Swedish In-Service Testing Programme on Emissions from Passenger Cars and Light-Duty Trucks

Annual Report 2013

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by

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Contents

1. List of Abbreviations

A4 / A5 / A6	4-speed / 5-speed / 6-speed automatic gearbox
CADC	Common Artemis Driving Cycle
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity of production
CPC	Condensation Particle Counter
CVS	Constant Volume Sampler; exhaust emission sampling system
EC	European Community
EUDC	Extra Urban Driving Cycle; Part 2 of the New European Driving Cycle
Euro 1	Type approval test in accordance with Directive 91/441/EEC
Euro 2	Type approval test in accordance with Directive 94/12/EEC
Euro 3	Type approval test in accordance with Directive 98/69/EC
Euro 4	Type approval test in accordance with Directive 98/69/EC, stricter requirements (incl. lower limit values in driving cycle, -7°C test)
Euro 5, Euro 6	Type approval test in accordance with Directive 715/2007/EC
FC	Fuel consumption
FTP 75	Federal Test Procedure 75 = US American driving cycle, defined in 1975
HC	Hydro carbons; see THC
KBA	Kraftfahrtbundesamt – German Federal Motor Transport Authority
M1	Vehicles for passenger transportation with a capacity of max. 8 seats excluding the driver and a maximum total vehicle mass of 3,500kg
M5 / M6	5-speed / 6-speed manual gearbox
MK	Miljöklass; Swedish Environment Class
N1	Vehicles for transportation of goods and a total vehicle mass of up to 3,500kg
NEDC	New European Driving Cycle according to Directive 98/69/EC and 715/2007/EC
NO_X	Nitrogen oxides
OBD	On-Board Diagnosis
PEMS	Portable Emission Measurement System
PM	Particle Mass
PMP	Particle Measurement Programme
PN	Particle Number
RPA	Relative Positive Acceleration
SHED	Sealed Housing for Evaporative Emissions Determination
STA	Swedish Transport Agency
THC	Total Mass of hydro carbons emitted by a vehicle, given in C_1 equivalent
TSN	Type code number
UDC	Urban Driving Cycle; Part 1 of the New European Driving Cycle
UNECE	United Nations Economic Commission for Europe

2. Summary

In this In-Service Conformity testing programme a total of 70 vehicles, spread over six vehicle types with positive ignition engine and eight vehicle types with compression ignition engine and particle filter, within one light duty vehicle type and one four wheel drive vehicle type were tested with respect to the exhaust emissions limited by law. All tested vehicle were type approved according the Euro 5 limits.

The measurements were carried out in the respective type approval cycle, the "New European Driving Cycle" (NEDC) in accordance with Directive 98/69/EC and 715/2007/EC (Type I test). In addition to this, measurements according to the Common Artemis Driving Cycle (CADC) were conducted for the emission factor programme and vehicle types were tested with the Portable Emission Measurement System (PEMS) method on road and in real traffic.
Two vehicles of each type with compression ignition were tested at two cold temperatures (5°C and -7°C). In this way it was possible to cover the entire operational range relevant to exhaust emissions for vehicles. During the measurements on the chassis dynamometer, the exhaust emissions were measured and the fuel consumption was calculated from the emissions of the carbon-containing exhaust components. Exhaust emissions at idle speed (Type II test) and crankcase emissions (Type III test) were measured of all vehicles with positive ignition engine. At two vehicles per type with positive ignition engine the evaporative emissions (Type IV test) were determined. In addition on two vehicles per type with positive ignition engine, the exhaust emissions at low ambient temperatures (Type VI test) were measured. With the Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars was introduced. With Directive 715/2007/EC the Diagnose of Compression ignition engines becomes more important. During this programme the OBD-data were registered. Additional, some emission relevant failures were simulated to control the function of the OBD system of one vehicle per type.

All six tested gasoline vehicle types complied with the limits given by the type approval during Type I test and fulfilled the requirements for In-Service testing according to the statistical procedure defined with Directive 98/69/EC and 715/2007/EC (Euro 5a). All cars complied already with the limit for Direct Injection gasonline vehicles that was implemented with Euro 5b. While measuring Particle number emissions half of the cars came close by, the other half missed the limit.

None of the compression ignition vehicles tested during this programme exceeded the limit for particle mass and for nitric oxides. According to the statistical procedure defined with Directive 98/69/EC and 715/2007/EC all compression ignition vehicle types complied with the requirements for In-Service testing

During the Type I test on twelve vehicle types the measured and the average fuel consumption was higher than the fuel consumption declared by the manufacturer. For one vehicle type the average deviation from the values given by the manufacturer was 28,3% on fuel consumption and 25,0% on CO_2 emissions.
On two vehicle type the deviation from the values given by the manufacturer was slightly lower on fuel consumption and CO_2 emissions.

Measuring exhaust emissions at idle speed during the Type II test no emission related problems were detected.

On all six vehicle types with gasoline engine no crankcase emissions were emitted into the atmosphere at the Type III test.

One of the gasoline vehicles failed the limit for evaporative emissions measured during the Type IV-test. According to the statistical procedure defined with Directive 98/69/EC and 715/2007/EC this vehicle type complied with the requirements for In-Service testing because of one of two tested vehicle failed the limit.

During the exhaust emission test at low ambient temperatures (Type VI test), all vehicles complied with the limits according to Directive 98/69/EC and 715/2007/EC.

During this project the OBD-data were registered. In addition some emission relevant defects were simulated to control the function of the OBD system at one of the vehicles per type. All simulated failures were detected by the OBD systems.

Testing the vehicles on different test cycles showed the influence of driving behaviour and driving conditions on the exhaust emissions. Dynamic driving, high speed, high engine load and cold start conditions cause an increase of carbon monoxide and hydrocarbon emissions, especially on vehicles with positive ignition engine. The major environmental exposure caused by compression ignition vehicles is nitric oxide and particulate emissions. NO_x was emitted by compression ignition vehicles especially during the CADC motorway cycle. This is due to the high temperature inside the combustion chamber at high engine load, combined with a surplus of oxygen within the cylinder. It became obvious that dynamic driving with strong accelerations on urban conditions gives the worst fuel consumption. Positive ignition engines suffer from cold start the most. Smoothly running traffic with moderate speed and acceleration gives the lowest fuel consumption.

3. Introduction

Well functioning transportation is vital for undertakings and citizens. Road transport dominates as it carries 46% of freight and 83% of passenger traffic in Europe. The rise of the population causes a rise of the number of passenger cars. **Figure 3.1** shows the trend for the last 100 years.

