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# Fuel Consumption and Emissions of Modern Passenger Cars

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### **Fuel Consumption and Emissions of Modern Passenger Cars**

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# 1 EXECUTIVE SUMMARY IN GERMAN

Die koordinierte Sammlung von europäischen Emissionsmessungen an PKW begann mit ARTEMIS, einem Projekt im 5. EU Rahmenprogramm und wurde mit dem Update des HBEFA fortgesetzt ([www.hbefa.net](http://www.hbefa.net)). Die vorliegende Studie ergänzt die Messdatensammlung mit ersten Tests an EURO 5 PKW. Insgesamt wurden für die vorliegende Studie Messungen an 367 PKW analysiert um die Trends der Emissionsniveaus im Typprüfzyklus (NEDC) und in einem „real world“ Zyklus (CADC) von EURO 0 bis EURO 5 darzustellen.

Mit insgesamt sieben EURO 5 Diesel PKW und zwei EURO 5 Benzin PKW ist die vermessene Stichprobe für EURO 5 relativ klein, was natürlich zu Unsicherheiten in der Aussage über einen zu erwartenden Flottendurchschnitt führt. Die Studie ist daher nur als eine erste Überprüfung der Emissionsniveaus aktueller PKW gedacht um die Annahmen bei der Abschätzung der Emissionsfaktoren von EURO 5 im HBEFA testen zu können. Die Messergebnisse sollen auch den noch bestehenden Handlungsbedarf für die kommende Abgasgesetzgebung aufzeigen.

Die Emissionen an Partikeln, HC und CO zeigten von EURO 0 bis EURO 5 deutliche Abnahmen, sowohl im NEDC als auch im CADC. EURO 5 Diesel PKW hatten etwa 98% niedrigere Partikelemissionen als EURO 0. Alle EURO 5 Diesel PKW hatten serienmäßig einen Partikelfilter. Im Mittel emittierten die EURO 5 Diesel PKW im CADC 1/3 Mix 0.003 g PM/km die EURO 5 Otto PKW kamen auf 0.004 g PM/km. Partikelmassemissionen von modernen Diesel PKW sind also bereits auf bzw. sogar unter dem Niveau neuer Otto-PKW.

Die Abnahmen der NO<sub>x</sub>-Emissionen waren allerdings im CADC deutlich weniger ausgeprägt als im NEDC. Im CADC 1/3 Mix blieben die durchschnittlichen NO<sub>x</sub> Emissionen der gemessenen PKW von EURO 0 bis EURO 5 auf dem gleichen Niveau während im NEDC eine Abnahme um 64% gemessen wurde. Die Trends waren in allen Sub-Zyklen des CADC ähnlich (Stadt, Ausserort und Autobahn). Die gemessenen Benzin PKW hatten ab EURO 3 generell bereits sehr niedere NO<sub>x</sub>-Emissionen. Die heutigen Diesel PKW haben daher etwa 40-mal höhere NO<sub>x</sub> Niveaus als Otto PKW. Dieses hohe Verhältnis ist auf die deutliche Emissionsminderung bei Otto PKW zurückzuführen während die Diesel bei NO<sub>x</sub> auf etwa konstantem Niveau blieben.

Infolge der Abgasnachbehandlung mit katalytisch aktiven Edelmetallen (Platin, Palladium, Rhodium) bei Diesel PKW ab etwa EURO 3, stieg der Anteil von NO<sub>2</sub> an den NO<sub>x</sub>-Emissionen (=NO + NO<sub>2</sub>) von etwa 8% bei EURO 1 auf ca. 45% bei EURO 4. Bei den EURO 5 Diesel wurde ein NO<sub>2</sub>-Anteil von 35% festgestellt. Konstant bleibende NO<sub>x</sub>-Emissionen in der PKW-Flotte mit zunehmenden NO<sub>2</sub> Anteilen führt zu negativen Wirkungen auf die Erreichung der Luftgüteziele, die ja anhand der NO<sub>2</sub>-Immissionen definiert sind. Neben der Senkung des Energieverbrauches und der CO<sub>2</sub>-Emissionen – was voraussichtlich dominante Themen der nächsten Jahrzehnte sein werden – bleibt die Reduktion der NO<sub>x</sub> Emissionen von Diesel PKW also ein wichtiges Ziel.

Ursachen der deutlich geringeren Abnahme der NO<sub>x</sub> Emissionen der Diesel PKW in real world Zyklen gegenüber der Grenzwerteabsenkung sind:

- Infolge der deutlich geringeren Serienstreuung bei heutigen PKW können die Kfz näher an die Grenzwerte appliziert werden ohne Gefahr zu laufen die COP-Tests nicht zu bestehen. Daher sinken die gemessenen Emissionen im NEDC weniger als die Grenzwerte.
- Der NEDC umfasst nur einen geringen Teil der Motorleistungs- und Drehzahlbereiche, die in realen Fahrzuständen auftreten. Emissionsoptimierungen in real world Zyklen werden vom Kunden nicht wahrgenommen und stellen daher keinen Mehrwert am Markt dar. Dementsprechend erfolgt die Emissionsoptimierung vorwiegend in den NEDC Lastprofilen.
- Infolge des Trade-Offs zwischen Wirkungsgrad und NO<sub>x</sub> bei der Auslegung der Verbrennung führt eine verbrauchsoptimierte Applikation außerhalb der NEDC Lastbereiche tendenziell zu hohen NO<sub>x</sub>-Rohemissionen. Da bei Diesel-PKW bis EURO 5 keine effiziente Abgasnachbehandlung für NO<sub>x</sub> in Serie ist, gelangen die NO<sub>x</sub> Rohemissionen ungemindert in die Atmosphäre.

→ Eine Verbesserung bedarf also insbesondere einer Adaption des Typprüfzyklus.

## Conclusions and Recommendations in German

Aus den Messergebnissen können Schlussfolgerungen und Empfehlungen für ein zukünftiges Typprüfverfahren und für die nächsten Schritte im HBEFA abgeleitet werden.

### Zukünftiges Typprüfverfahren

Um das Problem der im Vergleich zu den Emissionsgrenzwerten in vielen „real world“ Fahrzuständen relativ hohen  $\text{NO}_x$ -Emissionen von Diesel-PKW zu lösen, ist eine Änderung des Typprüfzyklus wesentlich. In (Hausberger, 2006) wurde schon die Schlussfolgerung gezogen, dass durch die EURO 5 Gesetzgebung keine deutlichen  $\text{NO}_x$ -Minderung in realen Fahrzyklen erwartet werden kann, wenn das Typprüfverfahren dabei unverändert bleibt.

Diese Aussage traf für EURO 5 ein und gilt auch weiterhin für EURO 6. Die modernen Abgasnachbehandlungssysteme in den EURO 6 Diesel-PKW müssen ihr Reduktionspotenzial im realen Verkehr nicht ausschöpfen, wenn das nicht durch einen anspruchsvolleren Testzyklus unterstützt wird. SCR-Systeme brauchen für ihre Funktion die Zudosierung eines Reduktionsmittels und  $\text{NO}_x$ -Speicherkatalysatoren zur  $\text{NO}_x$ -Regeneration Phasen fetten Abgasgemisches. Eine Anfettung des Dieselabgases bedeutet Mehrverbrauch und das SCR-Reduktionsmittel bedeutet Zusatzkosten und kürzere Nachfüllintervalle. Beide Katalysatoren benötigen ein thermisches Management um auch im Niederlastbereich von Dieselmotoren auf Betriebstemperatur zu gelangen. Wegen dieser Nachteile kann nicht davon ausgegangen werden, dass diese Systeme auch außerhalb der durch den Typprüfzyklus abgedeckten Lastbereiche auf niederste Emissionen optimiert werden.

