... Passenger Car and Heavy Duty Vehicle Emission Model
PM.............. Particulate mass
PN............... Particulate number
TUG .... University of Technology Graz
TA .... Type Approval of cars in the NEDC test cycle with 20°C to 30°C start temperature
UDC .... Urban Driving Cycle (part of the NEDC)

6 TASKS

For emission monitoring as well as for the analysis of suitable emission reduction measures it is necessary to have a reliable assessment of the emission behaviour of vehicles in real world traffic situations.

It is an obvious approach to include the data from CO_2 monitoring of the passenger car registrations into the process of determination of the emission levels of the new car fleets since all registered passenger cars are included in this data set. A direct use of the type approval values in emission inventories is not possible since real world driving differs from the type approval test and users of emission models typically need emission and fuel consumption factors for a set of different traffic conditions.

The actual real world CO_2 emission factors of the HBEFA 3.1 therefore have been computed with the detailed vehicle emission model PHEM for the EURO 4 vehicles from a large data base, [3]. To compute CO_2 emission factors for other years of registration, it was assumed that the relative change of the specific fuel consumption from one model year to another in real world driving is similar to the CO_2 monitoring data. This assumption was also used for predicting future CO_2 and fuel consumption values but no detailed analysis on this assumption is available yet.

To get more reliable predictions of the future development of the passenger car CO_2 emissions in Europe, the method to predict the real world specific fuel consumption of future new registrations from the targets in the type approval cycle shall be screened and improved if necessary.

In this work a first analysis was done to assess if the influence of modern vehicle technologies like start/stop-function, improved aerodynamic etc. on fuel consumption is different in the NEDC and in real world cycles. For the study six passenger cars were measured on the chassis dynamometer in different test cycles. The six vehicles were selected to build up three vehicle pairs, each pair representing the EURO 4 model and the EURO 5 successor. To have the most actual technologies, pairs were selected which use special fuel saving technologies in the EURO 5 model.

7 TEST PROGRAM

After the selection of the test vehicles coast down tests were performed with all cars. Then emission measurements on the chassis dynamometer were done using the measured driving resistance values.

The test program covered the NEDC (with cold and hot start) as well as the two sets of real world cycles (CADC and IATS). The urban cycle of the IATS was also measured with a cold start to assess also the fuel consumption in real world cycles with cold starts. The focus of the work was on the fuel consumption but also the limited pollutants (NO_x, CO, HC und PM) as well as the particulate number and the NO_2-emissions were measured.

The tested vehicles and the test cycles are described in this chapter.

Test vehicles

In total six passenger cars (three vehicle pairs) were chosen: Every vehicle pair consists of one actual model which is advertised from the manufacturer to apply special fuel efficient technologies such as start/stop-function, higher gear ratio in the highest gear, aerodynamic improvements, etc. and the second car being the former model without these technologies. This vehicle selection allows a direct comparison of the ratio of the CO_2 emissions between the EURO 4 and the EURO 5 model in all test cycles. **Table** 7-1 shows the tested models.

Table 7-1: Tested vehicles

	vehicle 1.1	vehicle 1.2	vehicle 2.1	vehicle 2.2	vehicle 3.1	vehicle 3.2
engine	Diesel	Diesel	Diesel	Diesel	Gasoline	Gasoline
	turbocharged	turbocharged	turbocharged	turbocharged	naturally aspirated	naturally aspirated
displacement [cm³]	1896	1968	1995	1995	1999	1999
rated power [kW]	77	81	89	105	110	111
gearbox	manual	manual	manual	manual	manual	manual
	5 gear	5 gear	6 gear	6 gear	6 gear	6 gear
exhaust aftertreatment	oxidation catalyst	oxidation catalyst	oxidation catalyst	oxidation catalyst	3-way catalyst	3-way catalyst
	no diesel particle filter	diesel particle filter	diesel particle filter	diesel particle filter		
year of manufacture	2004	2009	2005	2009	2007	2009
mileage [km]	129000	23900	74000	3000	37000	16000
vehicle weight [kg]	1605	1567	1605	1605	1370	1360
EURO class	EURO 4	EURO 5	EURO 4	EURO 5	EURO 4	EURO 5

Test cycles

To obtain information on the change of the emission levels between EURO 4 and EURO 5 versions of the tested vehicle models the type approval test and two different sets of real world cycles were measured.

7.1.1 NEDC

The NEDC is the type approval cycle of the European Union. It is split up in two parts the UDC (Urban Driving Cycle) which is repeated four times and the EUDC (Extra Urban Driving Cycle). The duration of the whole cycle is 1180 s, the UDC is 780 s and the EUDC is 400 s. Figure 7-1 shows the speed profile of the NEDC with the specific characteristics, the constant acceleration and the cruising parts. The gear shifting is defined at fixed vehicle speeds.

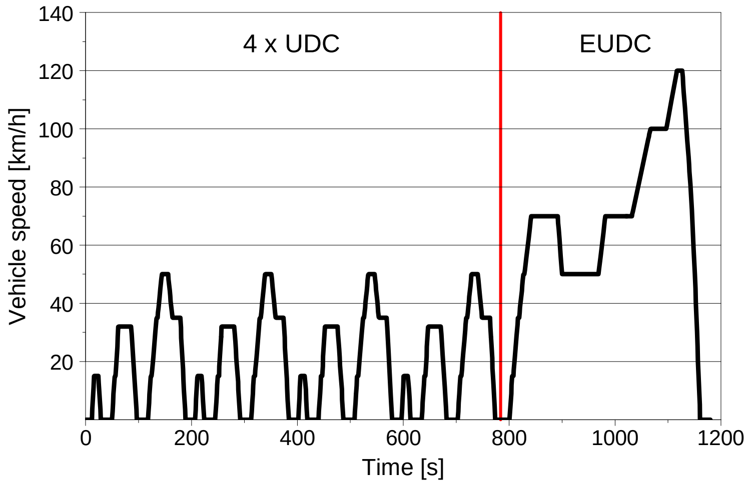

Figure 7-1: Speed profile of the NEDC

7.1.2 CADC

Within the framework of the European research program ARTEMIS, the Common ARTEMIS Driving Cycle (CADC) was developed, e.g. [1]. Three large data sets of on road recordings of driving behaviour were used for the cycle development: the multi-national Modem/Hyzem data, Swiss data, and German data. The final CADC driving cycle consists of 13 "kinematic segments" from the Modem/Hyzem data set. The single segments were extracted from the data set via a cluster analysis. Thus the mix of sub-cycles covers the relevant traffic situations. Due to practical reasons on the test bed each sub-cycle has a similar duration. Therefore the result of the CADC does not necessarily represent the shares of the traffic situations in real world driving. Since the sub-cycles of the CADC are not attributed to specific traffic situations no weighting factors of the single sub-cycles can be established.

The CADC consists of three parts, urban, road and motorway. The three parts can be used independently, and therefore all start and end with zero speed. The cycle duration and the bag times are given in Table 7-2.

Table 7-2: Cycle duration and Bag times of the CADC

	Cycle duration [s]	Bag start [s]	Bag end [s]
urban	993	73	993
road	1082	102	1082
motorway	1068	177	913

The CADC highway part exists in two versions: the 2 cycles are very similar, except in their second phase. In this second phase, the standard cycle reaches 150 km/h while the alternative one remains below 130 km/h. Due to temperature limits at the exhaust pipe the motorway part with the 130 km/h was measured here. Figure 7-2 shows the three main CADC parts with its sub-cycles.

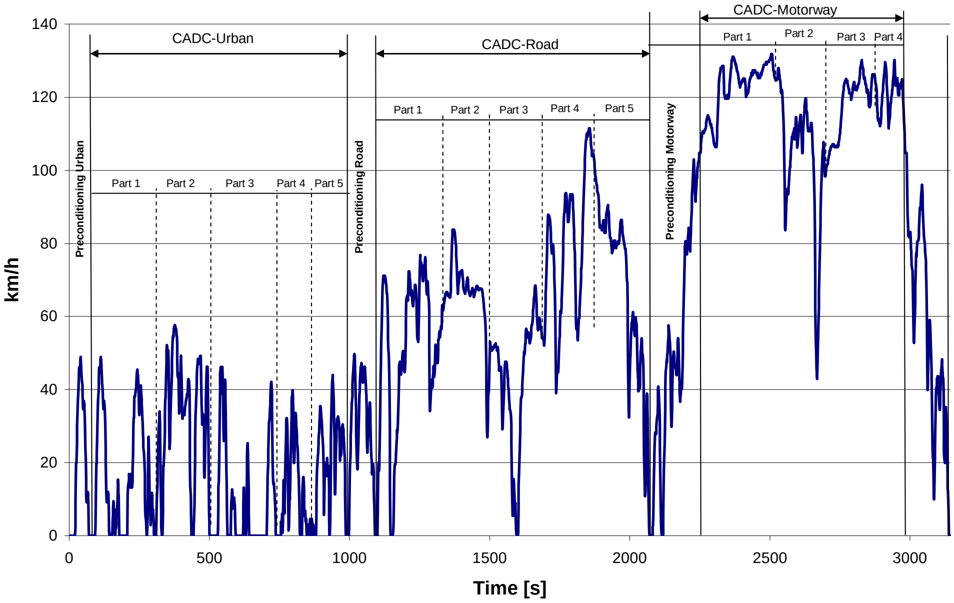

Figure 7-2: Speed profile of the CADC

Gear change has a significant influence on the emission level. A software was developed by INRETS to model gear changes for a given speed curve by reproducing gear-shifting measured on-road. In principle, this approach will yield a different gear-shift strategy for every single car/driver combination. For use within the CADC it was decided to define a limited number of fixed gearshift strategies, only depending on the vehicle’s technical characteristics. This lead to the definition of four vehicle classes. High-powered vehicles are clustered into the first class. This group only contains gasoline cars, mainly sports cars. Their power-to-weight ratio is above 76 [W/kg] and their "maximum speed" in the 3rd ratio is higher than 110 [km/h]. At the opposite, the 4th class is made of low powered vehicles: their power-to-weight ratio is below 60 [W/kg] and their "maximum speed" in the 3rd ratio is lower than 102 km/h. All diesel cars were measured with this gear shift strategy. The two other groups are made up of cars with intermediate power-to-weight ratio: Upper limit for the specific power is 76 [W/kg] for the 2nd class. There, cars are mainly differentiated by their maximal speed in the 3rd ratio. For the 2nd class, this speed is up to 118 [km/h]. Other cars belong to the 3rd class, with an average power-to-weight ratio and a "short gearbox". In the test program the gear shift strategy was selected from these CADC definitions.

7.1.3 IATS

The IATS-cycle was elaborated at the IVT to represent the average driving behaviour of cars in Styria/Austria. In contrary to the CADC the IATS is based on on-road measurements on defined test routes. Each test route as well as the times of testing was planned in detail to allow an allocation of the recorded speed curves to traffic situations. In each test the vehicle data, the vehicle speed and engine speed and the clutch activation was recorded in 1Hz. The traffic load on the different parts of the test routes was recorded in 30 minutes average values. Since the development of the IATS had no funding tests with only nine different drivers with eight different vehicles are available yet. However, at the moment no other data set is available which contains all information relevant for the development of a representative test cycle. From the data set average speed curves for the most relevant traffic situations have been elaborated to represent the according kinematic parameters as well as the engine load and emission levels of the entire sample, [12]. In total 24 traffic situations were selected and summarized to the urban, road and motorway parts of the IATS.

Similar to the CADC for the IATS-cycle also 4 vehicle classes with different gear shift strategy were defined. The selection of the gear shift strategy for a vehicle uses the same criteria as the CADC but the actual gear shift points are different.

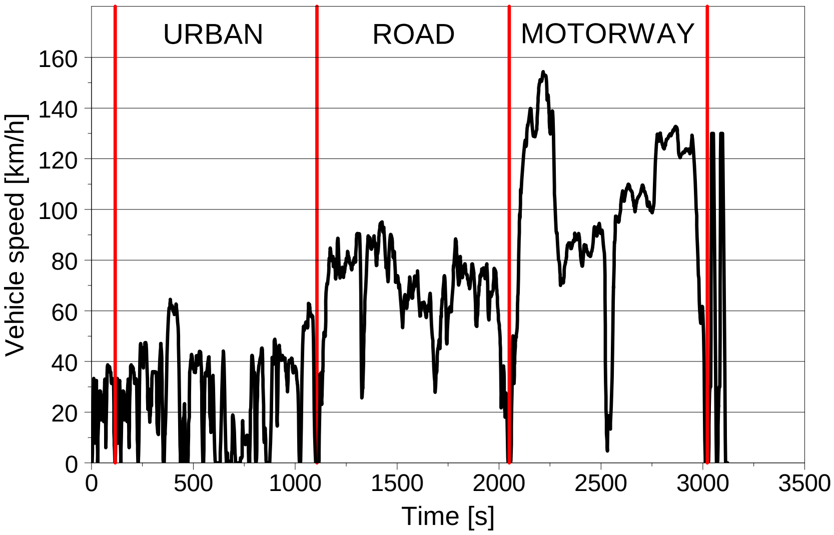

Figure 7-3: Speed profile of the IATS cycles

The three parts of the IATS-cycle can be used independently, and therefore every part starts and ends with zero speed. The cycle duration and the bag times are given in Table 7-3.

Table 7-3: Cycle duration and bag times of the IATS-cycle

	Cycle duration [s]	Bag start [s]	Bag end [s]
urban	1108	118	1108
road	945	1	945
motorway	1070	105	895

Chassis dynamometer

All tests were performed at the chassis dynamometer of the IVTof the University of Technology Graz. The technical specifications are:

Brake: 56 kW DC machine and 240 kW AC machine
Vehicle mass: 567 to 2325 kg
Max. vehicle velocity: 200 km/h
CVS-flow: 6, 10 or 20 m^3/min
Adjustable temperature: -30°C to +40°C
Adjustable humidity.

The test bed can be used for stationary test applications as well as for transient measurements. For stationary operations the test bed controls either a constant traction force of the wheel or a constant vehicle velocity. For the measurements in that project the transient operation mode was relevant. In that operating mode the test bed is simulating the driving resistance of the vehicle. For the actual measurements the driving resistance values were measured on the street with a coast down test. The driving resistance curve depicts the resistance forces from rolling resistance and from air resistance in dependency of the vehicle velocity.