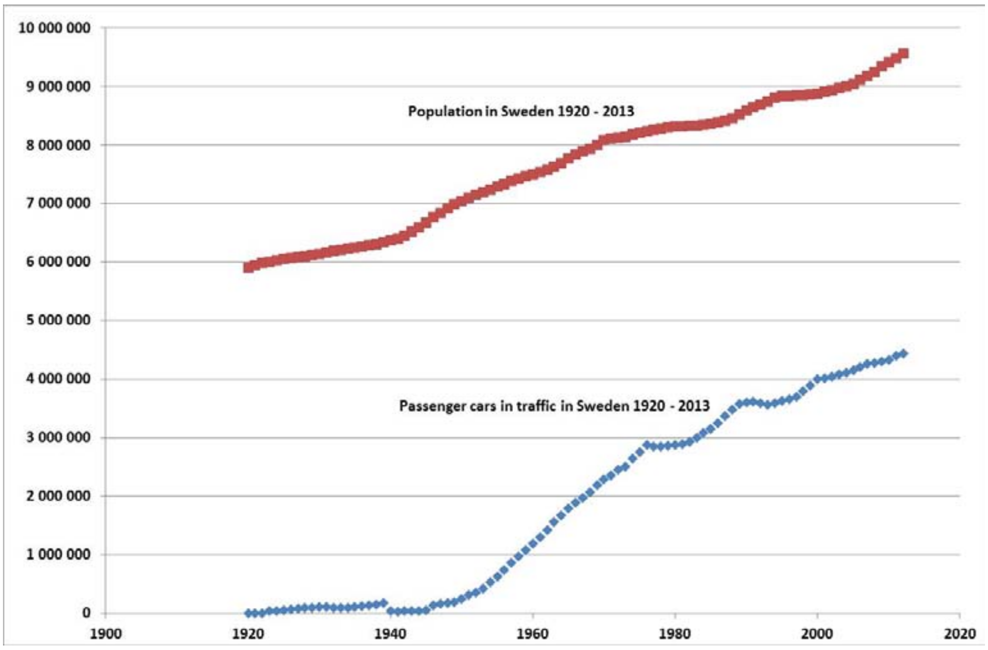

Figure 3.1: Number of population and passenger cars in Sweden

Within this rising number of passenger cars and population the pollution of the air by the emissions gets more and more important
Looking at the last six years the number of passenger cars equipped with a compression ignition engine increases from 20% in 2006 up to 65% in 2012. For 2013 it decreases slightly from 65% to 61%. Gasoline- and Electrical- or Hybrid cars increase. **Figure 3.2** illustrates the increasing influence of diesel cars to the traffic in Sweden from 2006 to 2013.

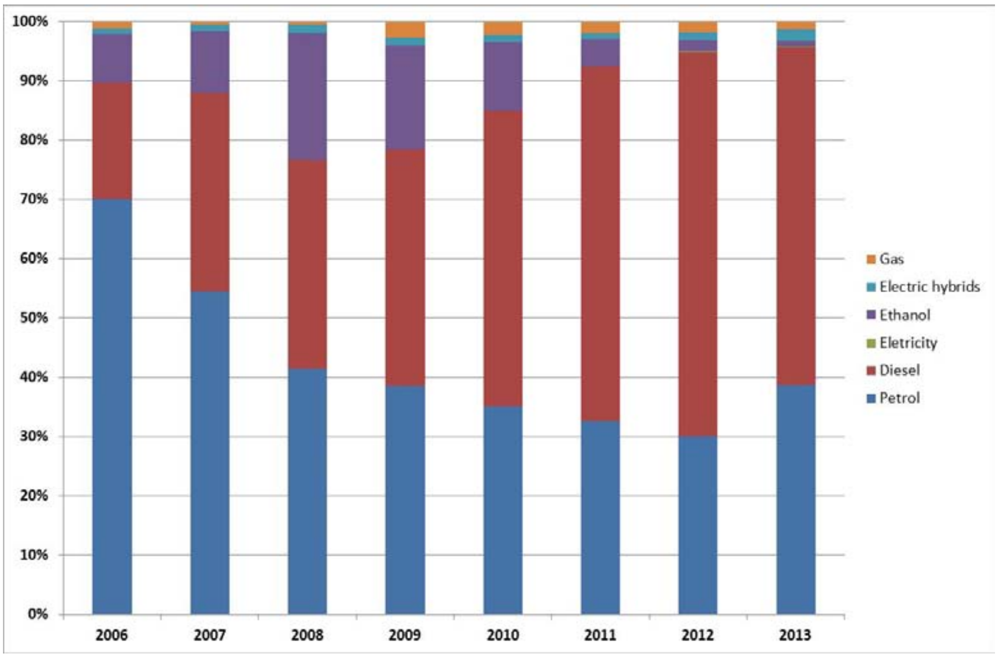

Figure 3.2: Use of different fuels in Sweden; Statistiska Centralbyrån (SCB)

In addition the use of Ethanol (E85) decreased from the highest use of 20% in 2008 down to 1% in 2013.

Transport policies aim at ensuring clean, safe and efficient carriage of passengers and goods. Increasing the efficiency and reducing negative effects of road traffic on the environment is a major challenge. Road traffic is still the main source of air pollution from carbon monoxide, hydrocarbons and nitrogen oxides in Europe. In order to counter environmental pollution from motor vehicle emissions, exhaust legislation has been stepwise tightened over the past few decades. There is now an extensive package of measures available to reduce air pollution due to road traffic. This includes both control of new vehicles and testing of vehicles in-use. The control of new vehicles comprises type approval, durability testing and conformity of production (COP). The control of vehicles in-service includes an on-board diagnosis (OBD) system in the vehicles, the periodic inspection of all vehicles on the road, vehicle manufacturers' In-Service Conformity testing, plus enhanced requirements regarding fuel quality. **Table 3.1** shows various statutory measures taken to reduce exhaust emissions from motor vehicles.

The In-Service Conformity test of vehicles in operation on the roads was introduced in October 1998 with the Directive 98/69/EC and is resumed in directive 715/2007/EC in the member states of the EU. Here privately owned vehicles which have been licensed under Directive 715/2007/EC are examined after a statistical selection process in a complete test procedure according to the type approval cycle. It is the vehicle manufacturer who is responsible for this test. In addition to the manufacturer's own In-Service Conformity test some countries in the EU have parallel national programs for In-Service Conformity. On a regular basis this started in Sweden in 1991, first based on the national emission regulation and later on the EC directive.

In numerous programmes it has been shown that In-Service Conformity testing can reveal type-specific and design-related faults or inadequate maintenance regulations which, after an extended operating period of the vehicle, lead to an inadmissible increase in exhaust emissions.

Swedish Transport Agency (STA) is responsible for type-approval together with other obligations, for motor vehicle emission controls. With that follows the obligation to carry out evaluations of the product performance in-service. The STA has commissioned TÜV Nord (Germany) in collaboration with Ecotraffic (Sweden) to carry out the test programme on light motor vehicles.

The objective of the Swedish test programme is to conduct screening tests on a number of vehicle models, picked out on a spot-check basis, to verify durability in the emission control concept. This is done in close collaboration with the vehicle manufacturers. This enables the manufacturers concerned to rectify any type-specific faults relevant to emissions of the vehicles on the road and serial production and to incorporate knowledge gained from the field monitoring in future developments. By proceeding in this way, this research programme contributes directly to lowering the environmental pollution from emissions caused by road traffic.

Besides In-Service Conformity testing it is also a minor objective of the programme to get information of emissions from vehicles during real world driving. These data will be used to update the European emission model HBEFA. HBEFA is used in Sweden for national emission inventories and as input to local air pollution calculations.

To get more information about real world driving the expert group of the European commission for Real Driving Emission on Light Duty Vehicles (RDE-LDV) declared the use of a Portable Emission Measurement System (PEMS) for type approval starting 2017. Up to now the RDE-LDV Group discusses how to proceed such measurements the right way. To update the database and to support the ongoing process three vehicle types of this program where tested with PEMS. The collected data were given to the Joint Research (JRC) Center of the European Commission.