Eine Absenkung der real world  $\text{NO}_x$ -Emissionen von Diesel-PKW braucht daher folgende Voraussetzungen:

- Einen Typprüfzyklus der alle Betriebspunkte umfasst, die im realen Verkehr relevant sind. Der derzeit verfolgte Ansatz, möglichst das durchschnittliche, globale Fahrverhalten darzustellen wird voraussichtlich keinen großen Kennfeldbereich abdecken. Ein Testzyklus sollte auch die Eckpunkte, nicht nur die Mittelwerte der Fahrzustände beinhalten.
- Mit einem passenden Testzyklus können bei gleichen Emissionsgrenzwerten deutlich niedrigere Emissionen im realen Verkehr erwartet werden als bisher mit dem NEDC erreicht wurden. Im Gegensatz dazu kann von einer weiteren Grenzwertverschärfung unter Beibehaltung des NEDC keine deutliche Minderung der realen  $\text{NO}_x$ -Emissionen erwartet werden. Daher können Emissionsgrenzwerte bei einem besseren Testzyklus weniger streng als im NEDC vorgegeben werden um die gleichen real world  $\text{NO}_x$  Niveaus zu erreichen. Würde ein schwerer Testzyklus gleichzeitig mit schärferen Grenzwerten eingeführt, so wäre das eine sehr herausfordernde Aufgabe für die Hersteller. Ein sinnvoller kurzfristiger Kompromiss wäre die Einführung eines ergänzenden „ $\text{NO}_x$ -Testzyklus“ zusätzlich zum Typprüfzyklus NEDC (WLTP in Ausarbeitung) und in diesem höhere Grenzwerte anzusetzen.
- Alternativ können auch sogenannte „Not To Exceed (NTE)“ Grenzwerte eingeführt werden, die dann in realen Fahrversuchen On-Board mit portablen Emissionsmessgeräten (PEMS) überwacht werden. Da die Definition der zugehörigen Testbedingungen und der Testauswertungsverfahren sehr komplex ist, kann eine NTE-Regelung wohl kaum innerhalb der nächsten 5 Jahre erwartet werden. Der zusätzliche „ $\text{NO}_x$ -Testzyklus“ wäre also eine Option um eventuell schon früher Emissionsminderungen zu anzuschieben
- Österreich sollte sich konstruktiv in die Ausarbeitung der zukünftigen PKW Testprozedur WLTP einbringen. Wegen der hohen Dieselanteile an den PKW sind niedrige real world  $\text{NO}_x$  Emissionen dieser Kfz wichtig um die  $\text{NO}_2$ -Luftqualitätsziele in Österreich einhalten zu können. Der österreichische Beitrag sollte mit anderen aktiven Staaten, wie etwa Deutschland, Niederlande und Schweiz abgestimmt sein und sich auf die Überprüfung der WLTP-Vorschläge sowie auf die Ausarbeitung eines eventuellen  $\text{NO}_x$ -Zusatztestzyklus konzentrieren.

### Nächste Schritte im HBEFA

Die seinerzeit aus einer Technologieabschätzung abgeleiteten und derzeit im HBEFA V3.1 implementierten Emissionsfaktoren für EURO 5 stimmen relativ gut mit den aktuellen Messdaten überein. Die Emissionsfaktoren von EURO 5 Diesel PKW sind im HBEFA auf gleichem Niveau wie EURO 4. Da bisher erst eine geringe Stichprobe an EURO 5 PKW gemessen wurde, kann derzeit aus den Messungen noch nicht sicher geschlossen werden, ob EURO 5 im Flottendurchschnitt bei  $\text{NO}_x$  etwas über oder etwas unter EURO 4 liegt. Die gemessene Abnahme an PM, PN, HC und CO wurde auch im HBEFA vorhergesagt. Daher müssen keine dringenden Korrekturen am HBEFA V3.1 vorgenommen werden.

Für das Anfang 2012 vorgesehene Update des HBEFA sind aber weitere Messungen an EURO 5 PKW erforderlich, die innerhalb der ERMES Gruppe koordiniert werden sollen.

EURO 6 PKW sollten ab 2011 gemessen werden da bereits erste Modelle am Markt sind. Da das  $\text{NO}_x$ -Emissionsniveau von EURO 6 Diesel-PKW im realen Verkehr wichtig für die Erreichung der  $\text{NO}_2$ -Grenzwerte sein wird, sollte das reale Emissionsverhalten möglichst bald bekannt sein. Dieses Wissen ist für die Entscheidungsträger wichtig, um politische Maßnahmen die eine vorzeitige Einführung von EURO 6 fördern oder auch restriktive Maßnahmen für Diesel-PKW beurteilen zu können.

## 2 SUMMARY

The coordinated collection of emission measurement data on passenger cars started as part of the 5<sup>th</sup> Framework project ARTEMIS, was continued during the work on the HBEFA V3.1 ([www.hbefa.net](http://www.hbefa.net)) and was complemented in the actual study by tests on EURO 5 cars. In total measurements on 367 passenger cars were used for the study. The test results for the type approval cycle (NEDC) and for the CADC (urban, road and motorway) were analyzed to obtain the trends in the development of emission levels from EURO 0 to EURO 5.

In total results for seven EURO 5 diesel cars and for two EURO 5 gasoline cars were available for the analysis. This sample certainly is rather small what results in high uncertainties for the average fleet emission level of EURO 5. However, the study is intended as a first screening of the emission levels from the actual car technologies. The screening allows a review of actual emission factors for EURO 5 cars, which up to now were all based on assumptions only. Additionally the results shall help to identify main tasks which are still open to be solved for the EURO 6 vehicle technologies.

The emissions of particulate matter, HC and CO were found to have clear and similar reduction rates in all cycles tested. EURO 5 diesel cars showed 98% lower PM emissions than EURO 0. All of the EURO 5 cars tested were equipped with an OEM diesel particle filter. On average EURO 5 diesel cars only had only 0.003 g/km PM emissions in the CADC 1/3 Mix. Gasoline EURO 5 cars in comparison had a PM emission level of 0.004 g/km on average. Thus the PM emission levels from modern cars are in general on a very low level. The particle filters also removed very efficiently the particle number emissions. As a result EURO 5 diesel cars have on average 95% lower PN emissions than the EURO 3 vehicles.

The reduction rates for NO<sub>x</sub> were found to be clearly higher in the type approval cycle than in the CADC. In the CADC 1/3 Mix, which covers urban, road and motorway driving, the NO<sub>x</sub> emissions from EURO 5 diesel cars are on the same level as NO<sub>x</sub> emissions from EURO 0 diesel cars. In the NEDC, for comparison the NO<sub>x</sub> emissions were reduced by approximately 64% from EURO 0 to EURO 5. Similar trends are found in the urban, road and motorway part of the CADC. In all of these real world test cycles the NO<sub>x</sub> emissions were on a similar level from EURO 0 to EURO 5. The gasoline cars tested had very low NO<sub>x</sub> emissions from EURO 3 on. The actual EURO 5 diesel cars have on average more than 40 times higher NO<sub>x</sub> emissions than the gasoline cars. This high ratio certainly is a result from the impressive reductions achieved for gasoline cars while NO<sub>x</sub> emissions for diesel cars kept constant over the last decades.

Due to more active exhaust gas after treatment systems an increasing share of NO<sub>2</sub> in the total NO<sub>x</sub> emissions from EURO 1 (8%) to EURO 4 (45%) was found. For EURO 5 the share of NO<sub>2</sub> dropped again to 35%. A constant level of NO<sub>x</sub> with increasing fleet average NO<sub>2</sub> emissions is certainly highly counterproductive to the stringent NO<sub>2</sub> air quality targets in the EU. Beside lowering the energy consumption and CO<sub>2</sub> emissions from all vehicles - which most likely will be a dominant tasks for the next decades - the reduction of NO<sub>x</sub> emissions from diesel cars remains an important topic.

Reasons for the rather constant NO<sub>x</sub> emissions from diesel cars in real world cycles compared to the reduction of the type approval limit values are:

- Due to a much lower spread for standard factory models in the emission behavior the vehicles can be designed to be generally closer to the type approval limit values. Thus the fleet emissions in the NEDC were reduced to a smaller extent than the limit values.
- The NEDC type approval cycle covers only a part of the engine loads driven in the CADC. Emissions from cars are typically optimized by the engineers in the relevant type approval cycle. Optimizations in other test cycles are rather not awarded by the customers and thus have no additional value on the market. As a result the “optimized” emission behavior in the NEDC is not reached in other test cycles.
- Due to the trade off between fuel efficiency and NO<sub>x</sub> emissions, an optimization towards low fuel consumption in driving conditions not controlled by the NEDC tend to result in rather high NO<sub>x</sub> emissions.

→ An improvement mainly needs an adaptation of the type approval cycle.

### 3 CONCLUSIONS AND RECOMMENDATIONS

From the results recommendations for a future type approval test cycle and for the next steps in the HBEFA can be made.

#### Future type approval test procedure

To overcome the ongoing problem of rather high NO<sub>x</sub> emissions from diesel cars in many real world driving conditions a change of the type approval cycle is crucial. Already in (Hausberger, 2006) it was concluded, that we can not expect high reductions in the real world NO<sub>x</sub> emissions from EURO 5 diesel cars if the type approval procedure remains unchanged.

This effect occurred for EURO 5 and the message is still valid for EURO 6. Even the modern NO<sub>x</sub> exhaust gas after treatment systems in EURO 6 cars will not have to make use of their entire potential for emission reduction in real world engine loads if this is not supported by an appropriate test cycle. Since for a proper NO<sub>x</sub> reduction the SCR systems need additional reagents and NO<sub>x</sub> storage catalysts need phases of rich exhaust gas mixture with drawbacks in the fuel efficiency, we can not assume these systems to be optimized for low emissions in driving conditions not controlled by the type approval cycle.