The driving resistance is simulated according to the following formula:

$$F = R_0 + R_1 * v + R_2 * v^2 \qquad \text{Eq. 7-1}$$

With F.......... braking force at the wheel [N]
R_i .... driving resistance coefficients
V......... vehicle speed [m/s]

In addition to the rolling resistance and air resistance also the inertia of the vehicle is simulated on the chassis dynamometer by means of variable sets of masses connected to the rollers.

The exhaust gas is diluted with a HORIBA full-flow-CVS-system and afterwards the diluted emissions (CO, CO_2, HC and NO_x) are measured with a AVL CEB II. The emissions are analysed from the bags as well as from the instantaneous emission measurement. The test stand fulfils the definitions EC 692/2008 in the actual amendment.

The speed curve over the time as well as the defined gear shift points of the particular driving cycle are given to the driver by a monitor (Figure 7-4).

Figure 7-4: Chassis dynamometer test cell

Coast down tests

To obtain the real driving resistance values a coast down test was performed for each of the six vehicles. The coast down tests for each pair of vehicles were performed on the same day to exclude influences of varying ambient conditions. The wind speed was zero during the test runs. The coast down tests were performed on a public street near the city of Graz on a strait and flat part. Each vehicle was coasting five times in each direction and the vehicle speed was recorded with a GPS system in 20 [Hz]. The evaluation of the coast down tests was made according to 70/220/EEC. The tyre pressure was set to 2.2 bar, which met the specifications from the OEM in all vehicles.

In a coast down test the vehicle is accelerated to 120 km/h, then the neutral position of the gear box is selected and the clutch is opened. Thus the vehicle coasts down and the driving resistance is equal to the inertia of the vehicle as shown in **Eq. 7-2**.

$$m \times a = F_{Air} + F_{Roll} \qquad \textbf{Eq. 7-2}$$

With m......... vehicle mass [kg]

A......... acceleration [m/s²]

F_{Air}...... air resistance [N]

F_{Roll}..... air resistance [N]

For the evaluation of the coast down tests the mass includes also the vehicle loading and 3% of the vehicle mass to consider the inertia of the rotating masses. In the type approval procedure 70/220/ECE the inertia of rotating parts is not considered. This simplifies the calculation, however, it systematically underestimates the driving resistance values.

$$\underbrace{(\mathrm{m_{Veh}} \times 1.03 + \mathrm{m_{Load}}) \times \frac{\mathrm{dv}}{\mathrm{dt}}}_{\textit{inertia}} = \underbrace{\frac{\rho_{Air}}{2} \times c_w \times A \times \mathrm{v}^2}_{\textit{air resistance}} + \underbrace{(\mathrm{m_{Veh}} + \mathrm{m_{Load}}) \times \mathrm{g} \times (\mathrm{k_{R1}} + \mathrm{k_{R2}} \times \mathrm{v})}_{\textit{rolling resistance}} \qquad \textbf{Eq. 7-3}$$

With m_{Veh}...............mass of the empty vehicle [kg]

m_{Load}..............mass of the loading (here 75 kg)

A ....frontal area of the vehicle [m²]

v ....vehicle velocity [m/s]

k_{Ri}..................Rolling resistance coefficients

The influence of different ambient temperatures and pressures on the air density was corrected according to 70/220/ECE.

Coast down tests on a public road most likely give higher driving resistances than the values used in the type approval. The reason is that the combination of tires and road pavement near Graz is not optimised for low driving resistances but represent real world conditions. The driving resistance values of the models applied in the type approval tests are generally not available. It is suggested to make the driving resistance data in future available in the approval certificate.

8 RESULTS

The measurement results of the coast down tests and the emission measurement on the chassis dynamometer are shown on the next pages.

Driving resistances

Driving resistances gained from coast down tests on the road without optimum settings of tyre type and pressure and road surface quality should lead to higher resistances values than the type approval procedure. In the type approval procedure only the dimension of the tires is prescribed to meet the manufacturer’s specification. All other settings as well as the road surface are not defined. Without coast down tests also mass dependent default resistance values can be used in 70/220/ECE. The default settings have the basic assumption that the rolling resistances of the vehicle on the roller test bed are similar than on the road. The default value for the air resistance is rather high for modern sedan vehicles. In this test series these default values have been found to be lower at low speeds than the results of the coast down tests (Figure 8-1). This is due to the high tire pressure used on the test bed, which reduces the rolling resistance and protects tires from overheating in the real world tests.

Since the study aims at testing the real world fuel consumption of the vehicles the default values have not been applied in the test procedure here. Using the default values would also lead to no difference between EURO 4 and EURO 5 vehicles since all three pairs do have only small differences in the mass from EURO 4 to EURO 5 and thus the follow up models fall in the same category for the default resistance data. The real world coast down tests however showed only for one of the EURO 5 vehicles (vehicle 1.2) a significant lower driving resistance compared to the predecessors.

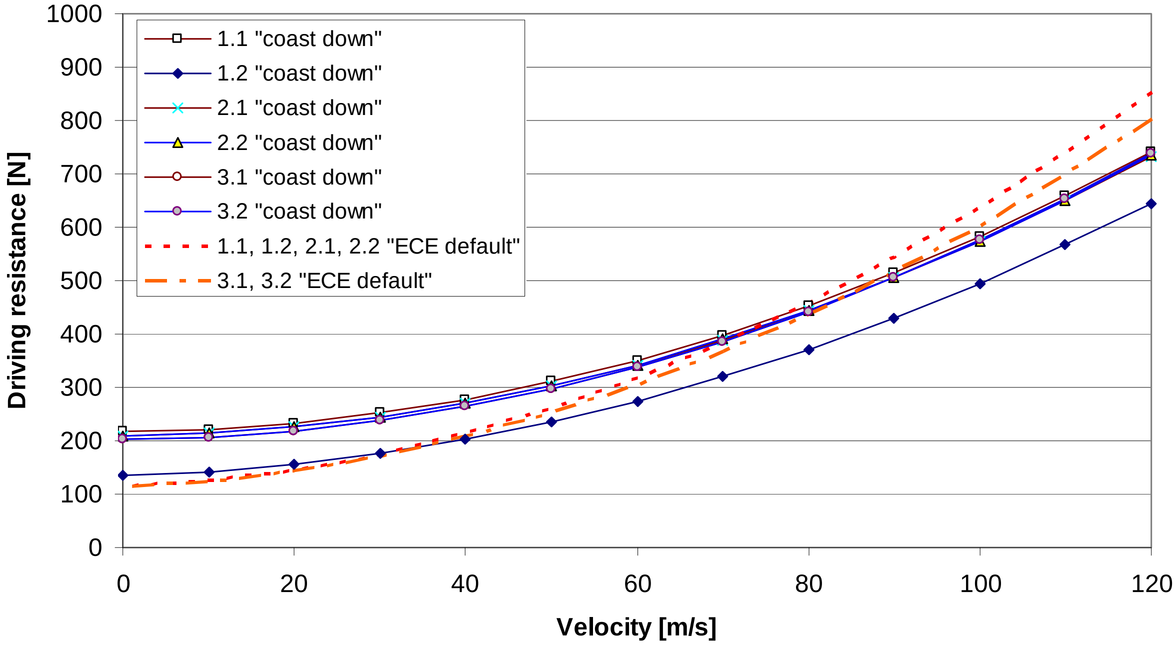

Figure 8-1: Driving resistance of all vehicles gained from the coast down tests compared to the default values in 70/220/ECE, chapter 3.2

The results for the single makes are described in detail below.

8.1.1 Manufacturer 1

The results of the coast down test with vehicle 1.1 and vehicle 1.2 are shown in Figure 8-2. It can be seen that the vehicle with the new technologies has clearly lower driving resistances as the former model. The differences are result of measures to reduce the air resistance coefficient as well as from special tires since R_0, R_1 and R_2 are lower for the EURO 5 model.

The reduction of the air resistance from the EURO 4 to the EURO 5 model calculated from the coast down tests is in line with the data given from the manufacturer in [5]. The OEM states -12.4% while the coast down tests resulted in -11.4. The relative difference between the models due to the lower rolling resistance was more pronounced than the difference of the air resistance. At 30 km/h the rolling resistance is 32% lower for the actual model.

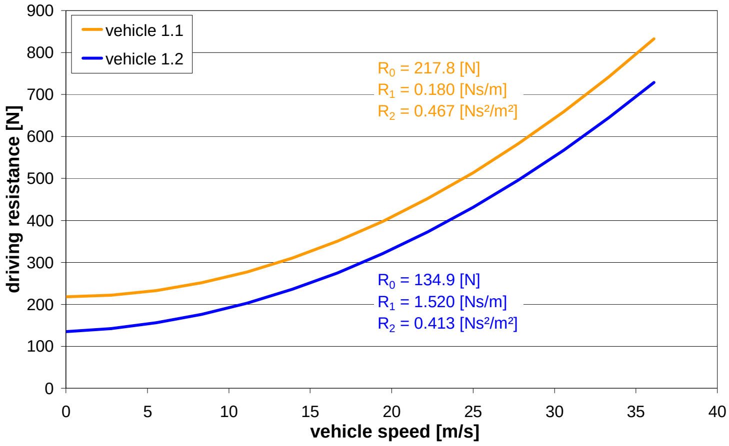

Figure 8-2: Driving resistance of vehicle 1.1 and vehicle 1.2

8.1.2 Manufacturer 2

The result of the coast down tests with vehicle 2.1 and vehicle 2.2 are shown in Figure 8-3. It can be seen that the vehicle with the new technologies has the same driving resistances as the former model. This is reasonable since the bodywork of both vehicles is similar. The newer vehicle was equipped with low-resistance tyres, but the difference of these tyres compared to normal tyres has no effects in the results of the coast down tests. Both vehicles from manufacturer 2 have a similar driving resistance as the EURO 4 vehicle from manufacturer 1.

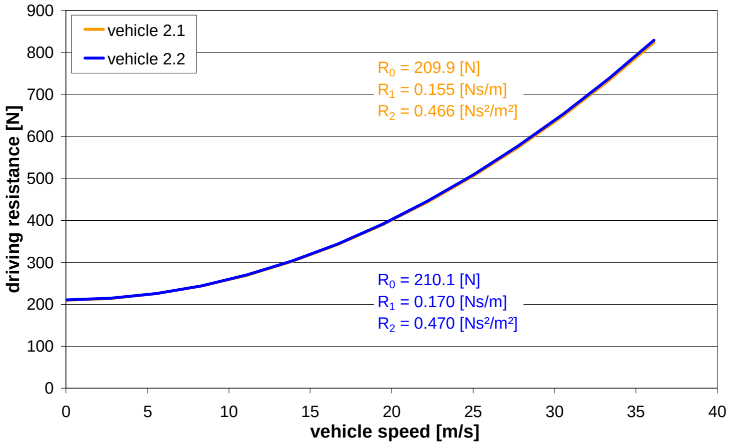

Figure 8-3: Driving resistance of vehicle 2.1 and vehicle 2.2

8.1.3 Manufacturer 3

The results of the coast down test with vehicle 3.1 and vehicle 3.2 are shown in Figure 8-4. Both vehicles have a similar driving resistance curve. From the available data this is logical since there was no difference visible between the two vehicles, not in the bodywork and also not in the tyres.

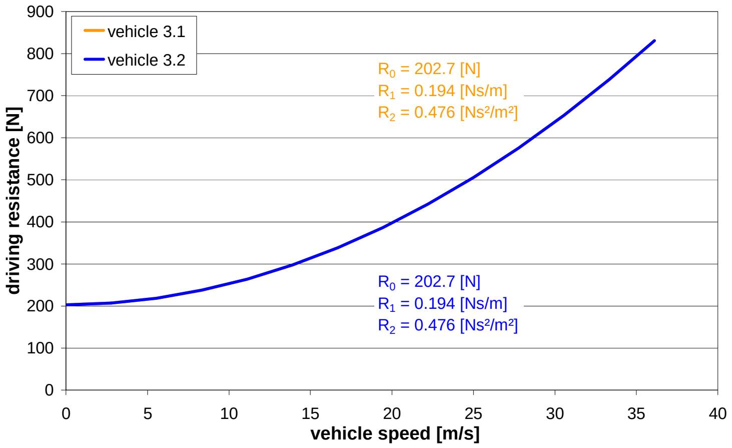

Figure 8-4: Driving resistance of vehicle 3.1 and vehicle 3.2

Emission measurement

The focus of the analysis was the difference in the emission levels between the actual model and its predecessor in the test cycles with driving resistance values from the coast down tests compared to the data given in the type approval documents. The results of the measurement campaign is also delivered to the measurement data base of the HBEFA and included in the emission model PHEM which calculates the HBEFA emission factors.

8.1.4 Manufacturer 1

The two models of manufacturer 1 represent modern diesel engine technology. The EURO 5 model has a redesigned engine concept and a more advanced injection system. Combined with an engine start stop system and measures to reduce air resistance and rolling resistance a very fuel efficient vehicle model is presented by the manufacturer. The rated engine power from the EURO 5 model is 5% higher than from the EURO 4 version.

The results of the measured CO_2-emissions of the two models from manufacturer 1 are shown in Figure 8-5. The CO_2 emissions of the new vehicle model are significantly lower than from the EURO 4 model in the type approval data as well as in all test cycles. The CO_2 values gained in the NEDC with the “real world” driving resistances are approx. 16% higher than the type approval data. This is due to the driving resistances which are obviously higher than in the type approval tests.