	New Vehicles			Vehicles on the Road		
	Type Approval Test	**Durability Test**	**Conformity of Production**	**In-Use Compliance testing**	**Periodic Exhaust Inspection**	**On-Board Diagnosis**
Aim:	Verification of compliance with statutory specifications by the vehicle type	Verification of compliance with statutory specifications by the vehicle type	Statistical back-up for serial production	Detection of type-specific design-related defects or inadequate maintenance instructions	Detection of high-emission vehicles, servicing condition	Malfunction detection and indications for immediate repair
Area of Responsibility	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Owner	Vehicle Owner
Vehicle Selection	Prototypes	Prototypes or serial vehicles	Random sample from serial production	Random sample of vehicle fleet in the field	All vehicles on the road	All vehicles on the road
Test Interval	One-off	One-off	Sporadic	Regular	Regular	Permanent
Type of Test	Type test	Continuous run (AMA) or fixed deterioration factor	Type test	Type test	Idle test	Actual conditions according to manufacturer's application
Influence on Emission Reduction	Technology used	Durability under laboratory conditions	Technology used and implementation in production	Technology used and implementation in the field	Servicing condition	Durability and servicing condition in actual traffic
Statutory Basis	European Directives governing measures to prevent air pollution from motor vehicle emissions 98/69/EC ; 715/2007/EC			98/69/EC; 715/2007/EC	96/96/EC	98/69/EC; 715/2007/EC

Table 3.1: Approaches to the reduction of exhaust emissions from motor vehicles

4. Project Implementation

4.1. Investigation Programme

Within the framework of this programme a total of six vehicle types with positive ignition engine and eight vehicle types with compression ignition engine and particle filter were tested with respect to the exhaust emissions limited by EU emission legislation. All tested vehicle were type approved according the Euro 5a limits.

The measurements were carried out in the respective type approval cycle, i.e. the "New European Driving Cycle“ (NEDC) in accordance with Directive 98/69/EC and 715/2007/EC. In addition to this the Common Artemis Driving Cycle (CADC) was investigated for the emission factor programme, three vehicle types were measured on road with PEMS. In this way it was possible to cover the entire operational range relevant to exhaust emissions for vehicles. The different driving cycles are shown in **section 4.3**.

During the measurements on the dynamometer, the emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X) and carbon dioxide (CO_2) were collected in bags in accordance with the regulations and the integral values were determined. For all vehicles particle mass was determined according to the current regulation. Some additional components were also measured during the CADC test. Parallel to this the exhaust emissions were recorded continuously every second (modal measurement). The results of the modal measurements serve as the basis for determining the emission functions with which the exhaust emission behaviour can be shown in all relevant traffic situations.

In addition to exhaust emissions, fuel consumption was determined in the respective type approval cycle in accordance with Directive 80/1268/EEC and 715/2007/EC. The fuel consumption was calculated from the emissions of the carbon-containing exhaust components (CO_2, CO and HC).

Exhaust emissions at idle speed (Type II test) and crankcase emissions (Type III test) were measured on all vehicles with positive ignition engine.

On two vehicles per type with positive ignition engine the evaporative emissions (Type IV test) were determined. Exhaust emissions at low ambient temperatures (Type VI test) of two vehicles per type with positive ignition engine were measured.

With Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars and light-duty vehicles was introduced and is resumed in directive 715/2007/EC. During this programme the OBD-data were registered. In addition some emission relevant failures were simulated to control the function of the OBD system at one vehicle per type.

The test date was agreed upon with the car manufacturer or importer concerned to enable him to be present during the tests. Representatives of the respective vehicle manufacturer were present, having been invited to witness the implementation of the tests.

4.2. Vehicle Selection

It was intended that the selected vehicles should cover as wide a spectrum of manufacturers as possible, while maintaining a representative cross-section of the vehicle types licensed in Sweden. Vehicle types from 12 different manufacturers were investigated in the programme. All selected vehicles were type approved according to directive 715/2007/EC.

Table 4.1 shows the exhaust emission limits valid for the type approval test of passenger cars and light duty vehicles. For passenger cars (M1) with a maximum mass bigger than 2,500 kg and light duty trucks (N1) separate limits can be applied according to the reference weight of the vehicle. The "New European Driving Cycle" is described in section 4.3.

Engine	Limit	Vehicle Class *)	Reference Mass (RM) [kg]	CO [mg/km]	HC [mg/km]	NMHC [mg/km]	NO_x [mg/km]	$HC+NO_x$ [mg/km]	PM [mg/km]	PN [#/km]
Gasoline	Euro4	M1 ≤ 2500kg	All	1000	100	-	80	-	-	-
		N1 class I	RM ≤ 1305	1000	100	-	80	-	-	-
		N1 class II	1305< RM ≤1760	1810	130	-	100	-	-	-
		N1 class III	1760 < RM	2270	160	-	110	-	-	-
	Euro5	M1 ≤ 2500kg	All	1000	100	68	60	-	-	-
		N1 class I	RM ≤ 1305	1000	100	68	60	-	-	-
		N1 class II	1305< RM ≤1760	1810	130	90	75	-	-	-
		N1 class III	1760 < RM	2270	160	108	82	-	-	-
Diesel	Euro4	M1 ≤ 2500kg	All	640	-	-	500	560	50	-
		N1 class I	RM ≤ 1305	640	-	-	500	560	50	-
		N1 class II	1305< RM ≤1760	800	-	-	650	720	70	-
		N1 class III	1760 < RM	950	-	-	780	860	100	-
	Euro5	M1 ≤ 2500kg	All	500	-	-	180	230	4,5	$6{,}0*10^{11}$
		N1 class I	RM ≤ 1305	500	-	-	180	230	4,5	$6{,}0*10^{11}$
		N1 class II	1305< RM ≤1760	630	-	-	235	295	4,5	$6{,}0*10^{11}$
		N1 class III	1760 < RM	740	-	-	280	350	4,5	$6{,}0*10^{11}$

*) N1 limits are also valid for class M vehicles with a maximum mass > 2500kg

Table 4.1: Emission limits for passenger cars and light-duty vehicles, valid for the Type I test (NEDC)

The vehicle selection was done in cooperation with local dealers to guarantee a good maintenance condition of the vehicles. Further criteria such as kilometre reading and date of first registration were taken into consideration. When the vehicles were taken over for the programme, additional data regarding repairs carried out on the vehicles as well as deviations from the series production condition was noted. The components which are relevant for exhaust emissions were checked for directly recognisable damage. OBD information was read to ensure that no emission relevant fault code was stored.

The following criteria were used as a basis when selecting individual vehicles:

- same type approval for vehicles of one type
- Kilometre reading between 15,000 km (alternatively at least 6 months in traffic) and 100,000 km,
- regular servicing according to manufacturer's advice
- vehicle is unmodified series production model
- no mechanical damage to components

The vehicle types which were investigated are shown in **Tables 4.2 and 4.3** along with the relevant technical data. All vehicles witch compression ignition engine were equipped with particle filter.