Further reductions of real world NO<sub>x</sub> emissions of diesel cars have to be based on

- A type approval cycle which covers all operation conditions relevant in real world driving. The actual approach to obtain a cycle which represents the average of the global driving will most likely not cover a large area of operation conditions. A test cycle has also to trace corners of driving situations, not only averages.
- With a proper test cycle similar limit values than in the NEDC would lead to clearly lower real world NO<sub>x</sub> emission levels than today. In contrary a reduction of emission limit values in the NEDC does not necessarily lead to reduced real world NO<sub>x</sub> emissions as the history from EURO 1 to EURO 5 shows. Thus in a proper test cycle the limit values can be than in the NEDC. A demanding test cycle combined with reduced emission limits would be a very heavy task to be taken in one step. A reasonable option could be to add such a demanding “NO<sub>x</sub> test cycle” to the standard test cycle (WLTP is in development) but to allow higher limit values in the additional cycle.
- Alternatively or in addition “Not To Exceed (NTE)” limits could be defined which then have to be tested in real world driving conditions with portable emission measurement equipment. Since the definition of the test conditions and of the test evaluation would be complex, a European regulation on NTE may not be expected to be in force within the next 5 years. Thus an additional NO<sub>x</sub> test cycle could be an option where results can be achieved earlier.
- Austria should bring in constructive work into the development of the future test procedure WLTP. Due to the high share of diesel cars low real world emissions are important for the air quality in Austria. The input could be coordinated with other active states, such as Germany, Switzerland and Netherlands and should focus on a screening of actual WLTP test cycle proposals and the development of an additional, more demanding test cycle if necessary.

#### Next steps in the HBEFA

The actual emission factors for EURO 5 cars in the HBEFA V3.1 do meet the test results quite well. In the HBEFA the NO<sub>x</sub> emissions of EURO 5 have been predicted on the same level as EURO 4. This is in line with the findings from the actual study. Since tests are available yet only for a limited number of cars, the fleet average emission values have too high uncertainties to conclude if EURO 5 is on average somewhat higher or lower than EURO 4 in terms of NO<sub>x</sub> emissions. The further reduction of PM, PN, HC and CO was also predicted already in the HBEFA V3.1. Thus no urgent actions have to be taken to correct emission factors in the HBEFA.



Further measurements on EURO 5 cars shall be coordinated in the ERMES group and shall be initiated quickly to have a larger sample available for the next update of the HBEFA which is scheduled for 2012.

EURO 6 vehicles should be measured from early 2011 on since first diesel models meeting the EURO 6 limit values are already on the market. Since the emission behavior of these vehicles will be very important for the NO<sub>2</sub> air quality developments in Europe in the next future the real world behavior has to be known rather soon. This is also very relevant for stake holders to decide policy measures which promote early EURO 6 implementation and/or further burdens for diesel cars.

## 4 ABBREVIATIONS

CADC.....	Common ARTEMIS Driving Cycle
CO .....	Carbon monoxide
CO <sub>2</sub> .....	Carbon dioxide
COP .....	Conformity Of Production (test of vehicles from the serial production)
CVS .....	Constant Volume Sample
C <sub>d</sub> .....	Aerodynamic Drag Coefficient [-]
DOC .....	Diesel Oxidation Catalyst
DPF.....	Diesel particulate filter
EGR.....	Exhaust gas recirculation
ERMES.....	European Research Group on Mobile Emission Sources (predecessor of the D.A.CH group, now extended to more European member states)
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 <sub>x</sub> .....	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)
WLTP.....	World Harmonized Light Duty Test Procedure

## 5 INTRODUCTION

Within the ERMES group national emission measurement programs are coordinated to reduce the costs for vehicle testing per member state and in parallel to increase the overall available sample on test results. The common data base is used to

- Monitor real world emissions of vehicles
- To establish emission factors from all available tests within the member states
- To draw conclusions and recommendations for future measures to reduce emissions from the road transport sector.

The level of PM and NO<sub>x</sub> emissions from diesel driven cars is of high relevance for meeting air quality targets in Austria due to the large number of diesel cars in the newly registered fleet. Thus the emission levels of actual diesel technologies are important for scenarios on the future development of NO<sub>x</sub>, CO<sub>2</sub> and PM emission levels and also for an assessment of measures which result in an accelerated renewal of the vehicle fleet, such as environmental zones.

Since the actual HBEFA V3.1 included only one measured EURO 5 passenger car the emission factors for this vehicle category were elaborated by an expert assessment on the vehicle and engine technology development. Thus to check these emission factors for EURO 5 diesel cars was an urgent task. In the actual project five passenger cars with EURO 5 certification were tested. From (Zallinger, 2009) tests on additional three EURO 5 diesel cars were available and included in the analysis. One vehicle was tested by FVT in the course of the HBEFA V3.1. Thus in total nine EURO 5 vehicles are included in this study. The test results of these vehicles are compared to the data base on EURO 0 to EURO 4 vehicles used in the HBEFA V3.1 (Hausberger, 2009 and [www.hbefa.net](http://www.hbefa.net)).

The study is an update of (Hausberger, 2006), where the actual behavior of the new EURO 4 vehicles was compared against EURO 0 to EURO 3 under contract of the BMLFUW.

## 6 TYPE APPROVAL LIMITS

Passenger cars and light duty vehicles are driven in the New European Driving Cycle (NEDC, see Figure 1) for type approval. Table 1 shows the relevant type approval limits for passenger cars with diesel-engines. From the EURO 3 level on, the NEDC was modified to start the measurements together with switching on the engine. Before EURO 3, there was a 40 second idling phase before the emission measurement started.

**Table 1:** Emission limits for passenger cars with diesel-engines ( $\leq 2.5t$  GVW,  $\leq 6$  seats) in the EU

	date	CO		HC+NO <sub>x</sub>		NO <sub>x</sub>		PM	PN
		Otto	Diesel	Otto	Diesel	Otto	Diesel	Diesel	
		[g/km]							[#/km]
ECE 15/04	1982	16.5	16.5	3.56	5.10				
EURO 1	1992	3.2	3.2	1.13	1.13			0.140	
EURO 2	1996	2.2	1.0	0.50	0.70			0.080	
EURO 3	2000	2.3	0.6	0.35	0.56	0.15	0.5	0.050	
EURO 4	2005	1.0	0.5	0.18	0.30	0.08	0.25	0.025	
EURO 5	2009	1.0	0.5		0.23	0.06	0.18	0.005	6x10 <sup>11</sup>
EURO 6	2014	1.0	0.5		0.17	0.06	0.08	0.0045	6x10 <sup>11</sup>

## 7 TESTED VEHICLES

All measurements are collected in the ARTEMIS 300 data base (A300db) as described in [www.hbefa.net](http://www.hbefa.net). The tests are performed in different European labs. The coordinated work started as part of the 5<sup>th</sup> Framework project ARTEMIS in Work Package 300 (Journard et al., 2006). In the course of the development of the HBEFA V3.1 the A300db was updated with all tests available until June 2009. In the meantime a work program for the next update of emission factors is discussed but

with exception of the actual study no additional test results on EURO 5 cars is available yet. In total more than 3000 cars are already stored in the A 300db (Table 2). For 1421 of these cars the CADC was measured while for almost all cars the type approval cycle was measured.

**Table 2:** Number of tested vehicles available in the A300db (including the EURO 5 cars tested in the actual study)

	Gasoline		Diesel	
	bag <sup>(2)</sup>	modal <sup>(1)</sup>	bag <sup>(2)</sup>	modal <sup>(1)</sup>
EURO 0	878	2	207	0
EURO 1	1191	3	48	0
EURO 2	164	4	54	4
EURO 3	156	9	135	8
EURO 4	208	23	99	24
EURO 5	2	2	7	7
EURO 6	0	0	0	0
<b>Total</b>	<b>2599</b>	<b>43</b>	<b>550</b>	<b>43</b>

(1).....modal data contains the emissions and vehicle speed courses at least in 1 Hz resolution. Modal data is typically needed for the elaboration of engine emission maps for setting up the emission model

(2)....bag data contains the average emission value per cycle or per sub cycle without the courses of the emissions. Bag data is available for all vehicles while modal data is available only for a sub-sample

The vehicle makes and models measured for the actual study and in (Zallinger, 2010) are listed in Table 3.

**Table 3:** EURO 5 vehicles measured in the actual study and in (Zallinger, 2010) with their type approval values

Marke	Fuel type	CO <sub>2</sub>	CO	HC	NO <sub>x</sub>	HC+NO <sub>x</sub>	PM
		Type approval values [g/km]					
Audi A3 Sportback	Diesel	116	0.1808		0.1489	0.1729	0.0004
BMW 318d	Diesel	125	0.312		0.201	0.237	0.0001
Fiat Doblo 1.6l	Diesel	138	0.29		0.156	0.211	0.001
Opel Astra 1.7CDTI 59kW	Diesel	125	0.189		0.13	0.151	0.001
Peugeot 407 SW	Diesel	150	0.167		0.155	0.189	0.0002
VW Golf VI	Diesel	119	0.391		0.116	0.186	0.001
VW Passat Blue Motion	Diesel	129	0.236		0.123	0.151	0
Fiat Punto EVO	Gasoline	134	0.395	0.042	0.018		
Mazda 3 2.0i	Gasoline	159	0.433	0.048	0.01		0.002

## 8 TEST PROGRAM

The main task of the study was to quantify the NO<sub>x</sub> emission levels for cars with certification levels from EURO 0 to EURO 5 in the NEDC and in the CADC. Certainly the other regulated exhaust gas components were also analyzed in this study.