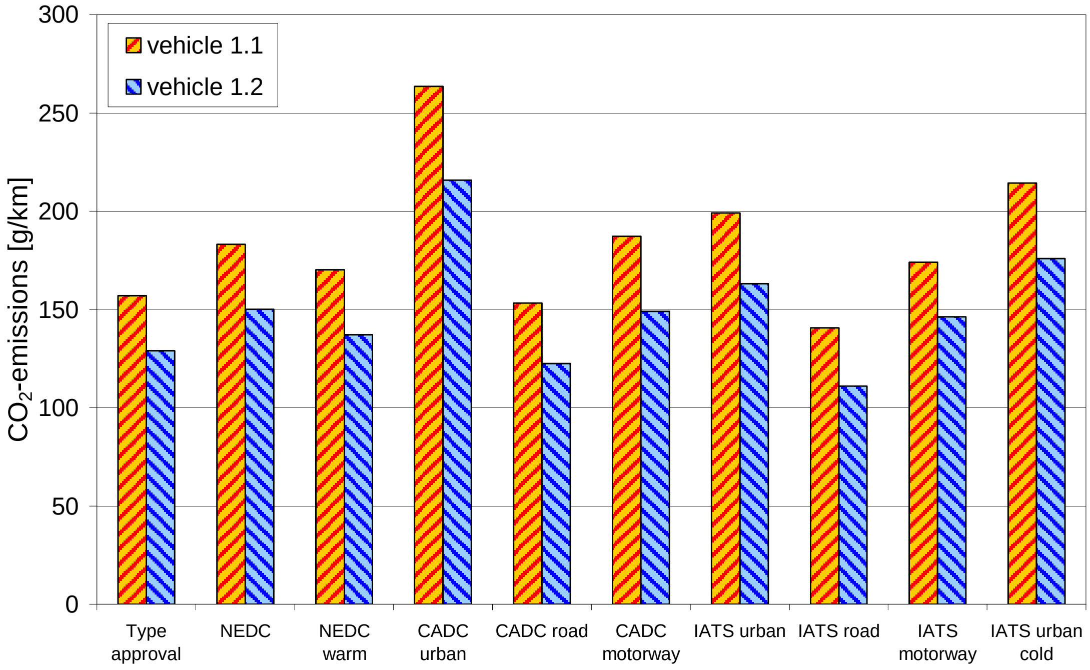

Figure 8-5: CO_2-emissions of the two models from manufacturer 1 in the different driving cycles

Testing the homologation cycle (NEDC with cold start) with the real world driving resistance values leads to a reduction of the CO_2-emssions from EURO 4 to EURO 5 by 18%. The type approval values give the same reduction rate (Figure 8-6).

The reduction of CO_2 from the old to the new model in the real world driving cycles was on average about 19%, which is slightly higher than the reduction rate in the NEDC test cycle with cold start. When the NEDC was started with a hot engine, the reduction rate from EURO 4 to EURO 5 was also 19%.

The average positive cycle work is the integral of the braking force and the distance over the test cycle where only these seconds are considered where the braking force is positive. This value is a good indicator on how the necessary engine work to overcome the driving resistance values helps to reduce the emissions. Due to the lower rolling resistance and air resistance and a slightly lower vehicle weight the engine work of the EURO 5 model is on average 12% lower than that of the EURO 4 engine in the NEDC and on average of all real world cycles. This is already 2/3 of the entire CO_2 reduction achieved. The remaining 1/3 is gained by a higher engine efficiency, a start-stop system, efficient auxiliaries, reductions of losses and also by the transmission ratio of the axis and the gear box. The engine operation points are shifted with the longer transmission of the EURO 5 model towards lower engine speed and higher torque which are ranges with a better engine efficiency.

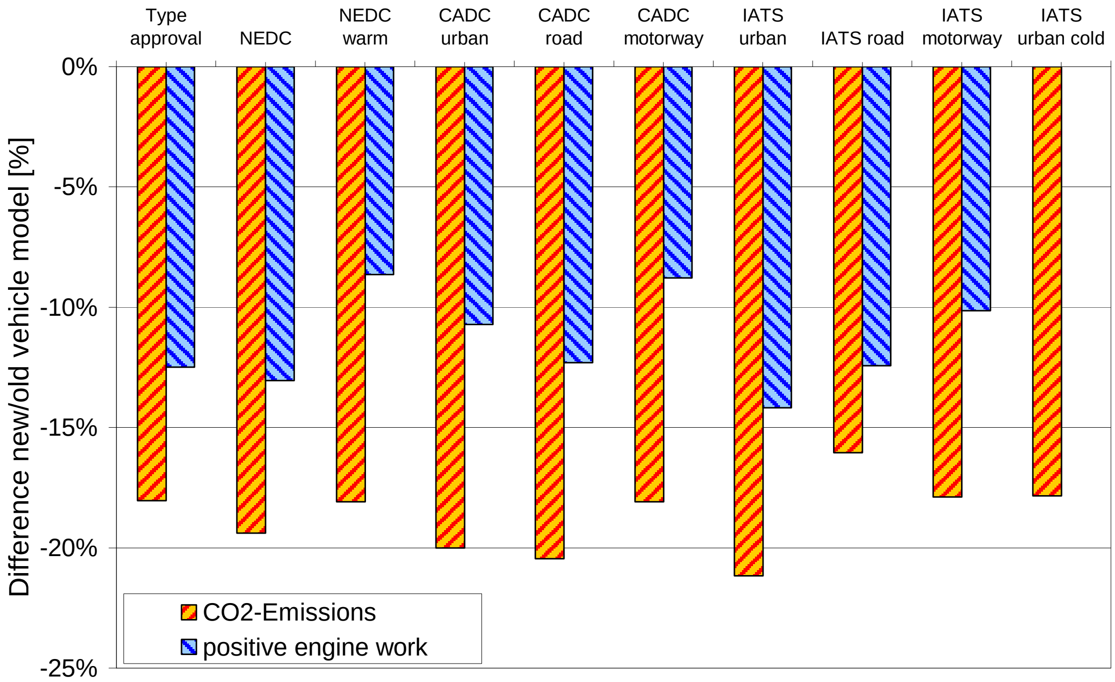

Figure 8-6: Changes of the CO_2-emissions and the cycle work between vehicle 1.1 and vehicle 1.2

Figure 8-7 shows the results for the NO_x-emissions of the two models in the different driving cycles. The NO_x-emissions of both vehicles in the NEDC are below the limit values even with the real world driving resistances. This leads to a 30% reduction of NO_x in the NEDC test cycle after cold start from the EURO 4 to the EURO 5 model (-37% according to the type approval data).

While for CO_2 a similar reduction was found in all cycles from EURO 4 to EURO 5, for NO_x a significant increase in all other cycles than the type approval NEDC is visible. The new model emits in the real world cycles between 15% and 90% more NO_x than the old model. Even in the NEDC cycle after hot start the EURO 5 model showed 60% higher NO_x. This indicates that in load and temperature ranges outside of the type approval test a part of the improvements of the engine efficiency is gained with a hotter combustion which increased the NO_x-emissions. This result indicates clearly that the actual test cycle is not effective to control the emissions of modern engines any more. The next test cycle (WLTP) shall therefore be checked to cover more load points and temperature ranges as well as to include more different transient load changes than the NEDC to enforce the optimisation towards low emissions over a broader range of operation conditions.

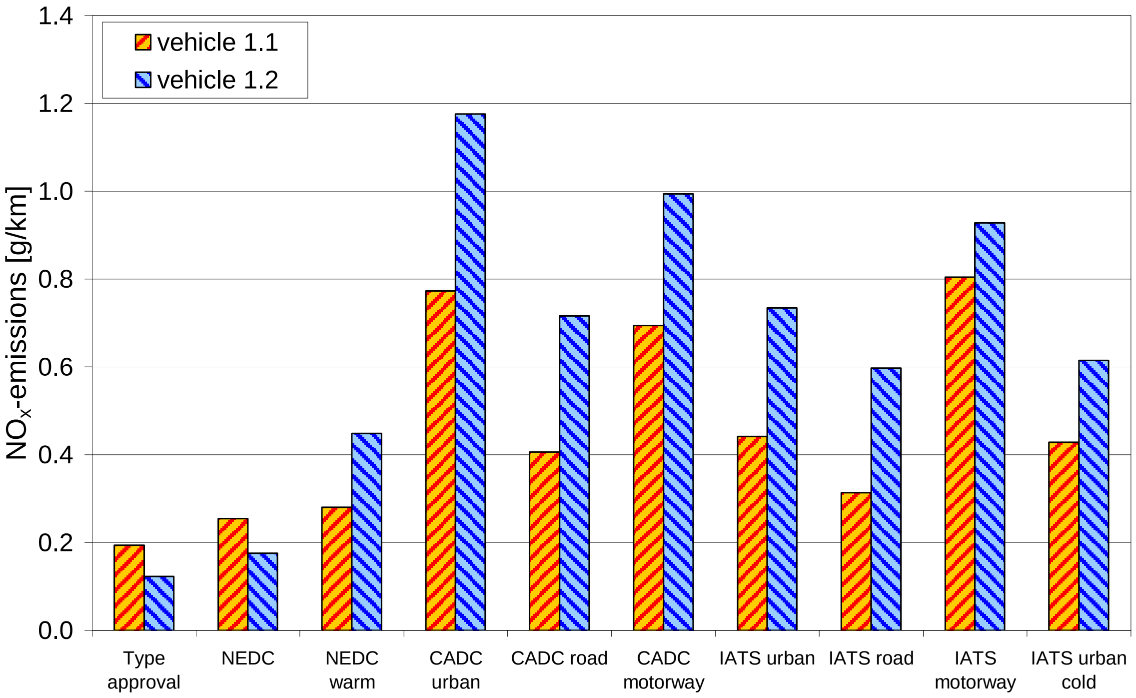

Figure 8-7: NO_x-emissions of the two models from manufacturer 1 in the different driving cycles

The NO_2-emissions of the two models in the different driving cycles are shown in Figure 8-8. Similar to NO_x, the NO_2-emissions of the EURO 5 model are higher than the NO_2-emissions of the EURO 4 vehicle in all driving cycles except the NEDC with homologation conditions. The ratio NO_2/NO_x was rather low for this vehicle (30% on average of the real world cycles for the EURO 5 model and 22% for the EURO 4 model).

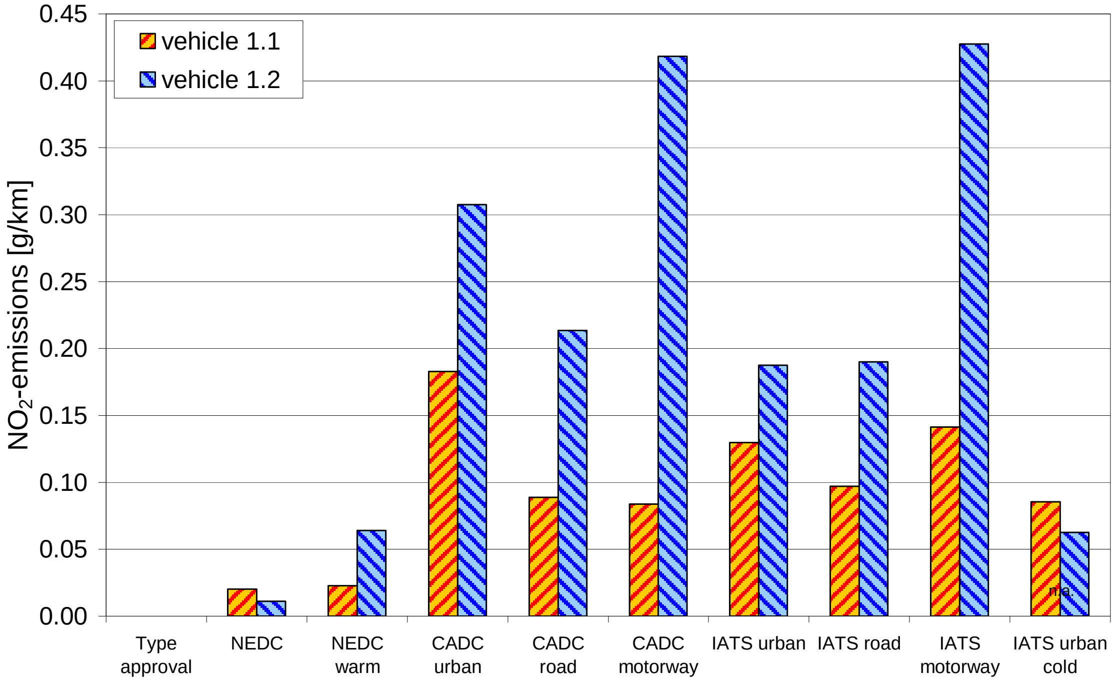

Figure 8-8: NO_2-emissions of the two models from manufacturer 1 in the different driving cycles

The result for the CO-emissions of the two vehicles in the different measured driving cycles is shown in Figure 8-9. The EURO 4 vehicle has higher CO-emissions in all performed driving cycles than the EURO 5 model. The CO emissions are in general on a low level.

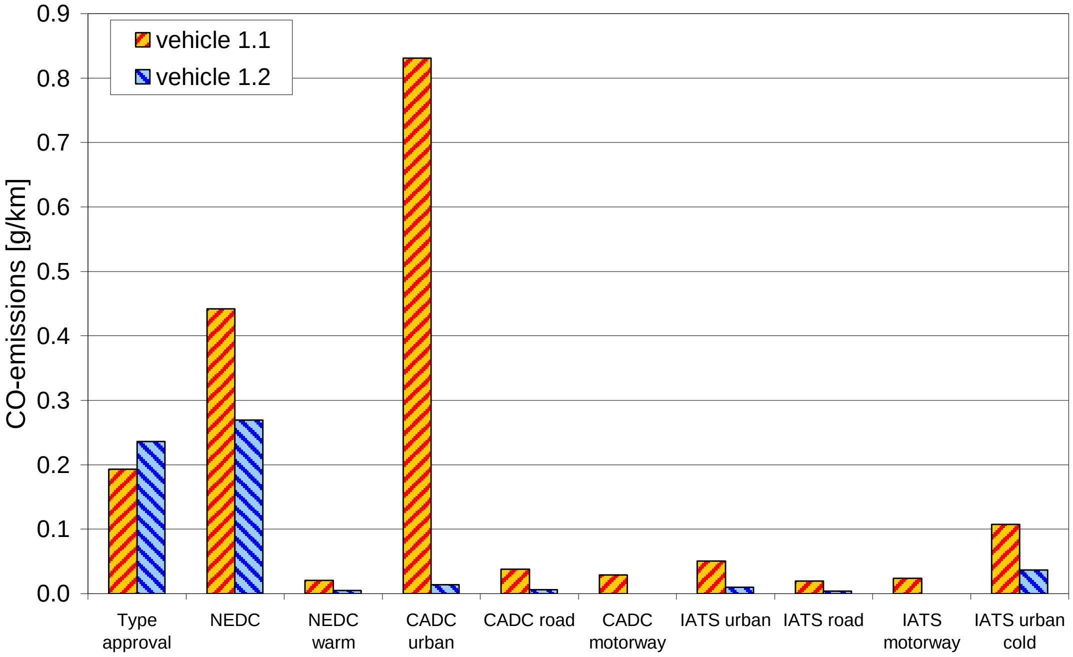

Figure 8-9: CO-emissions of the two models from manufacturer 1 in the different driving cycles

Figure 8-10 shows the results for the HC-emissions in the different driving cycles. For HC no specific limit value exists, only the total value of NO_x and HC is limited with 0.3 [g/km] for EURO 4 and 0.23 [g/km] for EURO 5. Also the HC emissions are generally on a low level. The EURO 5 model shows on average 82% lower HC than the EURO 4 model. Since the exhaust gas after treatment system had less running hours at the EURO 5 model than on the EURO 4 vehicle this may explain a part of the difference due to smaller aging effects (also for the CO results).