Type No.	Manufacturer	Type	Trade name	Engine type	Engine capacity [cm^3]	Power [kW]	Emission approval	Mileage min [km]	Mileage max [km]	Registration
1	TOYOTA	AB1	Aygo	1KR-FE	998	50	Euro 5	25,109	51,558	2010-10-08 to 2010-12-29
2	VOLKSWAGEN	6R	Polo	CGGB	1390	63	Euro 5	29,565	50,462	2010-04-01 to 2010-11-18
3	HYUNDAI	PA	i10	G4HG-5	1086	50	Euro 5	17,293	45,244	2011-03-09 to 2011-06-28
4	OPEL	P-J	Astra	A14NET	1364	103	Euro 5	19,394	89,227	2010-07-30 to 2010-12-02
5	SEAT	6J	Ibiza	CBZB	1197	77	Euro 5	37,950	59,683	2011-03-10 to 2011-07-27
6	TOYOTA	XP9F	Yaris	1NR-FE	1329	73	Euro 5	32,143	62,512	2010-09-14 to 2011-02-04

Table 4.2: Vehicle Types with positive ignition engine

Type No.	Manufacturer	Type	Trade name	Engine type	Engine capacity [cm^3]	Power [kW]	Emission approval	Mileage min [km]	Mileage max [km]	Registration
1	RENAULT	Z	Megane	K9K H8	1461	66	Euro 5	31,655	47,792	2010-05-21 to 2011-06-28
2	FORD	C307	Focus	G8DB	1560	80	Euro 5	33,611	74,783	2009-12-29 to 2010-11-18
3	KIA	ED	Ceed	D4FB	1582	94	Euro 5	34,757	53,725	2010-09-06 to 2011-08-23
4	PEUGEOT	4	Peugeot 308	9HR/9H05	1560	82	Euro 5	29,938	62,754	2010-09-13 to 2011-02-11
5	SUBARU	BM/BR	Legacy	EE20	1998	110	Euro 5	37,776	72,325	2010-06-23 to 2011-04-28
6	VOLVO	B	V70	D5204T2	1984	120	Euro 5	25,699	89,756	2009-04-01 to 2009-12-11
7	OPEL	X83	Opel Vivaro	M9R	1995	84	Euro 5 / class III	56,726	89,326	2011-11-01 to 2011-11-25
8	VOLKSWAGEN	3C	VW Passat	CFF	1968	103	Euro 5	31,408	49,236	2011-08-22 to 2012-11-06

Table 4.3: Vehicle Types with compression ignition engine

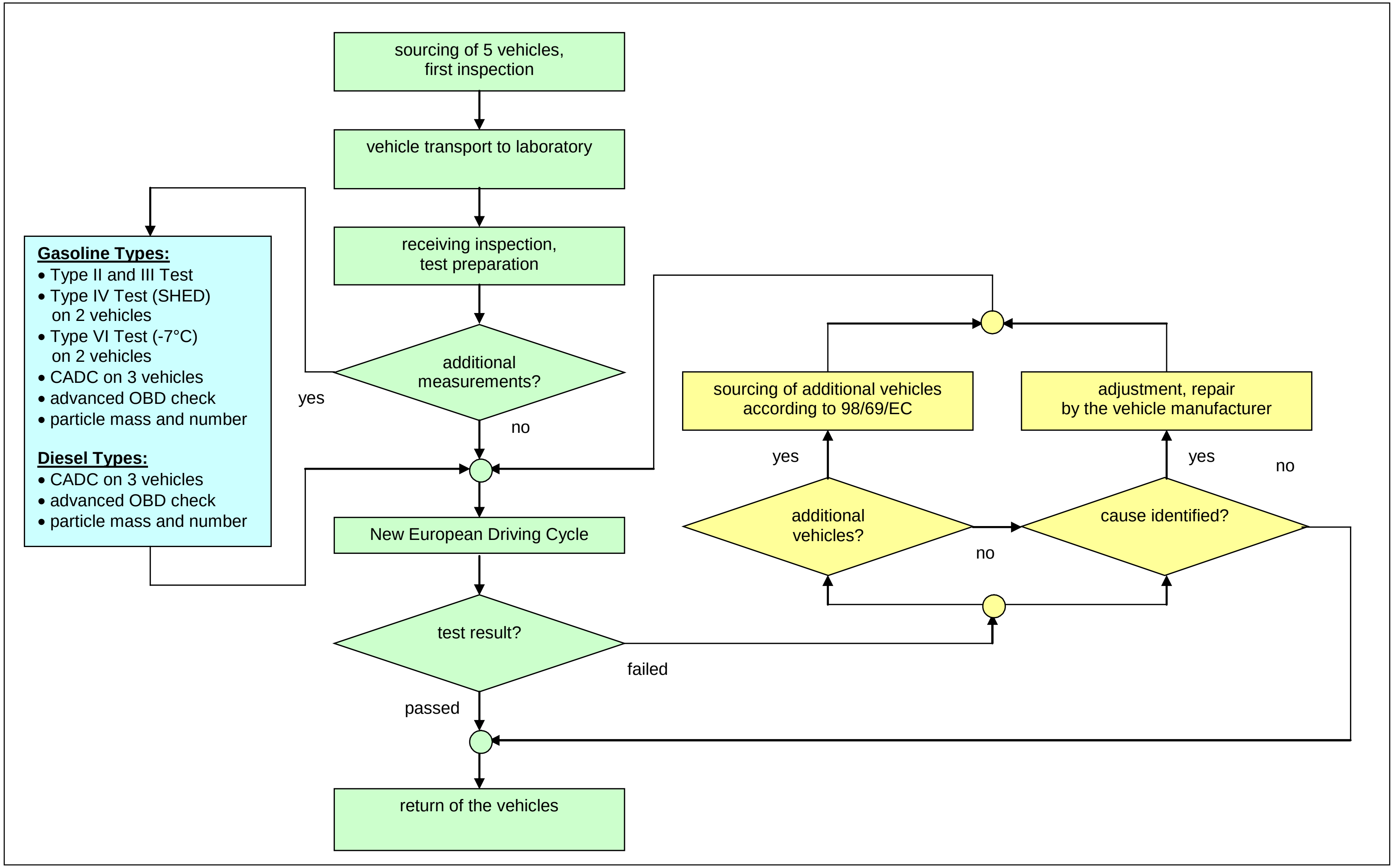

Figure 4.1: Simplified illustration of the In-Service Testing programme

4.3. Implementation of Tests

In **Table 4.4** the application of tests for type approval of passenger cars and light duty vehicles is illustrated.

Test	Description	Positive Ignition Vehicles	Compression Ignition Vehicles
Type I	tailpipe emissions after cold start	yes	yes
Type II	carbon monoxide emissions at idling speed	yes	-
Type III	emission of crankcase gases	yes	-
Type IV	evaporative emissions	yes	-
Type V	durability of anti-pollution control devices	yes	yes
Type VI	low ambient temperature tailpipe emissions after a cold start	yes	-
OBD	On Board Diagnosis	yes	yes

Table 4.4: Application of tests for type approval

Within the framework of the programme 14 vehicle types were tested. The investigations were implemented with reference to Directive 98/69/EC and 715/2007/EC. In order to obtain a reliable assessment if type-specific defects are present on a vehicle type, initially five vehicles per type were measured with respect to exhaust emissions.

The vehicles were selected in cooperation with authorized dealers to be sure that the vehicles were maintained according to the manufacturer's requirements. All vehicles were checked and the OBD information was read to ensure that no emission relevant fault code was detected. Before sending the chosen vehicles to the exhaust emission laboratory they were driven 50km for conditioning.