The cars were measured first in a **coast down test**. In a coast down test the driving resistance parameters, which have to be set later on the roller test bed, are measured by the deceleration of the vehicle from 120 km/h to 20 km/h. The tire inflation pressure was set according to manufacturer specifications. The tires were used as delivered by the dealer. All cars tested in this study had summer tires. The coast down tests were performed on a flat road in the north of Graz. The wind velocity was

near to zero in all the tests, and the road condition was dry and clean. The driving resistance values measured should be representative of real world driving. However, the driving resistance values obtained most likely are higher than the values used in type approval due to the not optimized rolling resistance values of the tire-road surface combination.

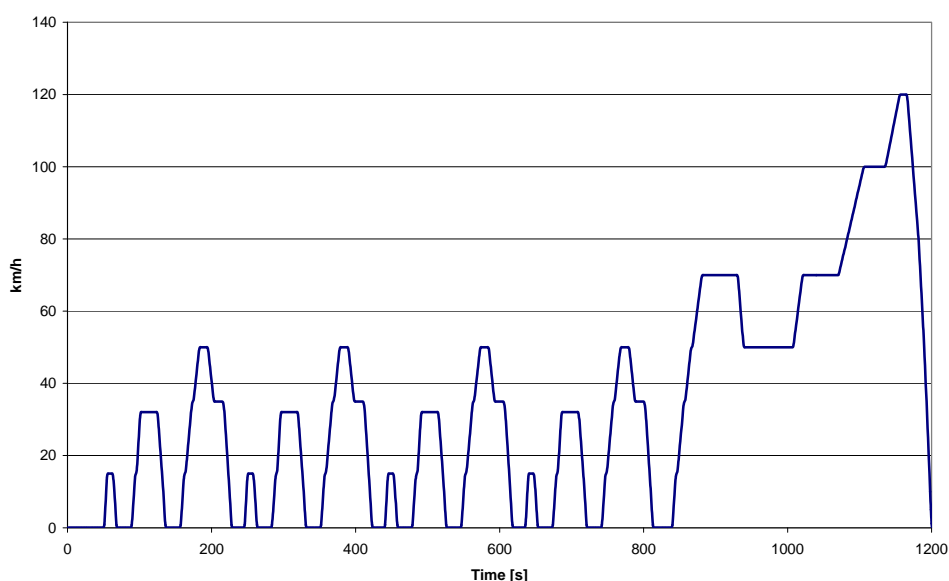
All the vehicles listed in Table 3 were measured in the following cycles:

- New European Driving Cycle (NEDC); from EURO 3 on, the modified version MVEG B was used,
- CADC urban,
- CADC road,
- CADC motorway
- IATS Urban
- IATS Road
- IATS Motorway

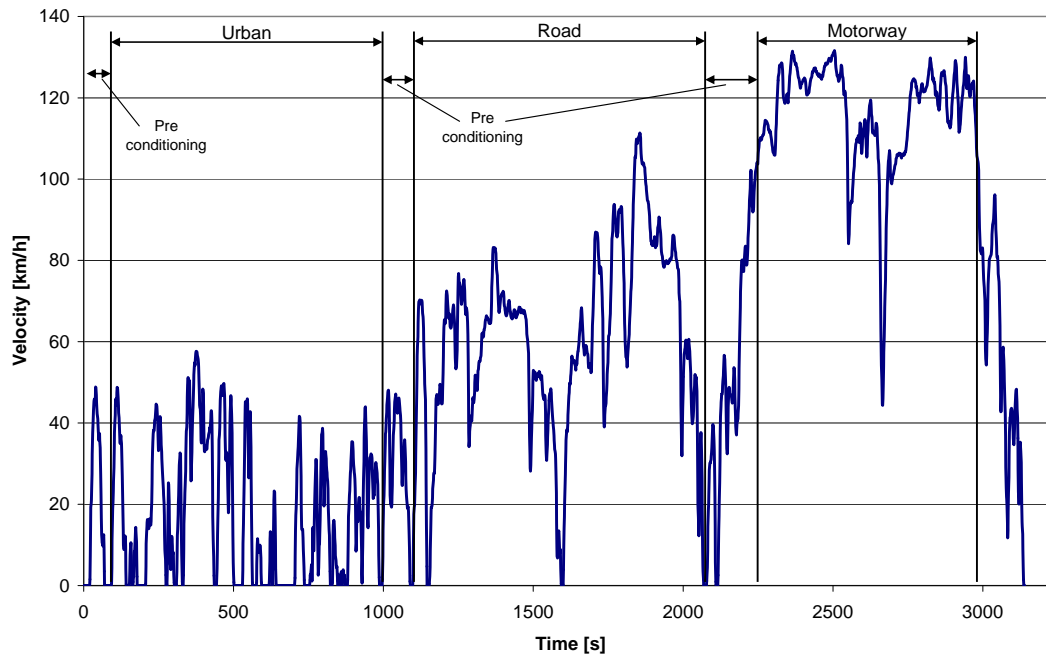
The CADC was selected as reference real world cycle since it was the most common real world test cycle in all national test programs within the ERMES group between 2001 and 2010. In an actual analysis of real world driving behavior, (Zallinger, 2010), new test cycles were developed which were measured in the actual study too. These tests are mainly foreseen for a future model validation since the EURO 5 cars measured here certainly shall be included in the next update of the HBEFA. In the model PHEM the CADC tests are used to set up the engine emission maps, while the TUG test cycles are then used for model validation and for the assessment of the uncertainties in the emission factors, e.g. (Zallinger, 2010). The set up of emission factors is not included in the actual study but shall be performed when more EURO 5 cars have been tested in the ERMES group.

All CADC sub cycles are real world driving cycles developed as part of ARTEMIS (Joumard et al., 2006), (Andre, 2000). The CADC was developed by INRETS-France from measurements of vehicle driving patterns in real world traffic. In total data on 2 650 hours driving from more than 80 vehicles in France, Germany, UK, Greece and Switzerland with more than 110 000km driven were analyzed to obtain the CADC.

Figure 1 shows the NEDC cycle, while Figure 2 plots the CADC. It is clearly visible that the CADC is much more dynamic than the NEDC and covers higher vehicle speeds and a broader range of acceleration levels. Especially highway driving is covered only to a small extent by the NEDC.

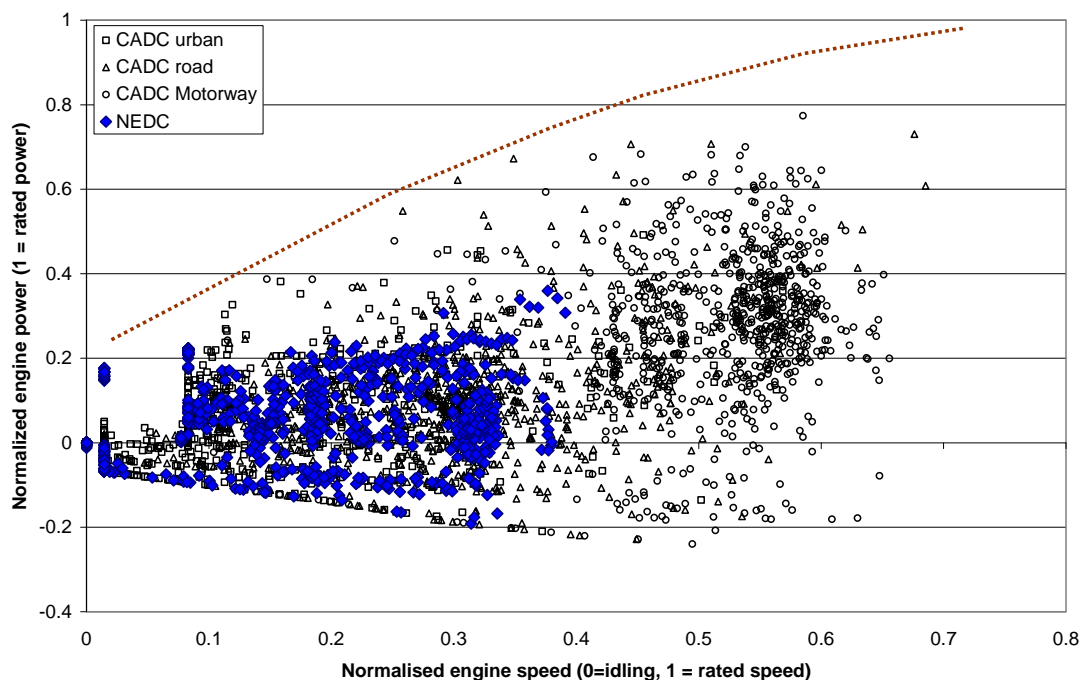


**Figure 1:** NEDC driving cycle



**Figure 2:** CADC driving cycle (version with maximum 130 km/h<sup>1</sup>)

The gear shift strategy of the CADC results in higher engine speeds and the higher acceleration levels in the CADC lead to higher engine power demands compared to the NEDC. Figure 3 compares the engine loads of the NEDC and the CADC for a mid size car. It is visible, that normalized engine speed levels above 40% and engine power demand levels above 30% of the rated power are not covered in the type approval test. In contrary such engine loads occur quite frequently in the CADC cycle. For cars with higher mass and higher rated engine power than plotted in Figure 3, the area not covered by the NEDC is even larger.