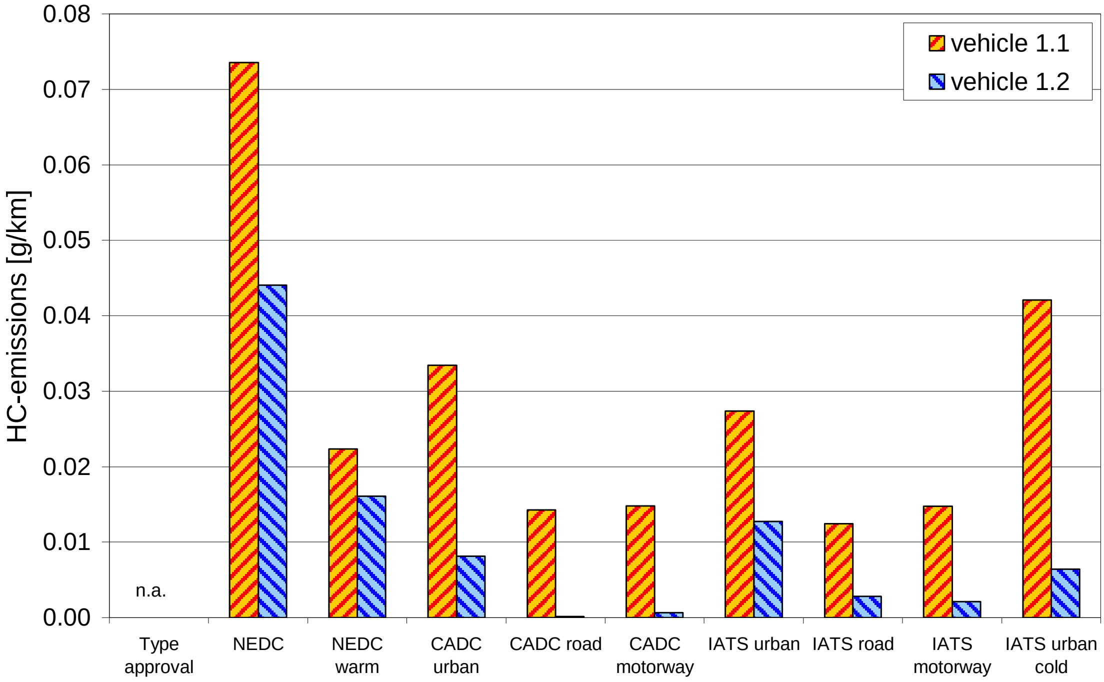

Figure 8-10: HC-emissions of the two models from manufacturer 1 in the different driving cycles

The results of the PM-emissions are shown in Figure 8-11. For the EURO 5 model with DPF the PM-emissions in all cycles are clearly lower than the PM emissions from the EURO 4 model which had no particle filter.

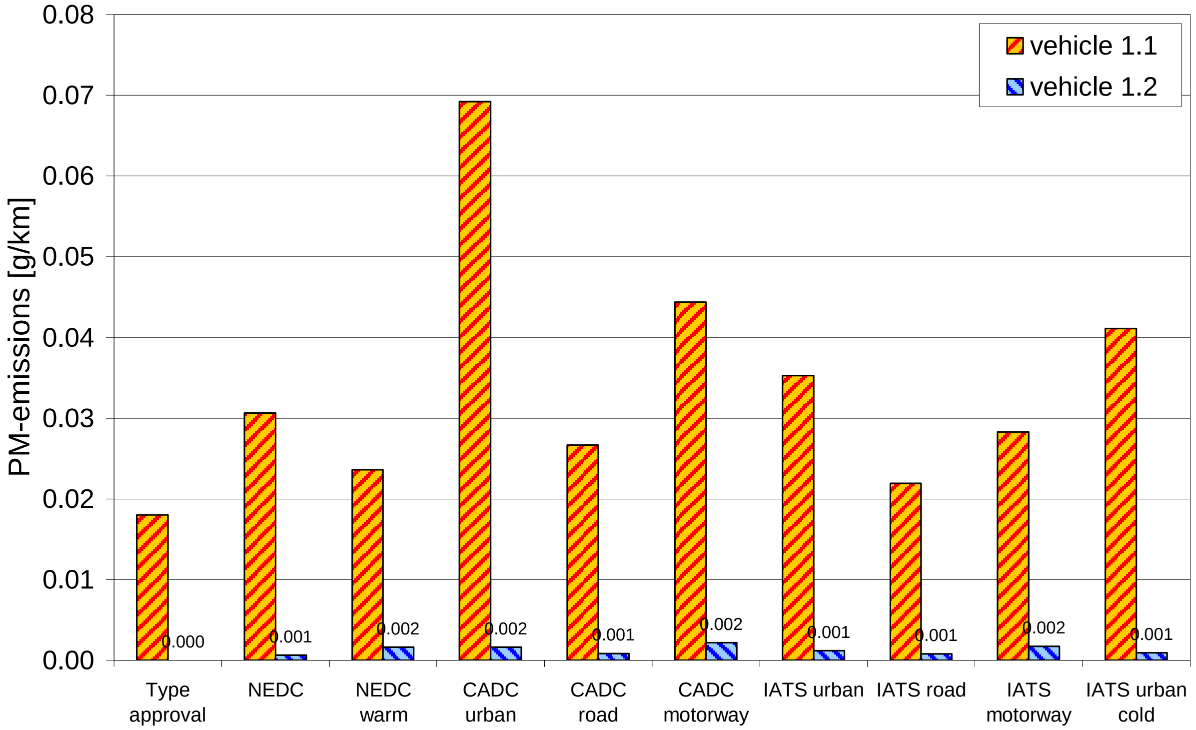

Figure 8-11: PM-emissions of the two models from manufacturer 1 in the different driving cycles

Figure 8-12 shows the PN-emissions of the two models in the different driving cycles. The EURO 5 model equipped with a particle filter shows three orders of magnitude lower PN-emissions compared to the EURO 4 vehicle without filter. The measured PN-emissions of the EURO 5 vehicle in every measured cycle are lower than the future limit value of 6 x 10^{11}.

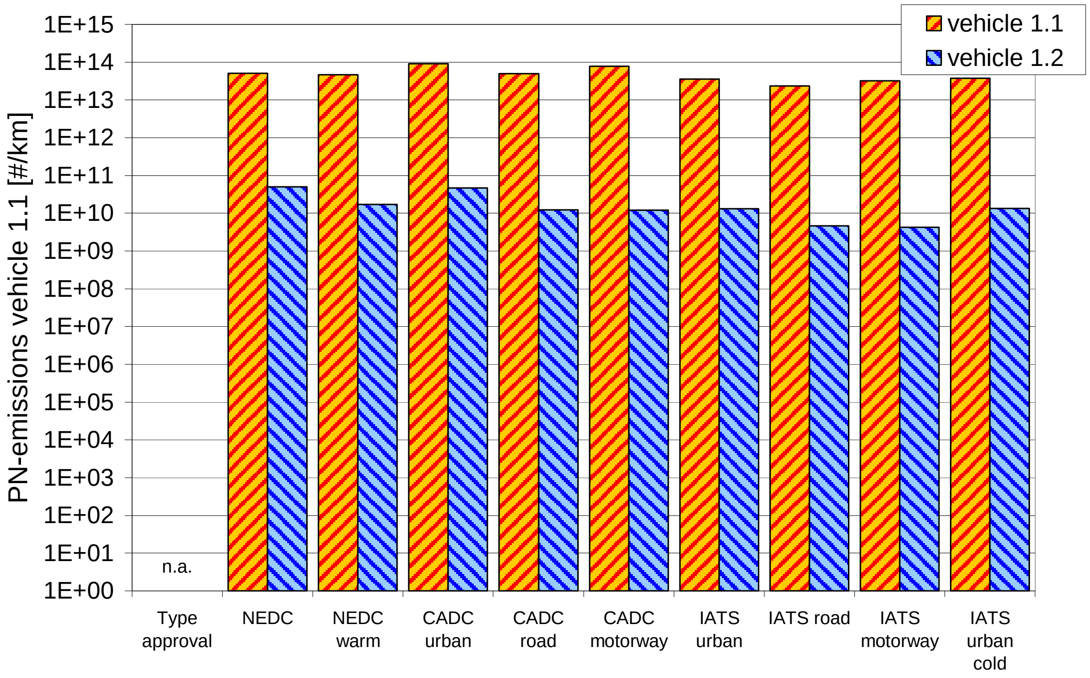

Figure 8-12: PN-emissions of the two models from manufacturer 1 in the different driving cycles (<u>logarithmic scale</u>!)

8.1.5 Manufacturer 2

The two models of manufacturer 2 also represent modern diesel engine technology. The EURO 5 model has a redesigned engine concept and 18% higher rated engine power compared to the EURO 4 model. Combined with an engine start stop system and measures to reduce the energy consumption of auxiliaries as well as tires with low rolling resistance the EURO 5 model combines several fuel efficiency packages.

The results of the measured CO_2-emissions of the two models from manufacturer 2 are shown in Figure 8-13. The absolute value of the CO_2-emissions in the NEDC with cold start is 178 [g/km] for the old model and 146 [g/km] for the new model. A comparison with the value of the homologation shows that emissions with the real world driving resistance values are approx. 15% higher compared to the type approval data for the EURO 4 model and 17% higher for the EURO 5 model. This is most likely due to the driving resistance values which are obviously similarly higher in real world then in the type approval test for manufacturer 1 and 2.

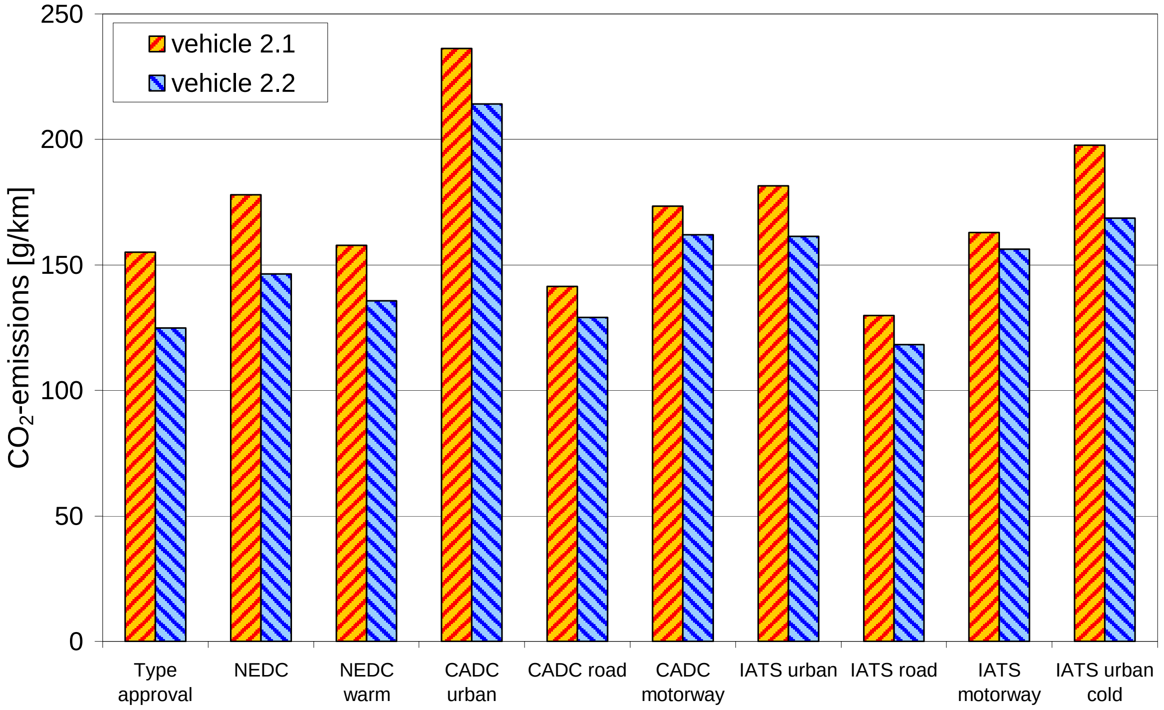

Figure 8-13: CO_2-emissions of the of the two models from manufacturer 2 in the different driving cycles

There is a significant reduction of CO_2 with the new vehicle model. In the NEDC with cold start using the real world driving resistance values the reduction is 18%. The type approval data gives 19% reduction. The reduction of CO_2 between the old and the new model in the real world driving cycles is on average 9%. In contrary to manufacturer 1 manufacturer 2 thus has lower CO_2 reduction rates in the real world cycles than in the type approval.

Due to the small difference in the coast down results between the two models, the average positive cycle work is similar for both models (Figure 8-14). Therefore the CO_2-reduction is resulting mainly from the improvements of the engine efficiency, the start-stop system and reduction of losses in auxiliaries. A higher differential transmission ratio in combination with an improved gear box which lowers the engine speed between 3% to 7% in the different gears leads to more fuel efficient operating conditions of the engine.