After the vehicles had been received at the laboratory, a check was made as to whether the specified maintenance intervals had been observed and that the vehicles were in a proper condition. Proof was provided by means of the service record manual. Before commencement of the measurements on the chassis dynamometer, the vehicles were checked with respect to the tightness of the exhaust system.

For dynamometer setting the same inertia weight and coast down values were chosen as for the type approval test. A deterioration factor was not used for evaluating the Type I test results. The vehicle types were assessed in accordance with Directive 98/69/EC and 715/2007/EC.

The vehicles were tested in a measuring programme which not only includes the tests applied for type approval, but also covers other test cycles like Common Artemis Driving Cycle to determine exhaust emission factors. Figure 4.1 gives a simplified illustration of the programme. It does not show the different tests in the order operated during the programme.

The Common Artemis Driving Cycle was driven in the beginning of the test-programm to implement an additional conditioning of the vehicles before starting the tests according to the directive. On the afternoon of the day before running the Type I tests, all vehicles were conditioned (NEDC for vehicles with positive ignition, 3 Extra Urban Driving Cycles (EUDC) for vehicles with compression ignition).

Type II and III tests on vehicles with positive ignition engine were carried out immediately after the Type I test. The OBD check was done at the end of the test procedure to make sure that the simulation of emission relevant failures could not affect the results of the other tests. **Table 4.5** displays the procedure of the different tests during the programme.

Step	Item	Positive Ignition Type	Compression Ignition Type
1	CADC	3 vehicles per type	3 vehicles per type
2	Conditioning	5 vehicles per type (NEDC)	5 vehicles per type (3 x EUDC)
3	Type I test	5 vehicles per type	5 vehicles per type
4	NEDC at 5°C	not relevant	2 vehicles per type (incl. Conditioning)
5	NEDC at -7°C	not relevant	2 vehicles per type (incl. Conditioning)
6	Type II test	5 vehicles per type	not relevant
7	Type III test	5 vehicles per type	not relevant
8	Type IV test	2 vehicles per type	not relevant
9	Type VI test	2 vehicles per type (incl. Conditioning)	not relevant
10	OBD check	1 vehicle per type	1 vehicle per type
11	PEMS	3 vehicles per 2 types	3 vehicles per 1 type

Table 4.5: Test programme

The different driving cycles are illustrated in the following section.

New European Driving Cycle (NEDC)

After conditioning the vehicle for at least 6 hours at an ambient temperature of 20 °C up to 30 °C the New European Driving Cycle (NEDC) begins with a cold start. The Urban Driving Cycle (UDC) has a duration of 780 seconds, a driving distance of 4.1 km, an average speed of 19 km/h and a maximum velocity of 50 km/h. It is followed by an Extra Urban Driving Cycle (EUDC) with a duration of 400 seconds, a driving distance of 6.9 km, an average speed of 62.6 km/h and a maximum velocity of 120 km/h. Exhaust emissions of both UDC and EUDC are combined to get a total test result.

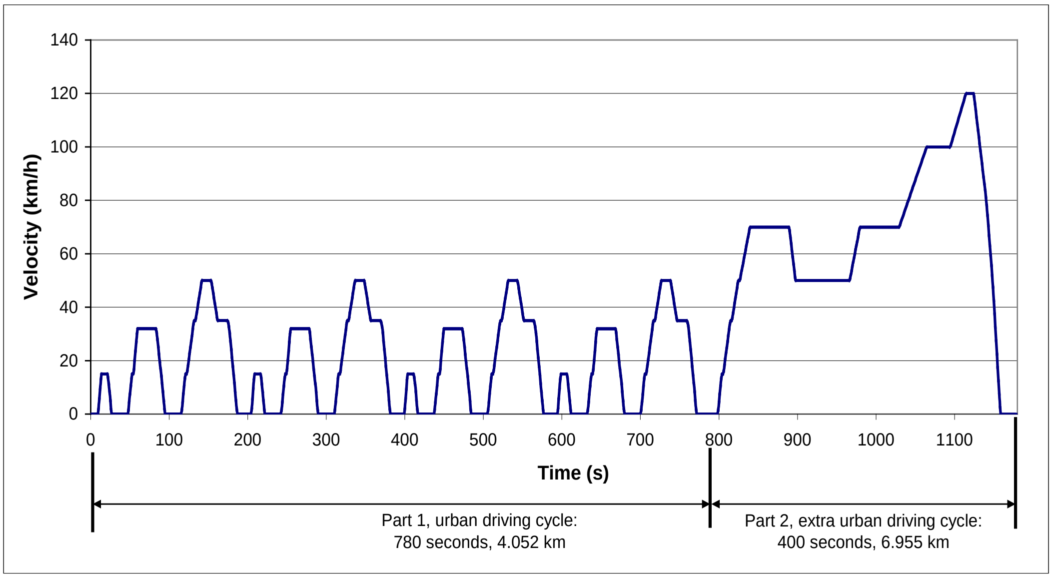

Figure 4.2: New European Driving Cycle

Common Artemis Driving Cycle (CADC)

The Common Artemis Driving Cycle was created in order to gain a better knowledge about emissions in real traffic. The CADC consists of three sub cycles:

- Urban driving cycle, duration 993 seconds, cold start
- Road driving cycle, duration 1082 seconds, warm start
- Motorway driving cycle, duration 1068 seconds, warm start

In addition the Urban part of the CADC was driven with warm start. Comparing the results of CADC Urban with cold start and with warm start gives information about cold start emissions.