**Figure 3:** engine load patterns for a Golf class vehicle with 77 kW rated engine power in the NEDC and in the sub cycles of the CADC (each dot represents one second in the cycle)

<sup>1</sup> Within ARTEMIS also a version of the CADC-Motorway was developed which has 150 km/h maximum speed.

Table 4 compares the average speed, the average positive engine power demand and the average positive cycle work [kWh/km] in the NEDC and the CADC. The average positive cycle work is similar in the NEDC and in the CADC road, while the positive cycle work is approximately 50% higher in CADC urban and CADC motorway than in the NEDC.

**Table 4:** parameters of the test cycles (engine power and engine work calculated for a Golf class car)

	Average speed [km/h]	Average positive engine power [NEDC = 100%]	Average positive cycle work per km [NEDC = 100%]
NEDC	33.4	100%	100%
CADC urban	17.6	79%	150%
CADC road	57.4	188%	109%
CADC motorway	96.9	427%	147%

Table 5 shows the length of each sub cycle of the CADC. Since each sub-cycle has the same test duration, most kilometers are driven in the motorway cycle due to its high velocity.

**Table 5:** length of the sub cycles of the CADC and share of the sub cycles on the total cycle length

	urban	road	mw	total
<b>Length [km]</b>	4.80	17.30	28.70	50.80
Share [%]	9%	34%	56%	100%

In real world driving situations typically urban, road and motorway have rather similar shares in the total vehicle mileage. In Austria the share of motorway driving is approx. 36%, extra urban 34% and urban 29%, (Hausberger, 2010). Since the distribution of the vehicle mileage includes high uncertainties an equal distribution of the mileage on urban, road and motorway as an average value for the different application of the HBEFA around Europe is a reasonable simplification for the analysis. To represent this real world mileage distribution the “CADC 1/3 Mix” was introduced in the later analysis. The “CADC 1/3 Mix” is simply the average emission value in [g/km] from the three sub cycles:

$$\text{CADC 1/3 Mix [g/km]} = \frac{\text{CADC Urban [g/km]} + \text{CADC Road [g/km]} + \text{CADC Motorway [g/km]}}{3}$$

Otherwise the average emission value for the CADC would be influenced most by the motorway sub cycle. The “CADC 1/3 Mix” is a change against the evaluation in the report from 2006, where the average CADC emission value was gained by the trip length weighted average of the sub cycles.

## 9 TEST RESULTS

In this chapter the results of the measurements are discussed.

### 9.1 Overview

In the CADC cycle, the emission levels were generally different than in the NEDC. NO<sub>x</sub> and PM emissions are higher in the CADC than in the NEDC due to the higher engine work, higher acceleration and deceleration levels, higher dynamics, higher engine speed levels and – relevant for NO<sub>x</sub> – a hot start instead of a cold start in the CADC.

HC and CO levels are lower in the CADC compared to the NEDC. This is mainly due to the hot start of the CADC where the oxidation catalysts are effective from the start of the test on and due to the higher share of motorway driving in the CADC, where both, CO and HC from diesel cars are on a very low level.

Table 6 shows the average emission levels of diesel cars measured for each Euro category in the NEDC and in the three CADC cycles.

**Table 6:** Average emission levels for the **diesel cars** in the different test cycles

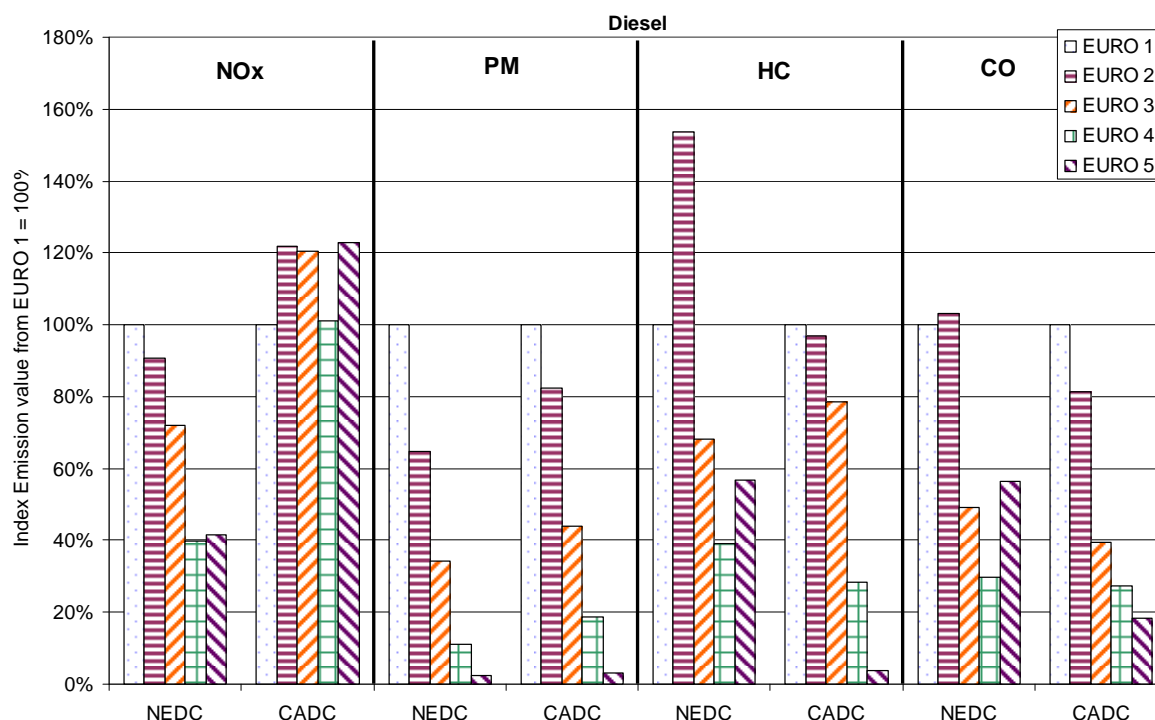
<b>NEDC</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
PreEURO 1	0.103	0.483	0.716	161.4	54.1	0.1163	
EURO 1	0.068	0.553	0.612	160.1	50.4	0.0747	
EURO 2	0.105	0.571	0.554	169.9	57.6	0.0483	
EURO 3	0.046	0.272	0.441	147.9	48.5	0.0256	
EURO 4	0.027	0.165	0.243	179.5	56.5	0.0082	
EURO 5	0.039	0.312	0.255	162.7	51.2	0.0018	1.459E+12
<b>CADC 1/3 Mix</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
PreEURO 1	0.081	0.52	0.71	193.1	62.2	0.124	
EURO 1	0.042	0.23	0.73	182.2	54.9	0.095	
EURO 2	0.040	0.19	0.89	193.3	63.0	0.079	
EURO 3	0.033	0.09	0.87	179.0	56.2	0.042	4.71E+13
EURO 4	0.012	0.06	0.73	197.0	62.2	0.018	2.27E+13
EURO 5	0.002	0.04	0.89	175.8	55.5	0.003	2.31E+12
<b>CADC urban</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
PreEURO 1	0.133	0.76	0.86	237.2	76.4	0.094	
EURO 1	0.073	0.33	0.90	223.1	66.0	0.073	
EURO 2	0.077	0.38	1.04	242.6	78.4	0.092	
EURO 3	0.073	0.22	0.92	223.6	69.4	0.039	5.50E+13
EURO 4	0.018	0.15	0.80	257.6	81.2	0.021	2.23E+13
EURO 5	0.008	0.11	0.94	226.8	71.5	0.004	2.74E+12
<b>CADC Road</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
Pre EURO 1	0.067	0.40	0.53	155.8	50.4	0.070	
EURO 1	0.030	0.18	0.53	141.3	42.9	0.057	
EURO 2	0.028	0.12	0.63	149.7	48.2	0.064	
EURO 3	0.014	0.03	0.57	134.1	42.3	0.028	3.82E+13
EURO 4	0.007	0.02	0.47	148.3	47.0	0.012	1.65E+13
EURO 5	-0.002	0.01	0.60	135.5	42.9	0.002	2.06E+12
<b>CADC Motorway</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
PreEURO 1	0.043	0.41	0.74	186.4	59.9	0.207	0.00E+00
EURO 1	0.021	0.18	0.75	182.2	55.7	0.156	0.00E+00
EURO 2	0.015	0.07	0.99	187.6	62.3	0.081	0.00E+00
EURO 3	0.011	0.02	1.13	179.1	57.0	0.059	4.82E+13
EURO 4	0.010	0.02	0.93	185.0	58.5	0.021	2.92E+13
EURO 5	-0.001	0.01	1.14	165.2	52.2	0.003	2.12E+12