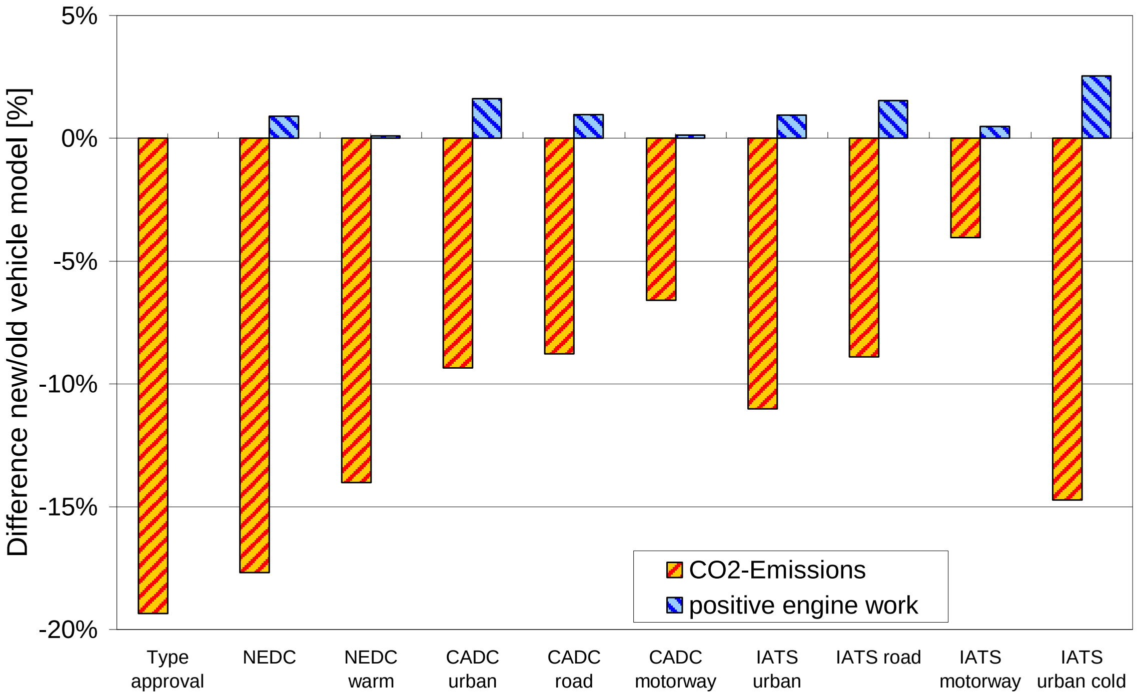

Figure 8-14: Changes of the CO_2-emissions and the cycle work between vehicle 2.1 and vehicle 2.2

Figure 8-15 shows the results for the NO_x-emissions of the two models in the different driving cycles. The type approval value is 19% lower for the EURO 5 vehicle than for the EURO 4 vehicle. In the real world test cycles the reduction was clearly higher and on average 40%. Even in the NEDC tests with the real world driving resistance values the NO_x reduction was 40%. Obviously manufacturer 2 followed with the new engine generation a different strategy than manufacturer 1. Manufacturer 2 obviously optimised the combustion process in the type approval engine loads towards high efficiency and just meeting the NO_x limit values while in the real world conditions the engine is relatively more tuned to lower the NO_x emissions than to lowest possible fuel consumption. Manufacturer 1 followed a rather inverse strategy. As a result manufacturer 2 has decreased the NO_x emission levels of the EURO 5 model to the level of the EURO 4 model from manufacturer 1. The NO_x from the EURO 5 model from manufacturer 1 are increased to the level of the EURO 4 model from manufacturer 2. This again shows that the modern engine control systems allow quite different strategies in the type approval test and in real world operation and that emission factors have to be based on a rather large number of tested cars to get representative trends for the vehicle fleet.

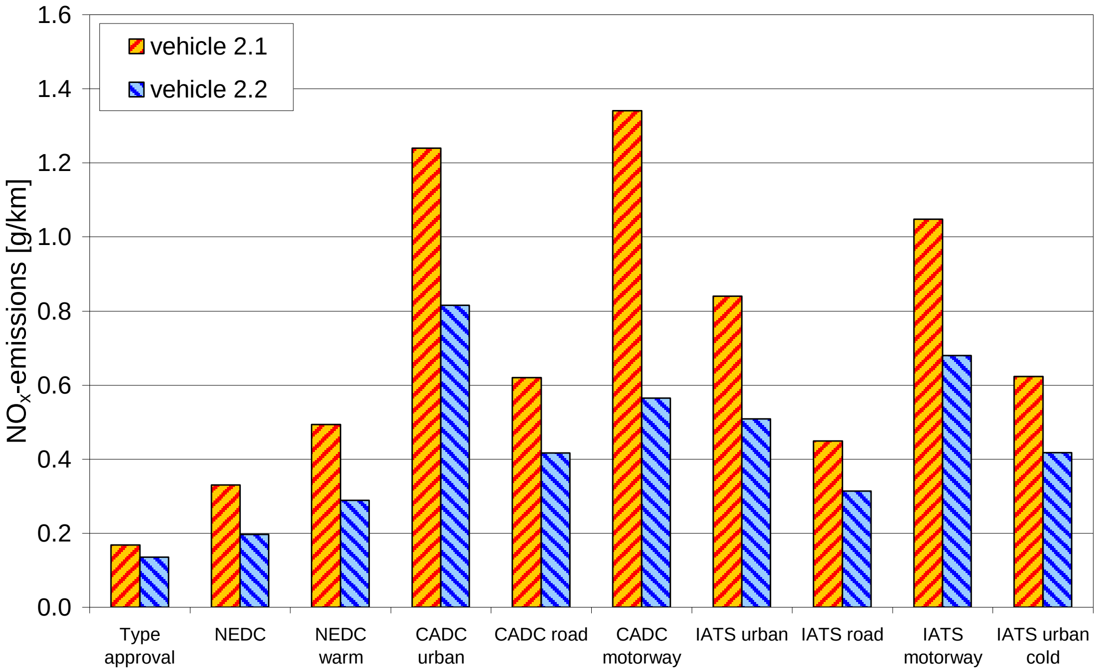

Figure 8-15: NO_x-emissions of the of the two models from manufacturer 2 in the different driving cycles

The NO_2-emissions of the two models are shown in Figure 8-16. The ratio of NO_2/NO_x is 40% in the real world cycles for the EURO 5 model and 49% for the EURO 4 model. In the NEDC with cold start 22% share of NO_2/NO_x was measured for the EURO 5 vehicle and 39% for the EURO 4 version. The lower NO_2 share in combination with the lower NO_x emissions leads to 66% lower NO_2 emissions in the type approval test (-52% on average over the real word cycles). Since the catalytic coating is more aged at the EURO 4 model, the lower NO_2 shares of the newer vehicle can be explained rather by the catalytic coating material (e.g. higher shares of Palladium, which shows lower aging effects at high temperatures than Platin but a lower activity in new condition).

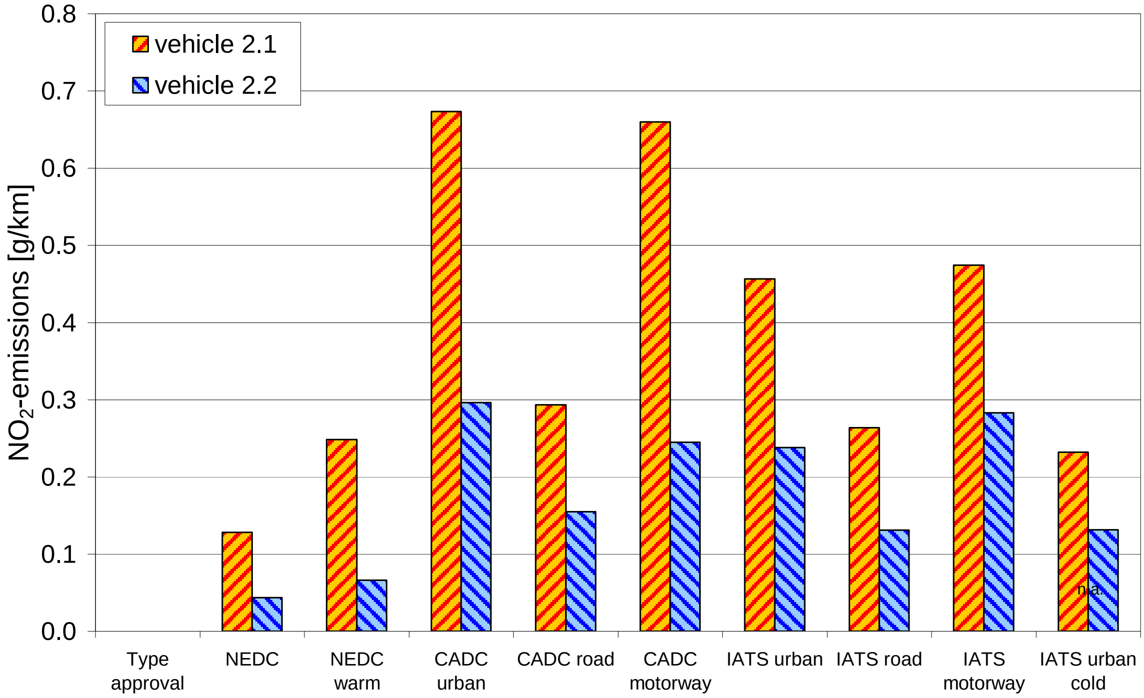

Figure 8-16: NO_2 emissions of the two models from manufacturer 2 in the different driving cycles

The result for the CO-emissions is shown in Figure 8-17. Due to the combination of DOC and DPF the CO-emissions of both cars are on a similar low level, except the NEDC with cold start where the EURO 4 vehicle has higher CO-emissions than the EURO 5. However, also with the higher "real world" driving resistance values from the coast down tests the emissions are below the limit value of 0.5 [g/km]. Higher emission levels of the EURO 4 model could be also a result of the more aged catalytic coating compared to the EURO 5 vehicle.

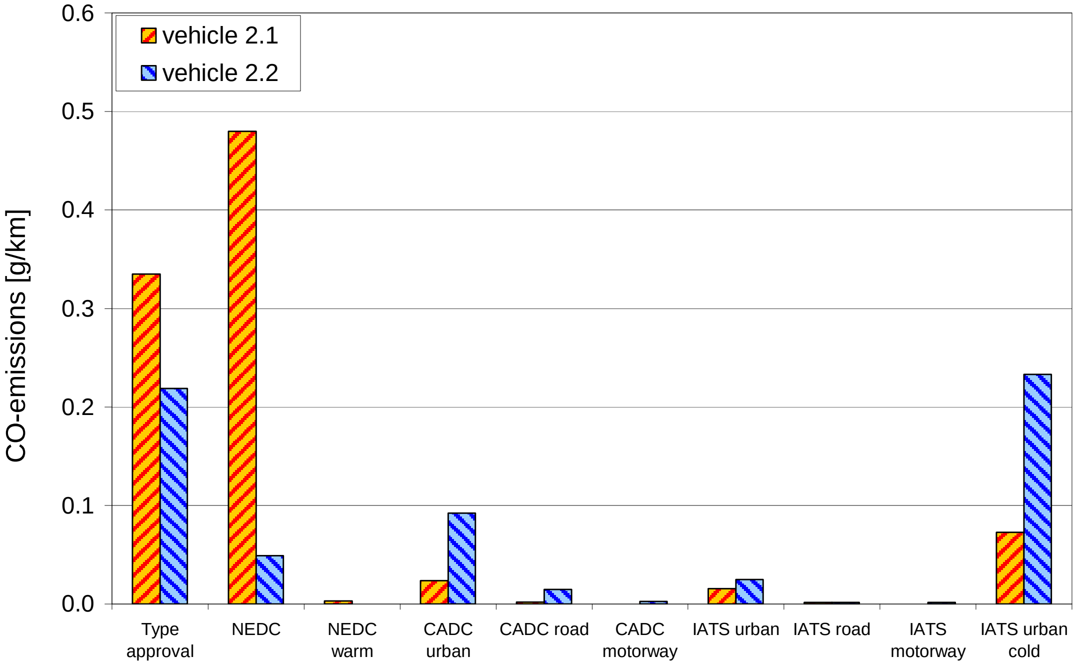

Figure 8-17: CO-emissions of the two models from manufacturer 2 in the different driving cycles

Figure 8-18 shows the results for the HC-emissions in the different driving cycles. For HC no specific limit value exists, only the total value of NO_x and HC is limited with 0.3 [g/km] for EURO 4 and 0.23 [g/km] for EURO 5. For HC we find similar trends as for CO, also an influence of thermal and chemical aging of the catalyst may influence the difference between EURO 4 and EURO 5.