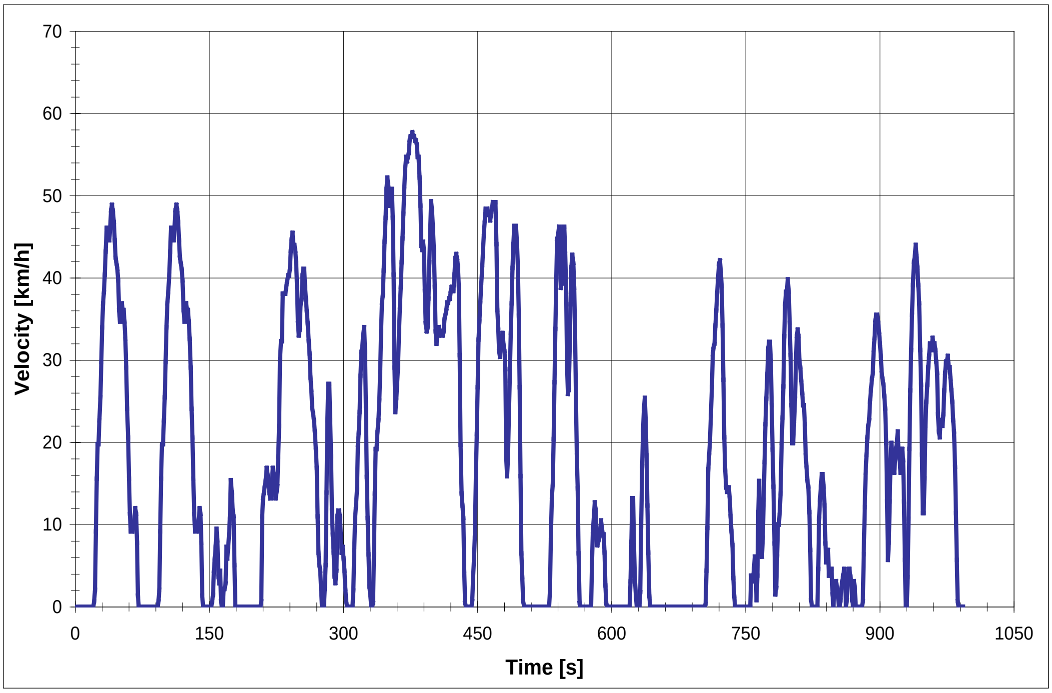

Figure 4.3: CADC Urban

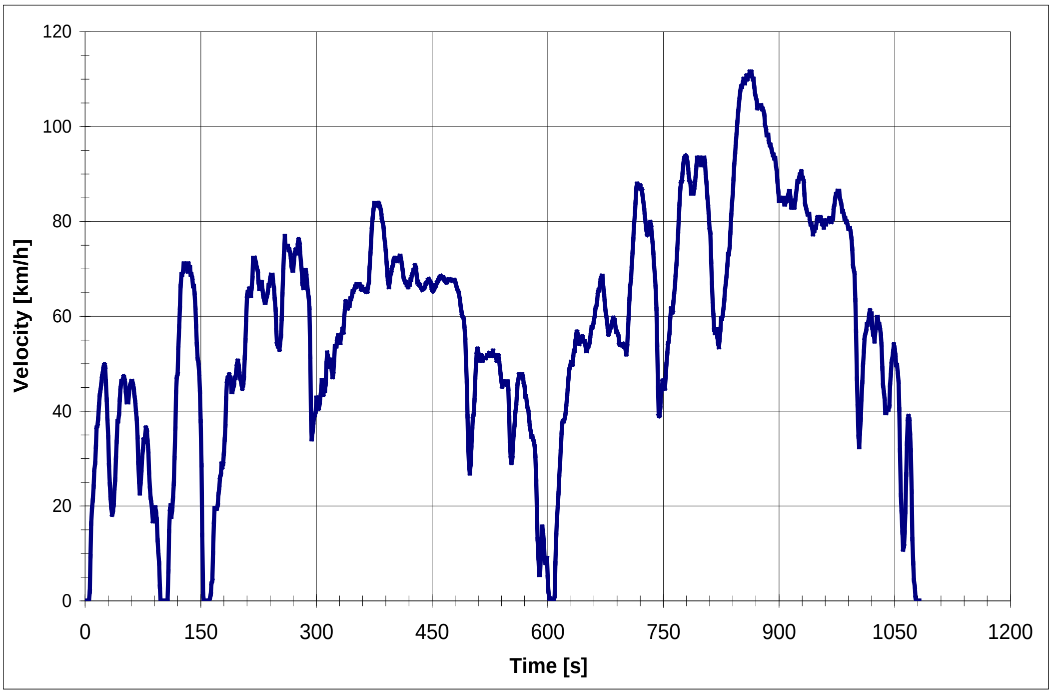

Figure 4.4: CADC Road

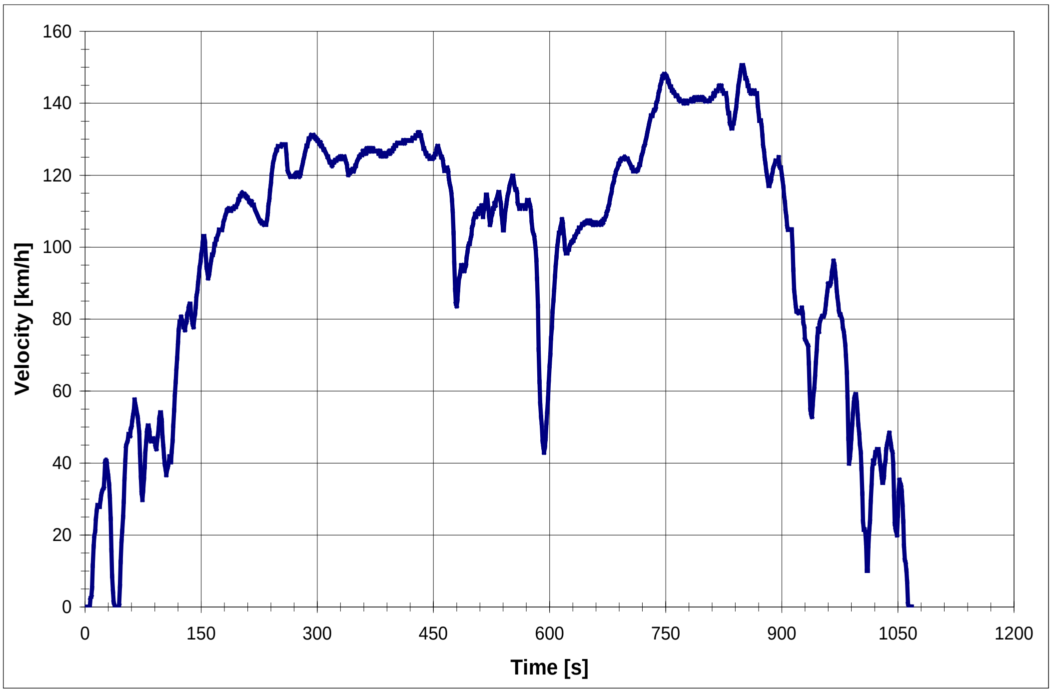

Figure 4.5: CADC Motorway

A comparison of the sub-cycles of NEDC and CADC is given in **Table 4.6.** The average speed of UDC is comparable to CADC urban. The same is valid for EUDC and CADC Road. However the CADC cycles are much more dynamic as can be seen from the Relative Positive Acceleration (RPA). The gear shifting points are determined in accordance with the vehicle's weight, engine power and engine revolutions.

Driving cycle	**NEDC**		**CADC**		
	UDC	**EUDC**	**Urban**	**Road**	**Motorway**
Distance [km]	4.1	7.0	4.5	14.7	24.6
Average Speed [km/h]	19	63	17	62	121
RPA [m/s^2]	0.13	0.09	0.35	0.18	0.11

Table 4.6: Comparison of driving cycles

Gaseous emissions in all driving cycles were measured integrally and in parallel continuously every second (modal measurement). The results of the modal measurements may serve as the basis for determining the exhaust emission behaviour in all relevant traffic situations.

Portable Emission Measurement System (PEMS)

During the measurements on road the Measurement System is equipped in the car. The emissions are measured second by second at the end of exhaust pipe. In addition to the Gaseous emissions (THC, NOx, CO, CO_2) the particulate mass was measured by a soot sensor. Figure 4.6 shows the most important information about the driving route used.