**Table 7:** Average emission levels for the **gasoline cars** in the different test cycles

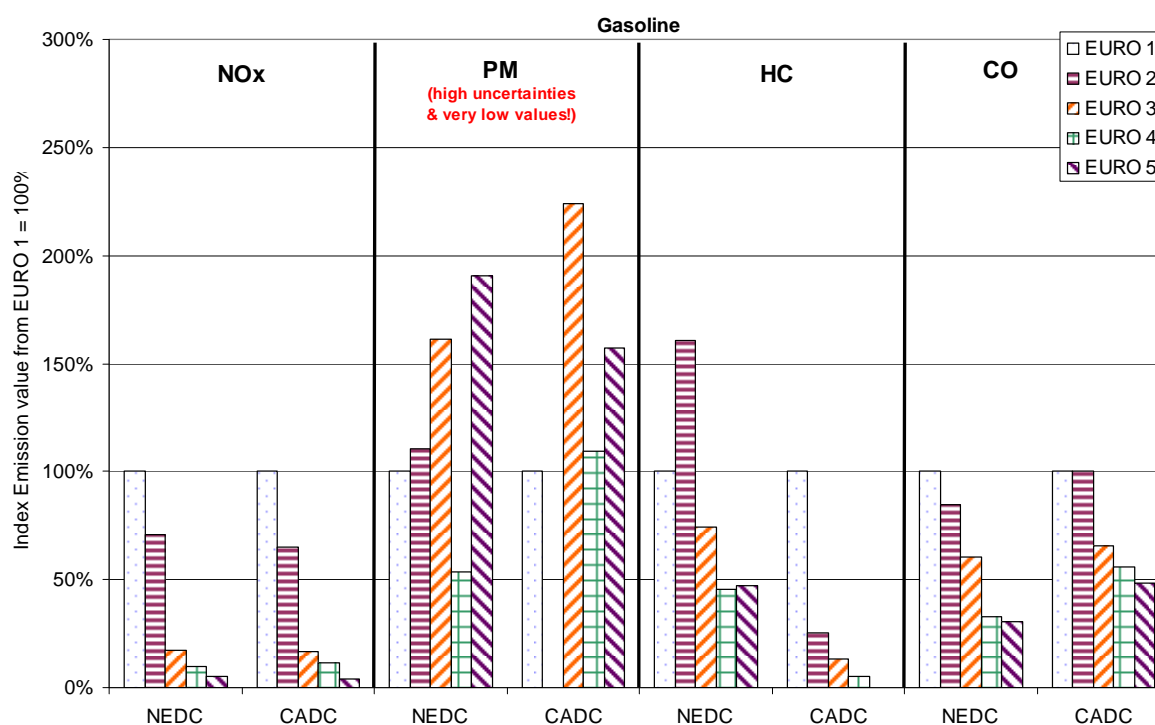
<b>NEDC</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
	[g/km]						[#/km]
PreEURO 1	0.798	5.316	1.312	170.1	62.2	0.116	
EURO 1	0.111	1.291	0.295	182.9	58.0	0.002	
EURO 2	0.179	1.093	0.209	190.5	59.7	0.003	
EURO 3	0.083	0.778	0.052	181.9	57.5	0.004	
EURO 4	0.050	0.421	0.028	182.0	56.7	0.001	
EURO 5	0.052	0.393	0.015	185.1	57.6	0.005	4.682E+12
<b>CADC 1/3 Mix</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
PreEURO 1	2.052	21.014	1.797	202.6	76.3		
EURO 1	0.240	1.977	0.506	191.3	62.4	0.003	
EURO 2	0.060	1.980	0.328	196.4	62.1	0.014	
EURO 3	0.032	1.301	0.084	204.3	64.6	0.006	
EURO 4	0.012	1.101	0.059	201.7	63.9	0.003	1.62E+12
EURO 5	0.000	0.952	0.021	199.7	63.3	0.004	3.58E+12
<b>CADC urban</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
PreEURO 1	3.620	29.104	1.328	272.4	103.5	0.151	
EURO 1	0.413	3.104	0.497	254.2	83.2	0.004	
EURO 2	0.096	1.282	0.490	263.0	81.8	0.003	
EURO 3	0.028	0.655	0.115	271.1	85.0	0.006	
EURO 4	0.013	0.353	0.078	268.3	84.9	0.002	8.27E+11
EURO 5	-0.007	0.110	0.048	258.5	81.8	0.004	5.44E+12
<b>CADC road</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
Pre EURO 1	1.453	15.157	1.274	151.2	56.6	0.305	
EURO 1	0.173	1.321	0.417	146.8	47.8	0.002	
EURO 2	0.039	1.281	0.285	152.0	48.9	0.016	
EURO 3	0.018	0.729	0.061	158.5	50.0	0.003	
EURO 4	0.005	0.330	0.038	152.5	48.1	0.002	6.93E+11
EURO 5	0.001	0.432	0.009	157.9	49.8	0.001	2.27E+12
<b>CADC motorway</b>	<b>HC</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>FC</b>	<b>PM</b>	<b>PN</b>
PreEURO 1	1.084	18.781	2.789	184.3	68.8	0.537	
EURO 1	0.134	1.505	0.604	173.0	56.2	0.002	
EURO 2	0.045	3.378	0.210	174.1	55.7	0.022	
EURO 3	0.051	2.518	0.075	183.5	58.7	0.008	
EURO 4	0.019	2.619	0.061	184.2	58.8	0.005	3.34E+12
EURO 5	0.006	2.312	0.005	182.7	58.3	0.007	3.03E+12

In the actual study the reduction rates achieved from EURO 1 to EURO 5 and especially the new results for EURO 4 to EURO 5 are more important than the absolute levels of the exhaust gas emissions in the different cycles since the reduction rates determine the future development of the emissions from the European car fleet. Reduction rates for PM, HC and CO were found to be high and quite similar in the NEDC and in the CADC. In contrary, the reduction rates for NO<sub>x</sub> are smaller in the CADC than in the NEDC, (Figure 4). Basically it can be concluded that no NO<sub>x</sub> reduction is visible in the CADC 1/3 Mix from EURO 1 to EURO 5.



**Figure 4:** Change of the emission levels from **diesel cars** in the NEDC (20°C cold start) and in the CADC 1/3 Mix (hot start) per type approval class compared to the EURO 1 type approval class

Figure 5 shows the trends found for the gasoline cars. Gasoline cars showed clear reductions in NOx, HC and CO from EURO 1 to EURO 5. PM emissions are available only for a few gasoline cars and thus include high uncertainties. However, PM emissions from the gasoline cars are generally on a very low level.



**Figure 5:** Change of the emission levels from **gasoline cars** in the NEDC (20°C cold start) and in the CADC 1/3 Mix (hot start) per type approval class compared to the EURO 1 type approval class

The results for the single exhaust gas components are discussed in more detail in the following chapters.

## 9.2 NO<sub>x</sub>

The average NO<sub>x</sub> emission levels showed a decreasing trend from EURO 1 to EURO 5 in the NEDC. In the CADC cycle EURO 2 and 3 had higher NO<sub>x</sub> levels than EURO 1 while EURO 4 is slightly below the EURO 1 NO<sub>x</sub>-level. EURO 5 is again 20% higher than EURO 1 in the CADC and thus on the same level as EURO 2 and EURO 3. In contrary there was an 80% reduction of the HC+NO<sub>x</sub> type approval limit from EURO 1 to EURO 5. In the urban, road and motorway sub-cycles of the CADC similar trends are found than in the CADC 1/3 mix, i.e. no NO<sub>x</sub> reduction from EURO 1 to EURO 5 (Figure 6).