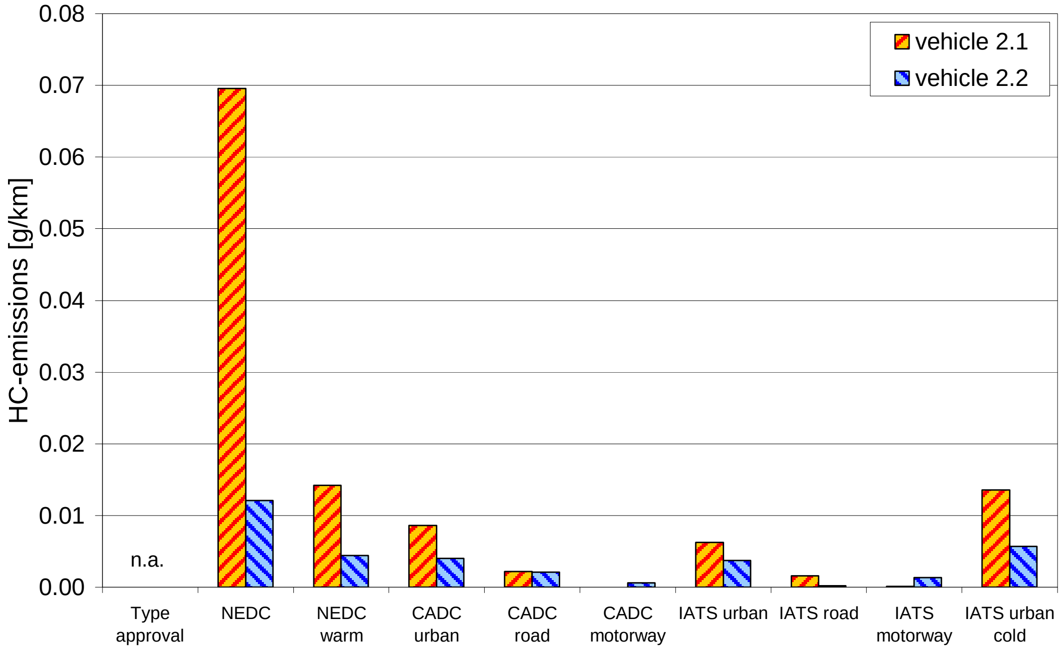

Figure 8-18: HC-emissions of the two models from manufacturer 2 in the different driving cycles

The results of the PM-emissions are shown in Figure 8-19. For both models from manufacturer 2 the PM-emissions are clearly lower than the EURO 5 limit value of 0.005 [g/km] in all measured driving cycles. The particle emissions from the EURO 5 model are lower than those of the EURO 4 model in most test cycles. Different trends over the cycles may be attributed also to different evolutions of the soot loading over the test series since a loaded filter typically has better removal efficiency than an empty filter. However, the emission levels are in the range of the measurement accuracy.

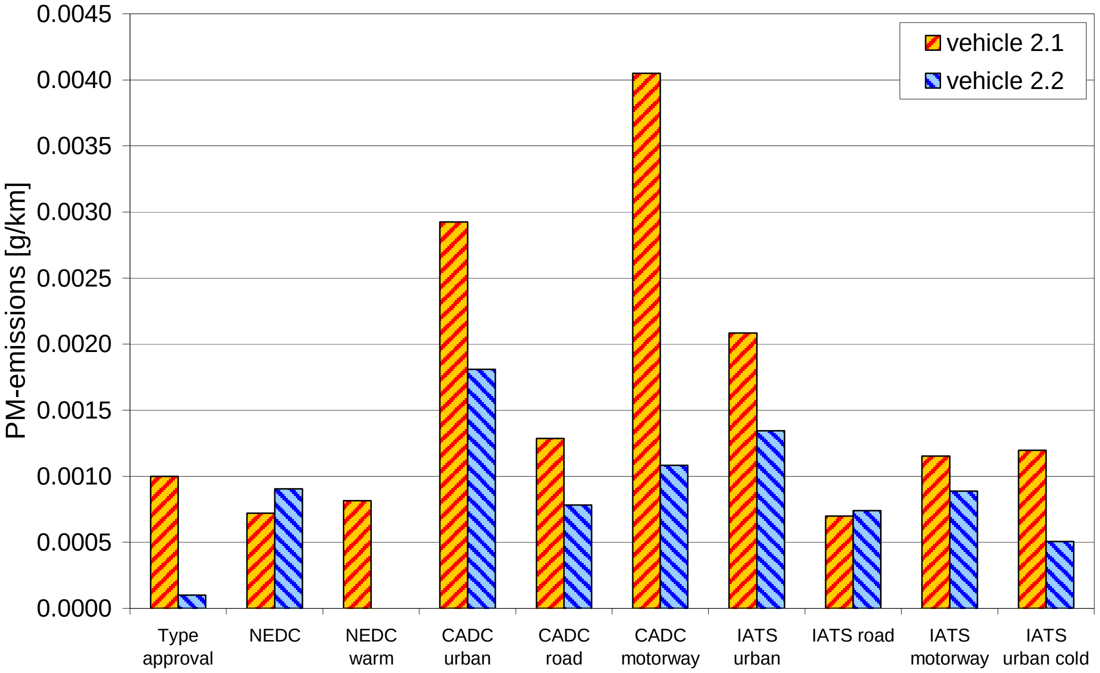

Figure 8-19: PM-emissions of the two models from manufacturer 2 in the different driving cycles

Figure 8-20 shows the PN-emissions for manufacturer 2. Both vehicles were equipped with a diesel particle filter. The measured PN-emissions of the Euro 5 vehicle in every measured cycle are lower than the limit value of 6 x 10^{11}.

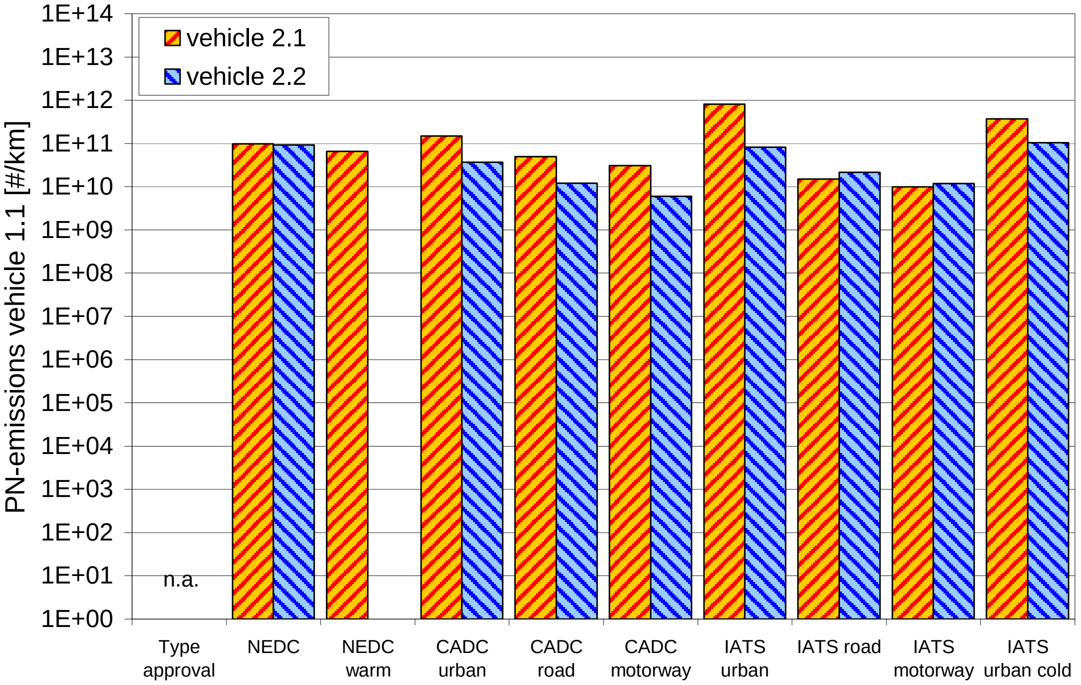

Figure 8-20: PN-emissions of the two models from manufacturer 2 in the different driving cycles (logarithmic scale!)

8.1.6 Manufacturer 3

The two models from manufacturer 3 represent modern gasoline engine concepts with rather high rated engine power values. The new model has a direct injection engine and an engine start-stop system. The rated engine power is nearly unchanged from EURO 4 to EURO 5 (+1kW).

The results of the measured CO_2-emissions are shown in Figure 8-21. The tests with the real world driving resistance values lead in the NEDC with cold start to 206 [g/km] for the old model and 197 [g/km] for the new model. Compared to the type approval data these values are 9% higher for the EURO 4 model and 24% higher for the EURO 5 model. It is not clear, why the difference to the type approval data is so much higher for the EURO 5 model than for the EURO 4 model. At the -7°C cold start test, which is relevant for pollutant emission limits from gasoline vehicles, the start-stop automatic was not active.

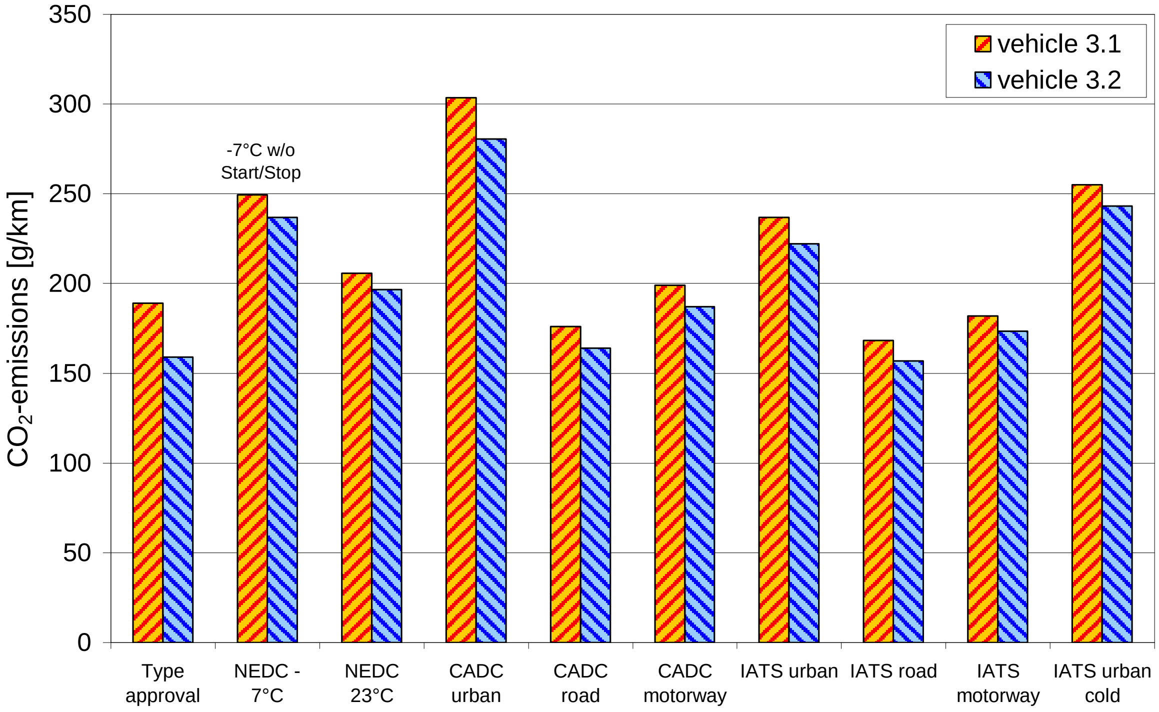

Figure 8-21: CO_2-emissions of the two models from manufacturer 3 in the different driving cycles

According to the type approval data the CO_2 emissions from the EURO 5 vehicle are 16% lower than those from the EURO 4 model while the CO_2 emissions measured with the real world driving resistance data lead to CO_2 reductions in the range of 6% over all test cycles (Figure 8-22).

Due to similar coast down results between the two models, the average positive cycle work is also similar for both models only the vehicle mass is different by about 10 kg.

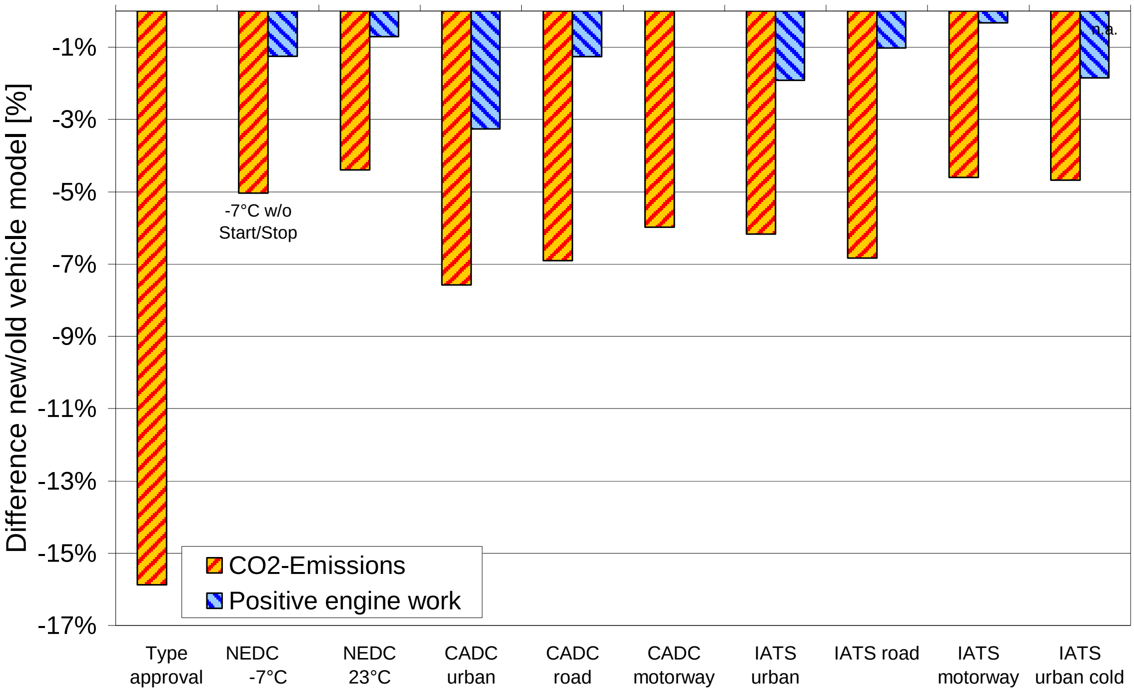

Figure 8-22: Changes of the CO_2-emissions and the cycle work between vehicle 3.1 and vehicle 3.2

Figure 8-23 shows the results for the NO_x-emissions of the two vehicles in the different driving cycles. The NO_x-emissions of both vehicles in the NEDC are below the type approval limit values and are in general on a very low level in all test cycles. Compared to the diesel models tested here the gasoline models have 98% lower NO_x emissions on average over the real world test cycles.