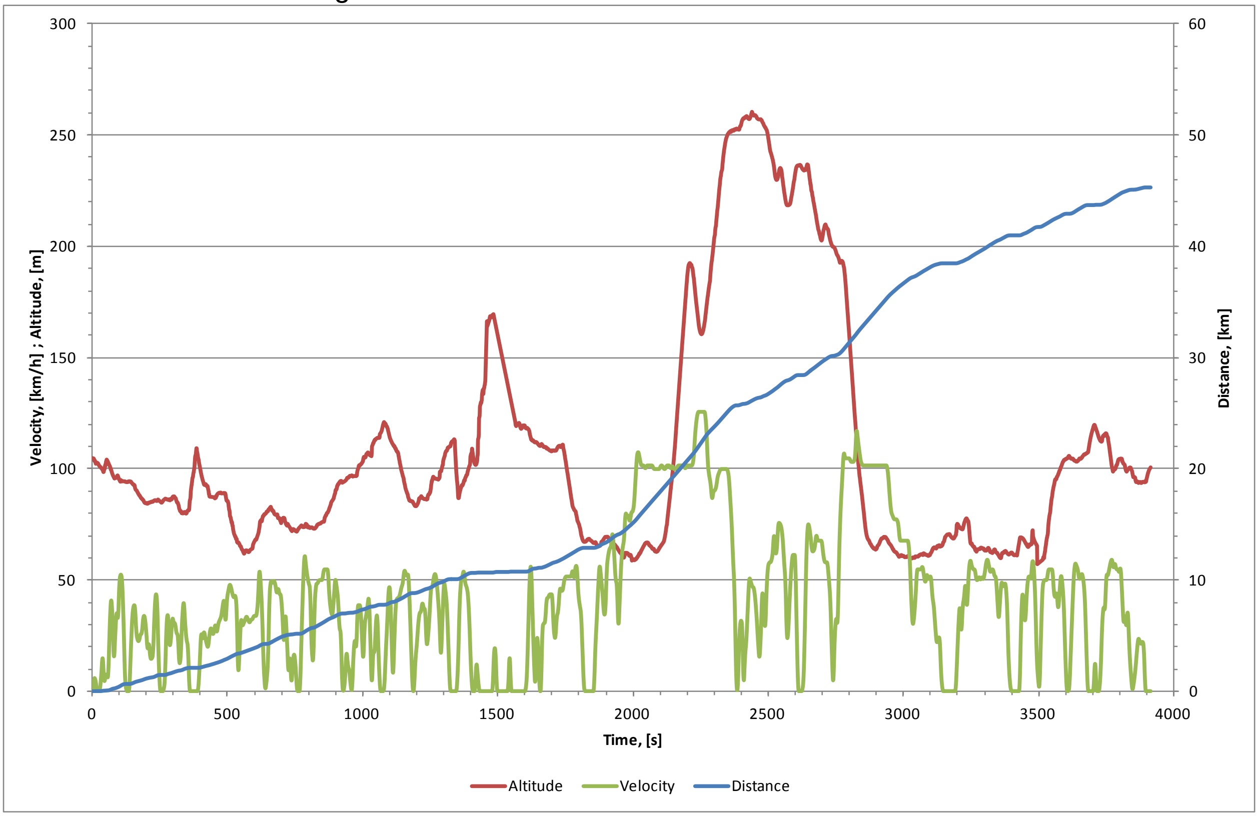

Figure 4.6: PEMS route

The results of the PEMS measurements carried out within this program were given to the Joint Research Center of the European Commission. Up to now the evaluation of the data is not pointed out and there are different solutions in discussion. After the Evaluation of the Data defined an extra report for the PEMS measurements will be published.

5. Presentation of Results

5.1. Exhaust Emissions (Type I test)

In the following sections the values for exhaust emissions and fuel consumption of the various vehicles in the respective approval cycle are examined. **Figures 5.1 to 5.3** give examples for the carbon monoxide emissions, the total hydro carbon emissions and nitric oxide emissions of one vehicle with positive ignition engine during Type I test.

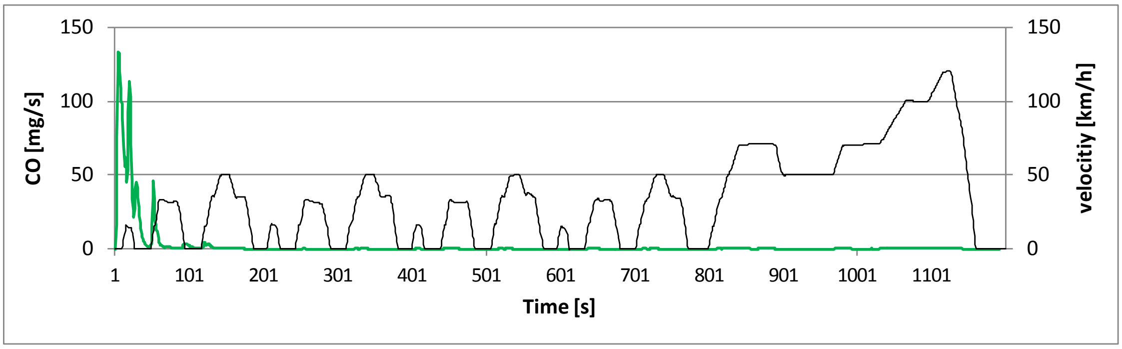

Figure 5.1: CO emitted by a positive ignition vehicle during NEDC

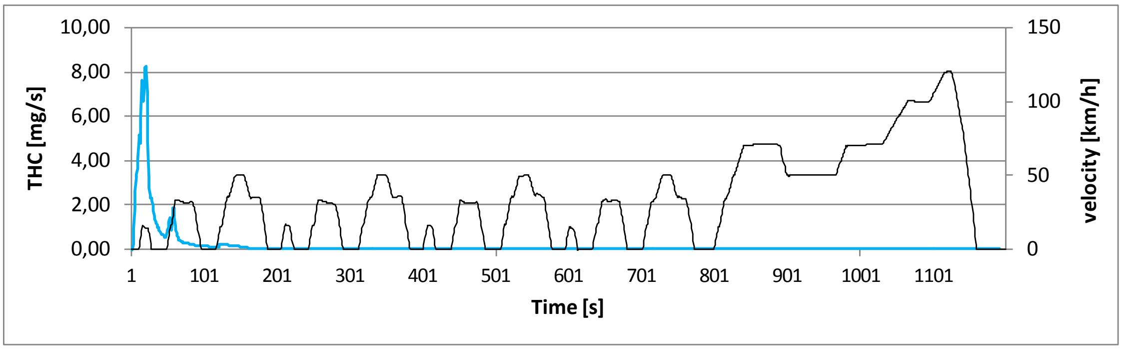

Figure 5.2: THC emitted by a positive ignition vehicle during NEDC

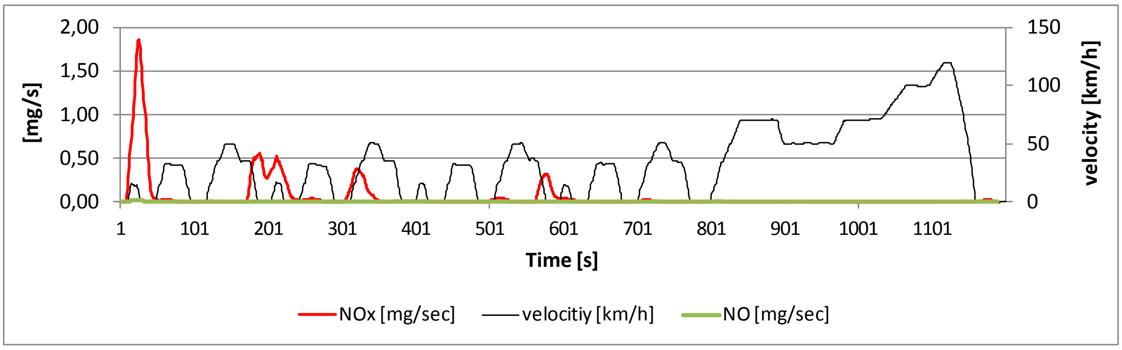

Figure 5.3: NOx and NO emitted by a positive ignition vehicle during NEDC

The major fraction of the CO, the THC and NOx emissions occurs at cold start conditions in the beginning of the driving cycle. As soon as the catalyst has reached its light off temperature of about 250°C carbon monoxide, hydrocarbons and nitric oxides are converted to carbon dioxide, water vapour and nitrogen.