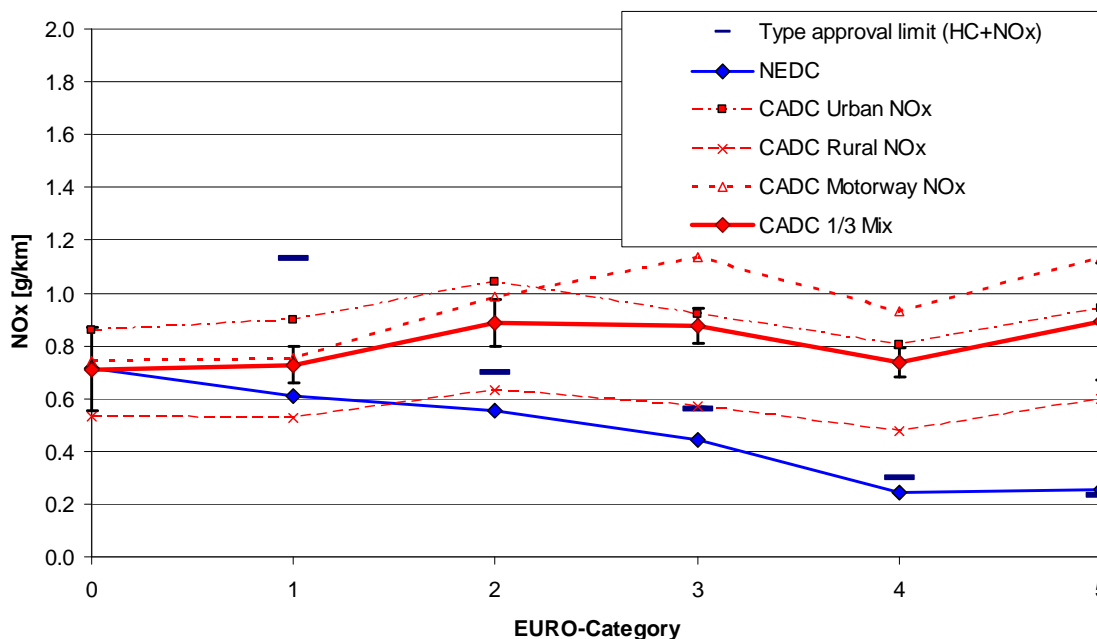
The emissions measured for the vehicle samples in the NEDC cycle dropped by almost 60% from EURO 1 to EURO 5. The lower reduction measured in the NEDC compared to the type approval limits may be attributed to two main reasons:

- 1) The distance to the limit values can be smaller for modern vehicles due to smaller spreads for standard factory models and thus less risk to exceed the limit values in the COP tests.
- 2) The driving resistance values were gained by coast down tests with the actual tires on a standard road for all EURO 5 cars while in the A300 db most likely many vehicles were tested with type approval resistance values, which typically are clearly lower than the average resistance values on the road. Higher driving resistances increase also the NO<sub>x</sub> emissions from diesel cars in the test cycle due to the higher engine work.

The increase of CADC NO<sub>x</sub> emission levels with EURO 2 most likely is an effect of the introduction of electronically controlled fuel injection systems in this period. Since the CADC includes high load points never driven in the NEDC, we may assume that in such off cycle loads the engine is tuned towards high fuel efficiency resulting in low CO<sub>2</sub> emissions and lower PM emissions but increased NO<sub>x</sub> levels due to the NO<sub>x</sub> – fuel efficiency trade off. This was not possible with purely mechanical controlled engines.

Actual technologies, like variable injection timing and exhaust gas recirculation, as well as future technologies, like alternative combustion processes, NO<sub>x</sub> storage catalysts and selective catalytic reduction (SCR), can be applied to a different extent across the engine load and engine speed ranges. Some technologies only show high NO<sub>x</sub> reduction potential at low engine loads and speeds, others need higher engine loads for a good efficiency (e.g. exhaust gas after treatment). Thus the discrepancy between NO<sub>x</sub> emissions in type approval and in CADC like driving may continue to increase in the future.

Therefore it can be concluded, that the NEDC can not guarantee low NO<sub>x</sub> emission levels in CADC like real world driving cycles for vehicles which do have a trade off between NO<sub>x</sub> and fuel consumption values (like for diesel cars).

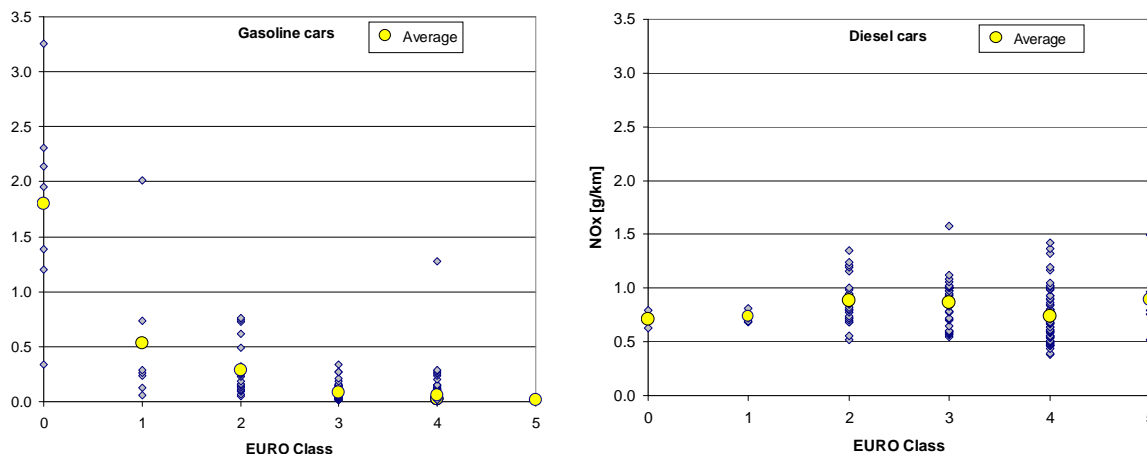


**Figure 6:**  $\text{NO}_x$  test results for the diesel cars in the NEDC (20°C cold start) and the CADC sub cycles (the error bars for the CADC 1/3 mix show the 95% confidence interval for the average value)

Figure 7 shows the results for the  $\text{NO}_x$  emissions measured for each car in the CADC 1/3 Mix. While  $\text{NO}_x$  from gasoline cars dropped significantly from EURO 0 to EURO 5 with only one outlier in the EURO 4 sample the diesel cars do not show a clear trend.

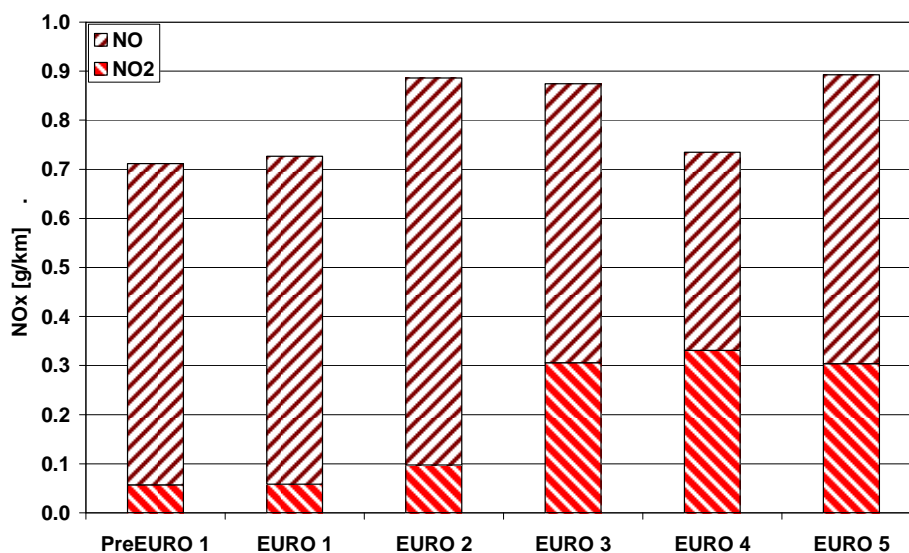
For diesel cars two contrary developments are visible: the lowest  $\text{NO}_x$ -emission value per EURO class shows a downwards trend from EURO 0 on but in contrary the highest  $\text{NO}_x$  emission value measured per EURO class shows an increasing trend. This certainly reflects the increasing vehicle sample from EURO 0 to EURO 4. However, this may also be influenced by improved  $\text{NO}_x$  control technology for several modern engines (downwards trend) and by the increasing share of large passenger cars in the diesel sample (upwards trend).

Figure 7 also shows, that the average  $\text{NO}_x$  emission value for the EURO 5 diesel cars has a rather high uncertainty ( $\pm 0.22$  g/km for the 95% confidence interval) due to two “outliers”, one towards high emissions and one in direction of lower emissions. Which of these emission levels is more frequent in the entire EURO 5 fleet is open yet and needs more vehicle testing in future.



**Figure 7:**  $\text{NO}_x$  test results in the CADC 1/3 Mix (hot start) for all single vehicles and the average values per type approval class (gasoline left picture, diesel right picture)

Due to the introduction of oxidation catalysts from EURO 3, the share of  $\text{NO}_2$  in the  $\text{NO}_x$  emissions from diesel cars increased from approximately 8% for EURO 0 up to 45% for EURO 4. At the EURO 5 vehicles on average 35%  $\text{NO}_2$  share was measured over the CADC 1/3 mix (Figure 8). The lower  $\text{NO}_2$  share may be a result of more Palladium and less Platinum on the oxidation catalyst in front of the particle filters. The Palladium tends to reduce the thermal aging of the catalyst and can thus help to provide reasonable  $\text{NO}_2$  concentrations for continuous DPF regeneration over the lifetime of the vehicle.