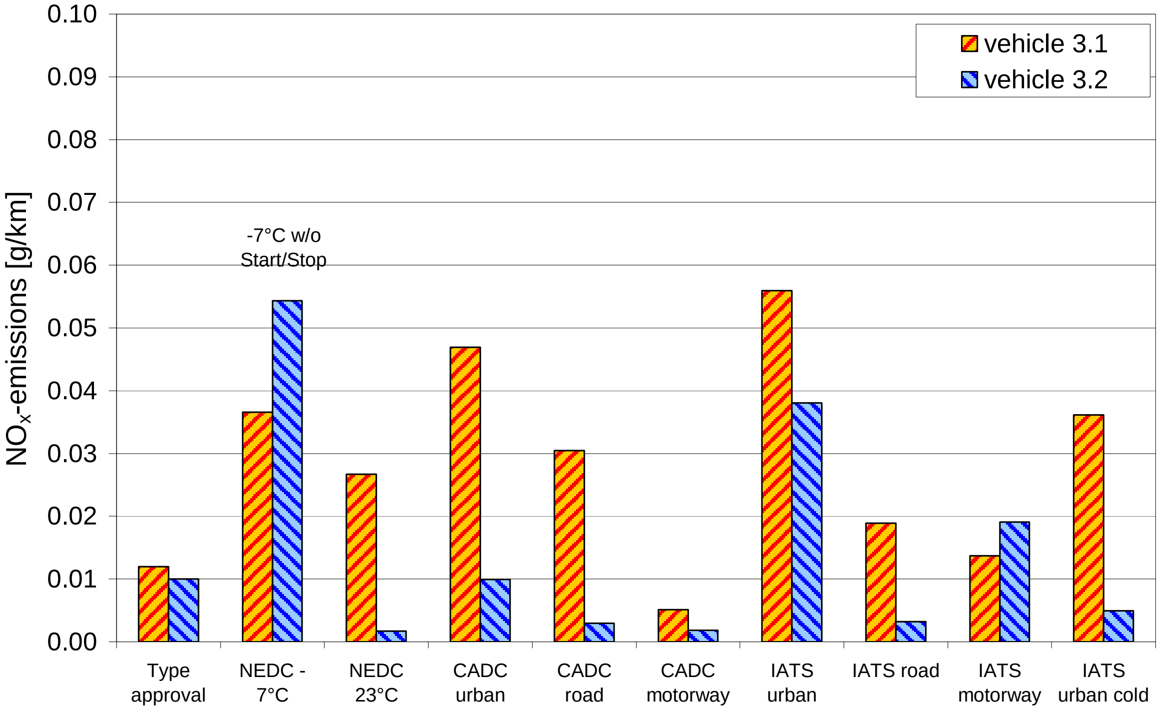

Figure 8-23: NO_x-emissions of the two models from manufacturer 3 in the different driving cycles

The NO_2-/NOx ratio of the two vehicles was on average 20%. Due to the already very low NO_x emissions the NO_2 ratio is not very relevant for these vehicles. The NO_2 emissions of the two models in the different driving cycles are shown in Figure 8-24.

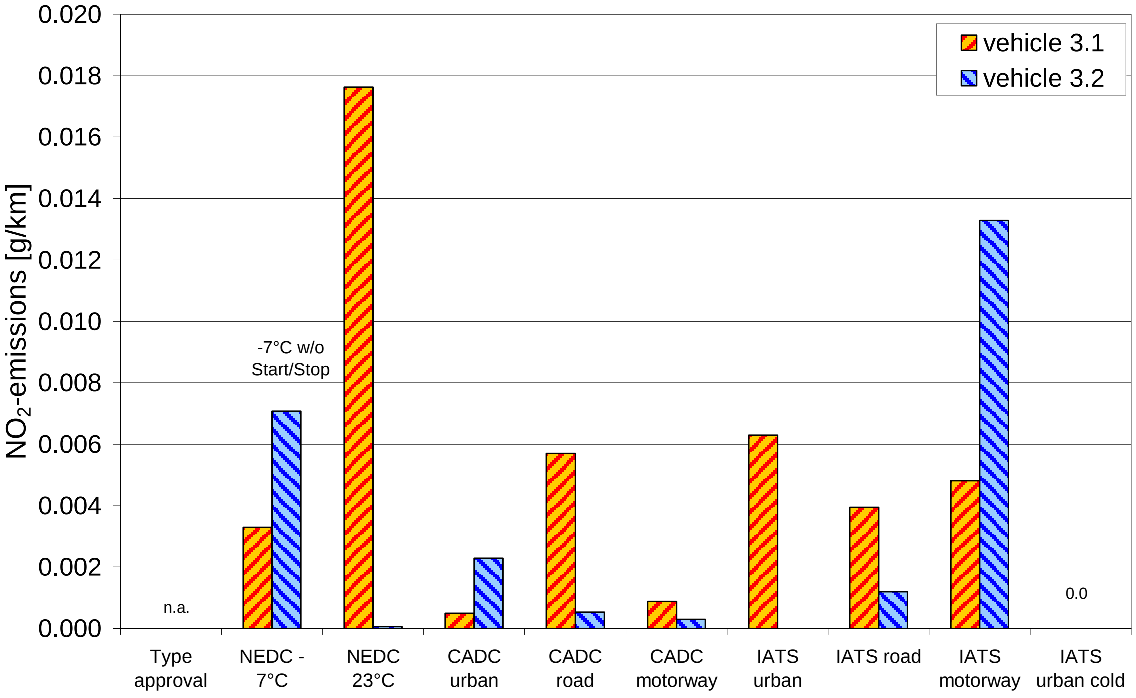

Figure 8-24: NO_2-emissions of the two models from manufacturer 3 in the different driving cycles

The results for the CO-emissions of manufacturer 3 are shown in Figure 8-25. Noticeable emissions were measured with the EURO 4 model in the cold start NEDC with -7°C and also in the IATS motorway cycle. The sensibility of gasoline vehicles against low temperatures due to the light off time necessary for the catalyst and in high load phases due to an enrichment of the combustion to protect the catalyst against overheating is already known. Since CO air quality levels are not critical this behaviour seems to be not relevant.

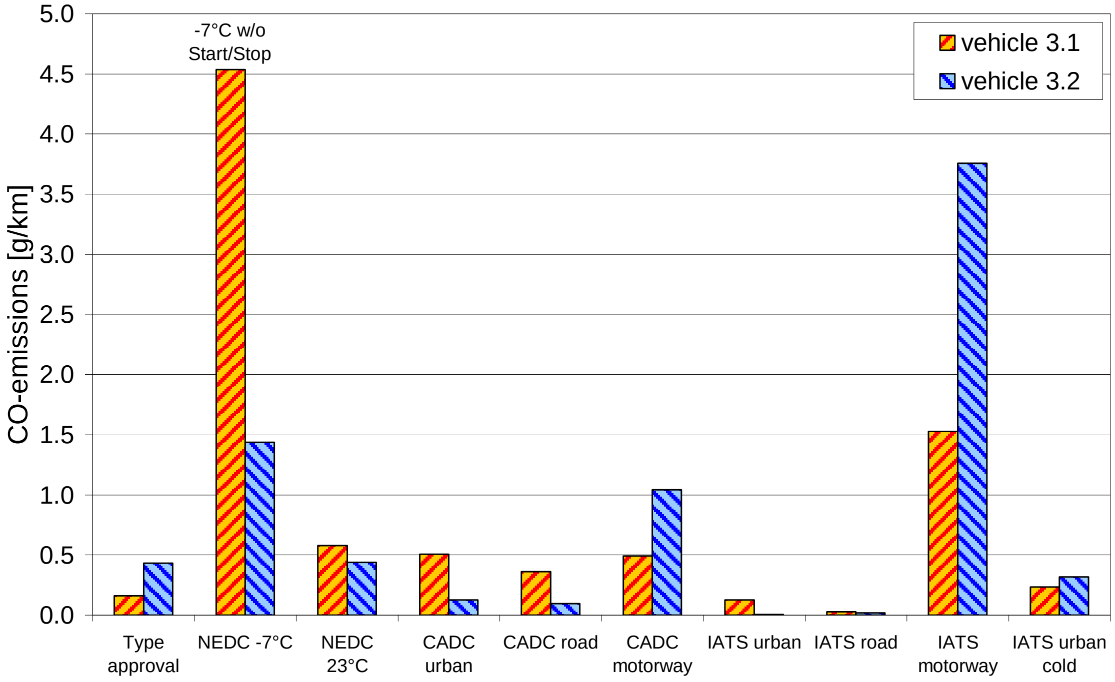

Figure 8-25: CO-emissions of the two models from manufacturer 3 in the different driving cycles

The HC emissions are low in all real world cycles (Figure 8-26). Compared to the diesel cars they are approx. two times higher. Due to the inactive catalyst and the necessity to enrich the air to fuel mixture for stable running conditions at low temperatures the start at -7°C leads to clearly increased HC levels.

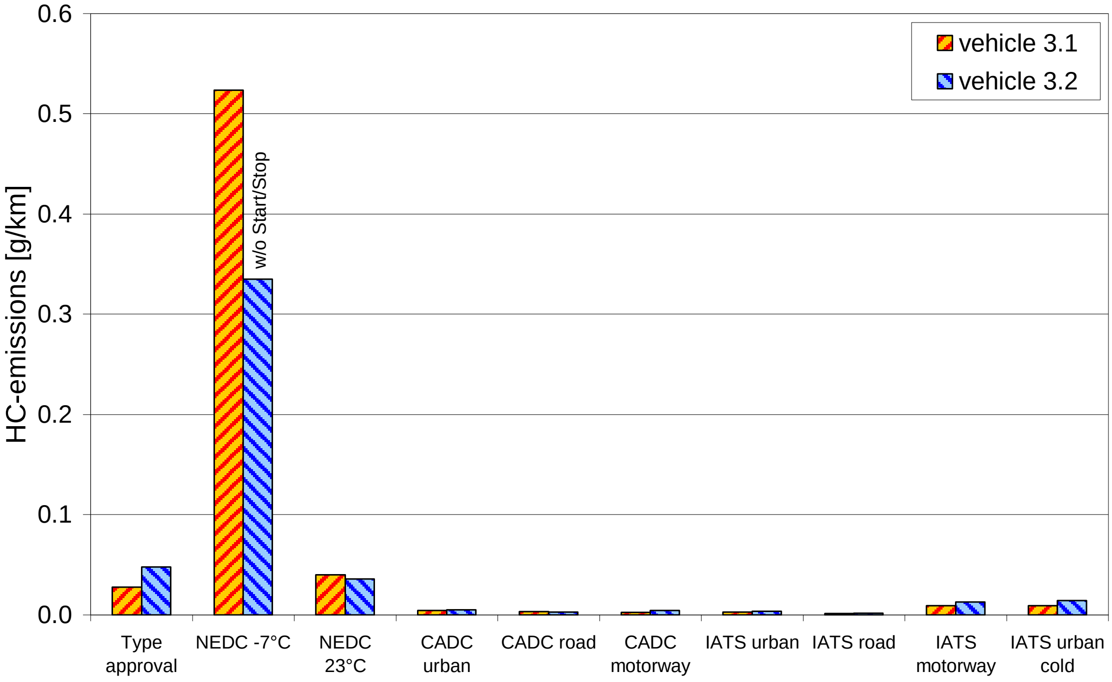

Figure 8-26: HC-emissions of the two models from manufacturer 3 in the different driving cycles

The results of the PM-emissions are shown in Figure 8-27. For the EURO 4 model the PM-emissions are not limited and they are lower than the PM-emissions of the EURO 5 model. The EURO 5 vehicle is equipped with a direct injection engine which has systematically higher PM-emissions as a port injection engine. Using the real world driving resistance values in the NEDC with cold start at 23°C leads to higher PM emissions than stated in the type approval (the limit value for EURO 5 is 0.005 g/km).

The PM-emissions of the EURO 5 direct injecting gasoline model are approximately 5 times higher in the real world test cycles compared to the PM-emissions of the two measured EURO 5 diesel vehicles which have a DPF. However, this PM level still is low: compared to the EURO 4 diesel model without DPF the PM emissions of the EURO 5 gasoline car are 85% lower.

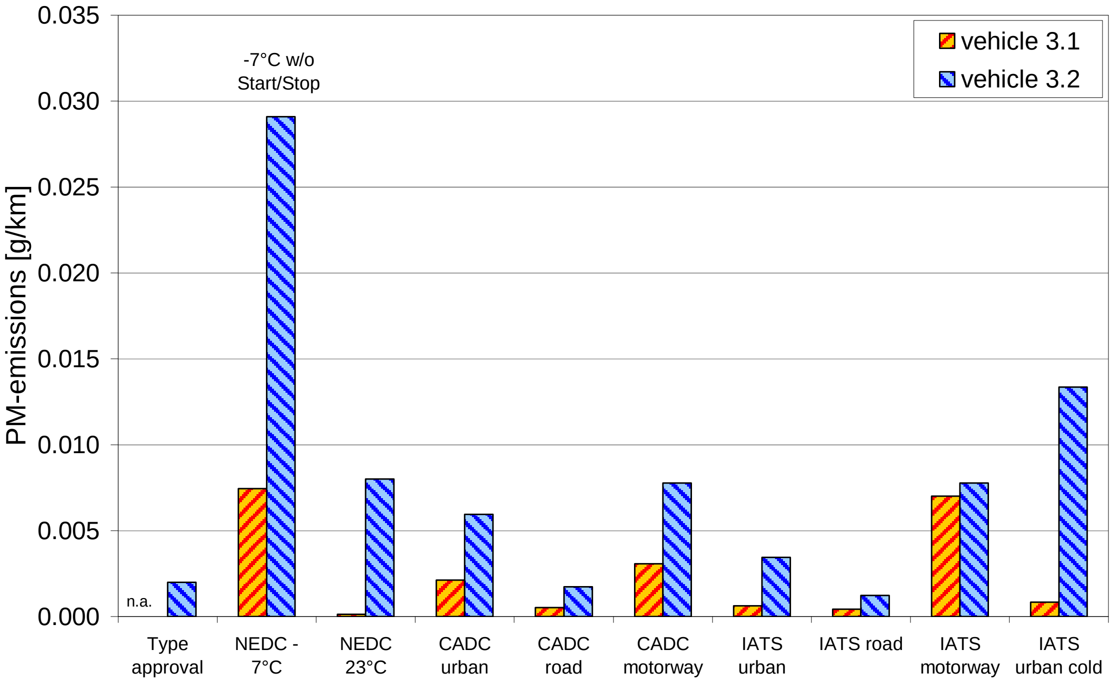

Figure 8-27: PM-emissions of the two models from manufacturer 3 in the different driving cycles

The PN-emissions of the EURO 4 vehicle with port injection are clearly lower then the PN-emissions of the EURO 5 vehicle with direct injection (Figure 8-28). This trend is known and discussed also in connection to future type approval limits for PN emissions for gasoline cars. Compared to the EURO 5 diesel vehicles with DPF the EURO 5 gasoline vehicle has two order of magnitude higher PN-emissions. However, the morphology of the particles from the gasoline car are certainly different to the morphology of diesel raw exhaust emissions since a similar number of particles is emitted but a much lower particle mass. How this may influence health effects and if the measurement method developed for the PN of diesel cars is appropriate for gasoline direct injection engines is not clarified yet.