**Figure 8:**  $\text{NO}_x$  emissions from diesel cars splitted into NO and  $\text{NO}_2$  in the CADC 1/3 Mix (hot start; NO emissions are given as  $\text{NO}_2$ -mass equivalent value)

### 9.3 Particulate Matter

For particulate matter exhaust gas emissions, a clear decreasing trend is visible both in the type approval cycle and in the CADC (Figure 9). From EURO 1 to EURO 5, the average emission level dropped by more than 95% in all cycles measured here. Compared to the average EURO 4 PM level the EURO 5 has more than 80% lower particle emissions. This is due to the fact, that all tested EURO 5 diesel cars are equipped with a DPF while in the EURO 4 sample less than 50% had a DPF.

The particle emissions from the two gasoline EURO 5 cars measured had on average 0.004 g/km while the average for the EURO 5 diesel is 0.003 g/km. Thus, PM emissions from modern diesel cars are on an even lower PM emission level than gasoline cars.

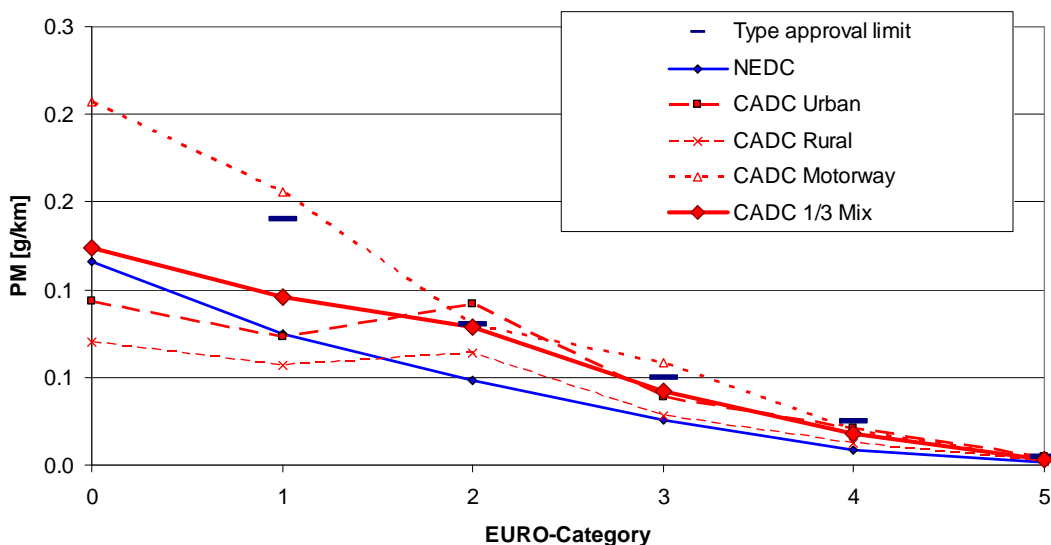


Figure 9: **PM** test results from **diesel cars** in the NEDC (20°C cold start) and the CADC sub cycles

## 9.4 HC

Figure 10 shows the test results for HC. Hydrocarbon emissions show a clear decreasing trend towards EURO 5 for both, gasoline and diesel cars. The EURO 5 gasoline cars had zero mg HC/km, the diesel EURO 5 cars had on average 2 mg/km in the CADC 1/3 Mix. In the NEDC test with cold start the emissions from gasoline cars were slightly higher than that from the diesel cars (0.05 versus 0.04 g/km). However, HC emissions from actual cars seem not to be a reason for concern.

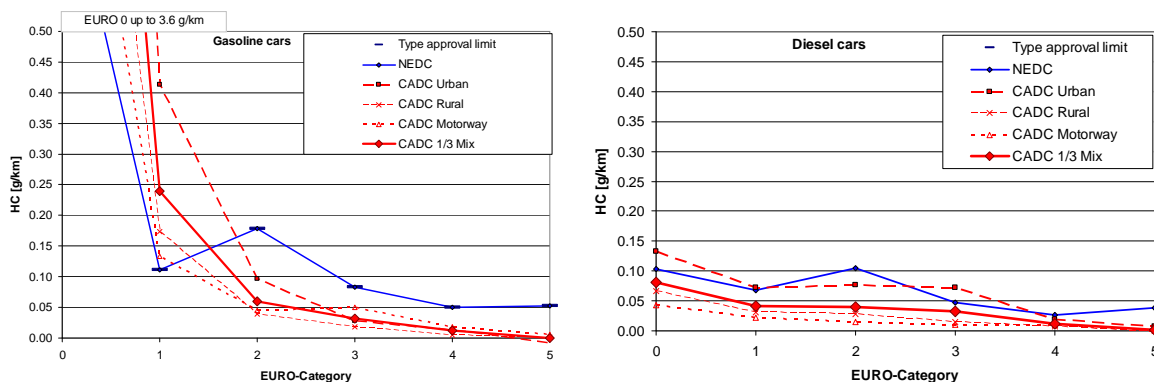


Figure 10: **HC** test results in the NEDC (20°C cold start) and the CADC sub cycles

## 9.5 CO

Figure 11 shows the test results for CO. CO emissions dropped similarly as HC emissions from EURO 0 on. CO from diesel cars was in general at a very low level. For gasoline and diesel further reductions seem not to be necessary.

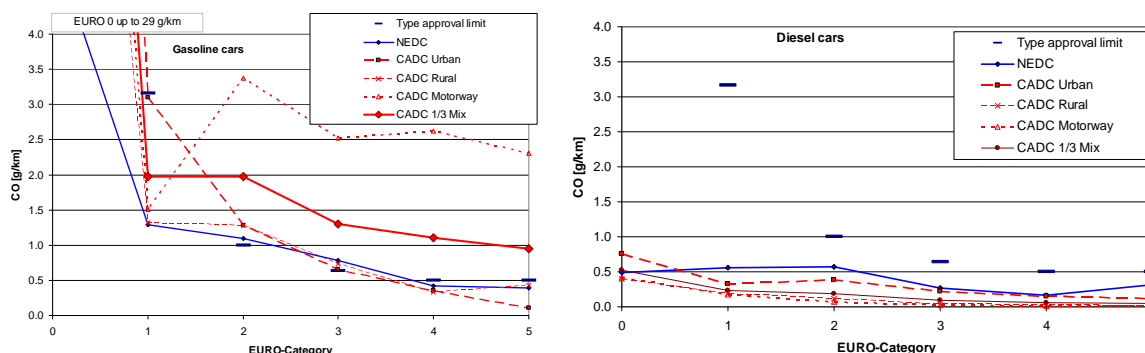


Figure 11: CO results in the NEDC (20°C cold start) and the CADC sub cycles

## 9.6 Particle Number emissions

Figure 12 shows the test results for PN. Test results for PN emissions are not available for older vehicle classes from comparable test procedures. Even EURO 3 and EURO 4 data may have different measurement methods for several vehicles since the PMP test protocol, which regulates the PN measurement, was not generally available for testing before 2008. The regulation is still not finally approved but the basic test methods for PN emissions have not been changed tremendously over the last two years. The EURO 5 tests for diesel and gasoline at TU Graz followed (UK, 2010) in all relevant settings. The tests procedure however, is not prescribed for gasoline cars. Five of the tested diesel vehicles had already emissions of less than  $6 \times 10^{11}$  particles per kilometer which is the future type approval limit. One EURO 5 diesel car had  $9 \times 10^{12}$  particles per kilometer which is a clear outlier which heavily influences the average PN emission value for the tested diesel cars. One of the two tested gasoline cars had  $8.4 \times 10^{12}$  particles per kilometer in the NEDC, the other  $9.4 \times 10^{11}$ . Emissions in the CADC are on a similar level as PN emissions in the NEDC.

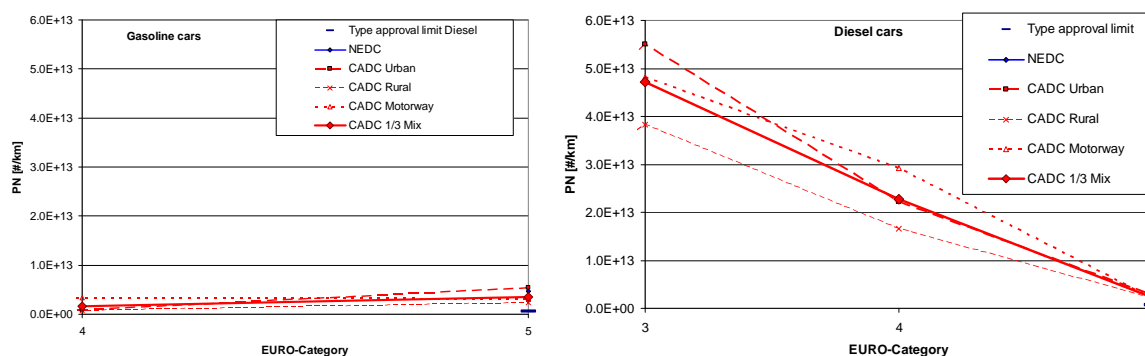


Figure 12: PN results in the NEDC (20°C cold start) and the CADC sub cycles

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