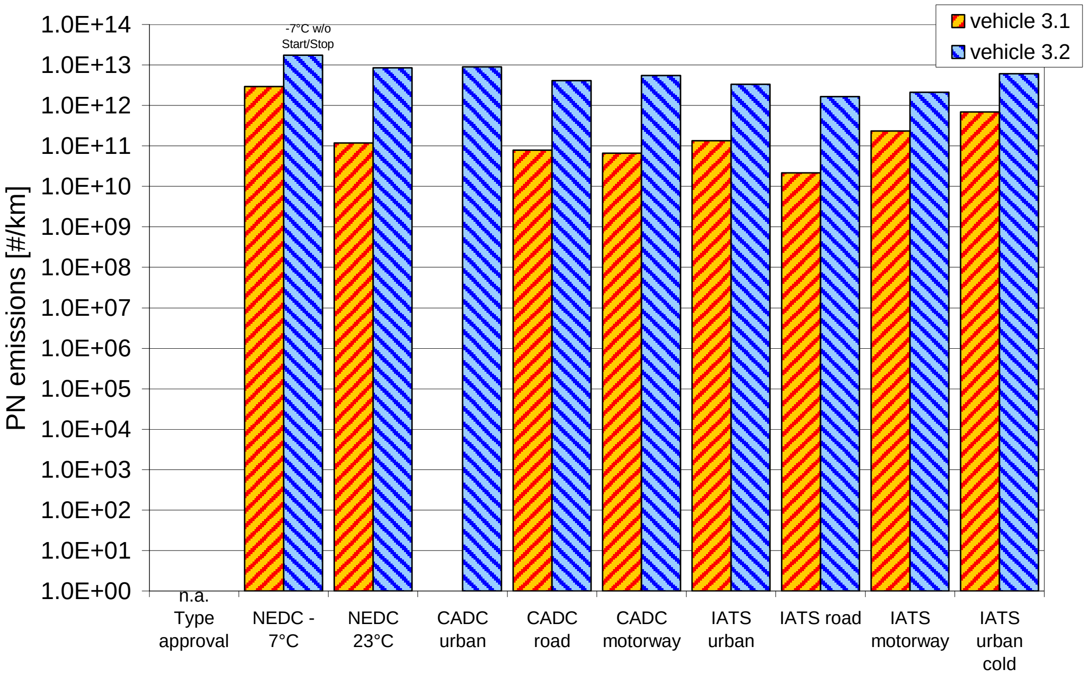

Figure 8-28: PN-emissions of the two models from manufacturer 3 in the different driving cycles

9 COMPARISON OF THE MEASUREMENT RESULTS AMONG ALL VEHICLE MODELS

The comparison of the type approval values with the NEDC with hot and cold start and a “real world mix” (calculated with the CADC, IATS and IATS cold start) is analysed here (Figure 9-1). When the real word driving resistance values were used from the coast down tests the vehicles showed on average 17% higher CO_2 emissions than stated for the same test procedure in the type approval data. This difference can be attributed to different driving resistance values which certainly are closest to optimum combinations of tire and road surface, tire pressure and ambient conditions for type approval tests while the “real world” tests were performed on a public road segment with standard tire conditions. This difference leads to approximately 1 litre/100km higher fuel consumption in the real world conditions. The highest deviation was +24% with the EURO 5 gasoline model, the lowest deviation had the EURO 4 gasoline car (+9%) while the diesel models were in the range of + 15% to +17%.

When the NEDC is tested with the real world driving resistances and hot start, 8% higher CO_2 emissions are measured than stated in the type approval data for the NEDC with cold start. The additional fuel consumption due to the cold start in the NEDC was on average 9.5%.

The real world test cycles resulted on average in 21% higher CO_2 emissions than the type approval data. Again the highest deviation was found for the EURO 5 gasoline model (+28%), the lowest deviation was found for the EURO 4 diesel car from manufacturer 2 (+13%). For diesel cars we see the effect, that the models with rather high NO_x emissions in real world cycles do have less increase in the CO_2 emission levels between type approval and real world and vice versa. The trade off between fuel efficiency and NO_x together with the low representatives of the NEDC test cycle for real world operation conditions are causing this effect.

At vehicle 1.2 tests with deactivated start-stop function of the engine were also run. The results suggest that the start-stop system saved approx 6% fuel in the NEDC. The average share of stop phases in European driving conditions is not known today. The real world mix used here however had lower shares of idling on the total fuel consumption. As a result the start-stop function reduced the fuel consumption only by a bit more than 2%. An analysis of data collected for the development of the future test cycle WLTP may give more reliable data on the influence of idling conditions in the EU.

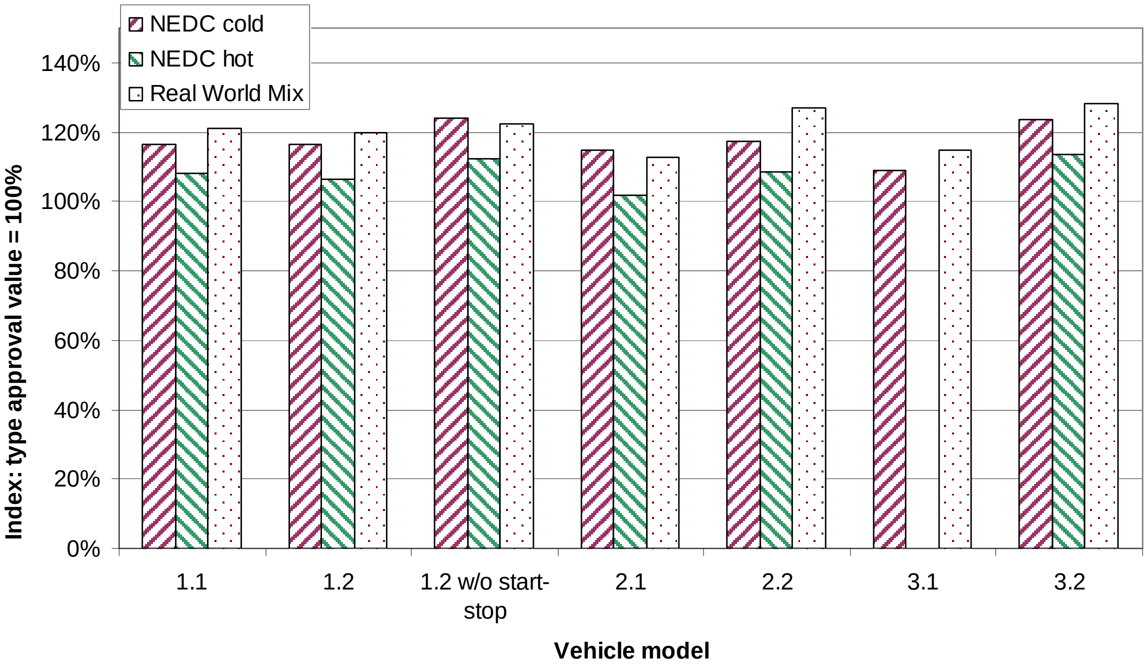

Figure 9-1: Ratio of CO_2-emissions in different test cycles using real world driving resistance values compared to the type approval data

The variation between type approval and real world results for NO_x is shown in Figure 9-2. Some diesel models showed already in the NEDC with hot start clearly higher NO_x emissions than in the NEDC with cold start. To reduce NO_x emissions from diesel cars in cold running conditions is a reasonable strategy to meet type approval limits. However, using much lower effort for NO_x control in the same load points at hot running conditions and especially in load points not covered by the NEDC leads to high NO_x emission levels in most real world test cycles. Since the most recent NO_2 air quality limits are exceeded in many areas around Europe NO_x control for diesel cars will remain an important topic for EURO 6. It has to be pointed out, that a reduction of type approval limits without adaptation of the test procedure will most likely not solve the problem since trade offs between efficiency and NO_x will remain also for the EURO 6 technologies.

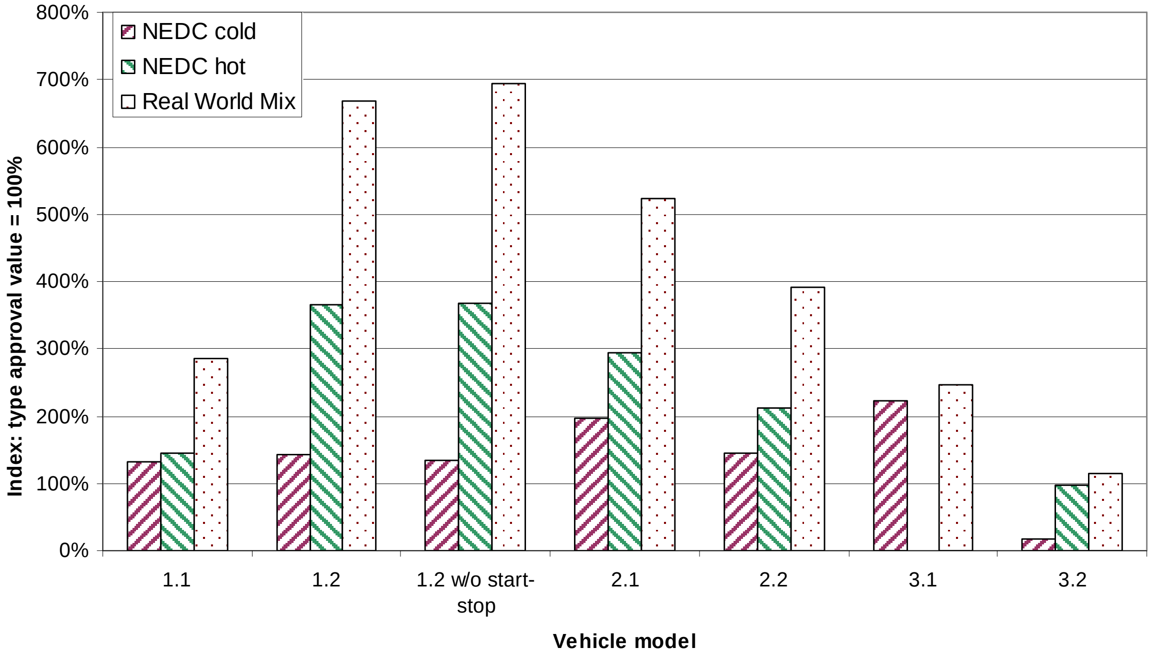

Figure 9-2: ratio of NO_x-emissions in different test cycles using real world driving resistance values compared to the type approval data

Certainly the tests performed cover only a very small sample of vehicle models and it has to be pointed out that there is a statistical spread between single vehicles in a model range. Additionally the EURO 4 models had between 21 000 and 100 000 km more mileage before testing than the EURO 5 models. Furthermore the real "real world" driving conditions are not known and the available test cycles do not necessarily reflect the European average conditions.

Thus the test results can only indicate trends. These are:

- A main parameter for underestimation of real world fuel consumption values by the type approval data seem to be the lower driving resistance values used at type approval.
- The ratio between type approval data and real world mix fuel consumption and CO_2 emissions varies strongly between makes and models. This is due to differences in the driving resistances and also due to different tendencies for optimisations of the engine and vehicle control strategies in type approval and in other driving conditions.
- The real world CO_2 emissions are in the range of +20% compared to the type approval data. Since only a small vehicle sample was tested and the actual real world driving behaviour is not well known a more exact statement for the tested vehicles is not possible.
- To obtain more sounded ratios between real world and type approval more vehicles will have to be analysed (such an analysis for fuel consumption values is at the moment performed for JRC).

- A prediction of future trends of real world CO_2-emissions from new vehicle registrations based on the CO_2 targets for the manufacturers will include reasonable uncertainties an may lead to an overestimation of CO_2 reduction rates but is at least the best available indicator yet.
- NO_x emission control needs a different test cycle than the NEDC.

10 ANNEX

The makes and models of the tested vehicles are documented in this annex.

Since tests of single vehicles can overestimate as well as underestimate the emission levels compared to the entire series due to the spread for standard factory models and also due to eventual malfunctions which have not been detected in the inspection before the measurements the single test results should not be allocated to the makes and models in any publication.

	VW Passat TDI **vehicle 1.1**	**VW Passat Bluemotion TDI** **vehicle 1.2**	**BMW 318 d** **vehicle 2.1**	**BMW 318 d Efficient Dynamics** **vehicle 2.2**	**Mazda 3** **vehicle 3.1**	**Mazda 3 i-Stop** **vehicle 3.2**
engine	Diesel	Diesel	Diesel	Diesel	Gasoline	Gasoline
	turbocharged	turbocharged	turbocharged	turbocharged	naturally aspirated	naturally aspirated
displacement [cm^3]	1896	1968	1995	1995	1999	1999
rated power [kW]	77	81	89	105	110	111
gearbox	manual	manual	manual	manual	manual	manual
	5 gear	5 gear	6 gear	6 gear	6 gear	6 gear
exhaust aftertreatment	oxidation catalyst	oxidation catalyst	oxidation catalyst	oxidation catalyst	3-way catalyst	3-way catalyst
	no diesel particle filter	diesel particle filter	diesel particle filter	diesel particle filter		
year of manufacture	2004	2009	2005	2009	2007	2009
mileage [km]	129000	23900	74000	3000	37000	16000
vehicle weight [kg]	1605	1567	1605	1605	1370	1360
EURO class	EURO 4	EURO 5	EURO 4	EURO 5	EURO 4	EURO 5

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