Figures 5.4 to 5.6 show the carbon monoxide emissions, the total hydro carbon emissions and nitric oxide emissions of a Euro 5 vehicle with compression ignition engine during Type I test.

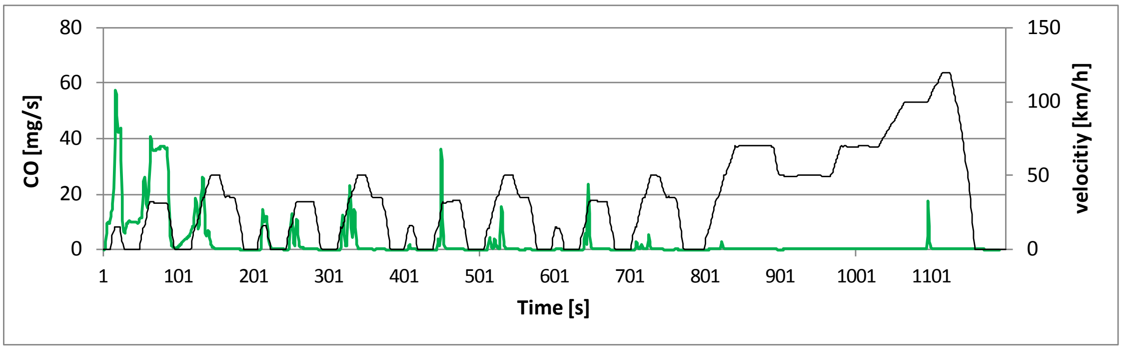

Figure 5.4: CO emitted by a compression ignition vehicle during NEDC

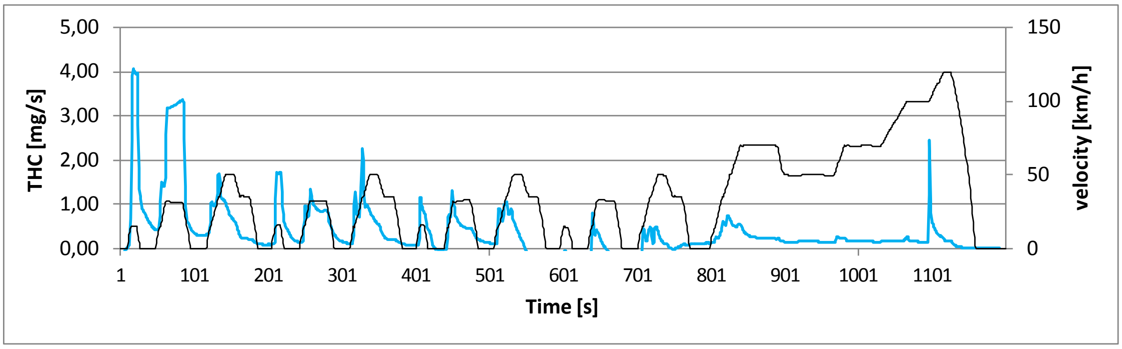

Figure 5.5: THC emitted by a compression ignition vehicle during NEDC

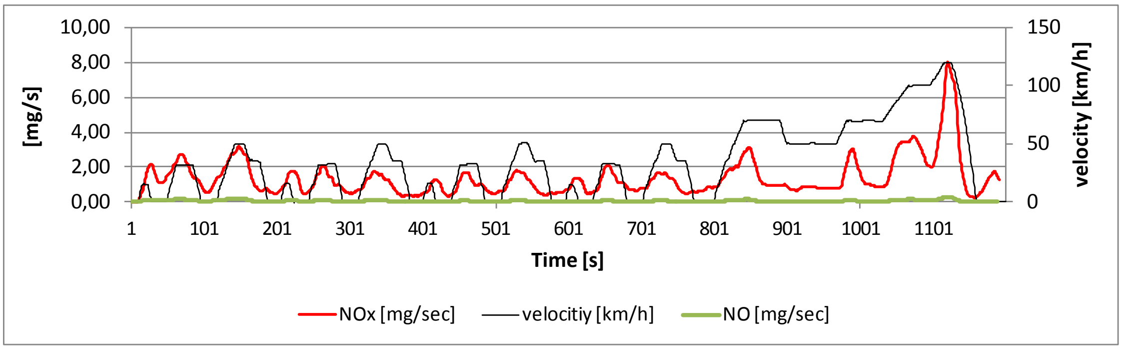

Figure 5.6: NOx and NO emitted by a compression ignition vehicle during NEDC

Carbon monoxide and total hydro carbon emissions of compression ignition vehicles show a graph similar to gasoline vehicles on a lower level. Due to cold start the major fraction of CO and THC are emitted during the first minutes of the test. As soon as the catalyst has reached its light off temperature, carbon monoxide and hydro carbons are oxidised. Because of the different combustion process, compression ignition engines generate higher nitric oxide emissions than positive ignition engines. High temperatures and a surplus of oxygen in the combustion chamber cause nitric oxide emissions. These conditions are found especially during accelerations. Due to an oxygen surplus within the exhaust gas these nitric oxides cannot be converted by a three-way catalytic converter on diesel cars.

In **Table 5.1** the average of the measured exhaust emissions for the different vehicle categories are compared to the type approval limits. The average emissions of all types tested complied with the limits given by the directive.

Category	Directive	Cycle	Average Exhaust Emissions						
			CO [mg/km]	THC [mg/km]	NMHC [mg/km]	NO_x [mg/km]	THC+NO_x [mg/km]	PM [mg/km]	PN [#/km]
Positive ignition	Euro 5	UDC	448,689	64,417	58,679	31,795	-	-	-
	Euro 5	EUDC	182,397	1,657	1,325	7,483	-	-	-
	Euro 5	NEDC	280,742	24,463	22,432	16,430	-	0,488	5,30E+11
Limit	**Euro 5**	**NEDC**	**1000**	**100**	**68**	**60**	**-**	**4,5**	**-**
Compression ignition	Euro 5	UDC	513,935	-	-	198,340	251,262	-	-
	Euro 5	EUDC	6,385	-	-	120,650	124,688	-	-
	Euro 5	NEDC	193,078	-	-	149,194	171,224	0,138	1,11E+11
Limit	**Euro 5**	**NEDC**	**500**	**-**	**-**	**180**	**230**	**4,5**	**$6,0x10^{11}$**

Table 5.1: Average exhaust emissions during Type I test

Positive ignition:

Figure 5.7 presents the carbon monoxide emissions and the hydrocarbon emissions of positive ignition vehicles during Type I test. None of the gasoline vehicle types tested exceeded the Euro 5 limits for carbon monoxide and hydro carbons during Type I test.

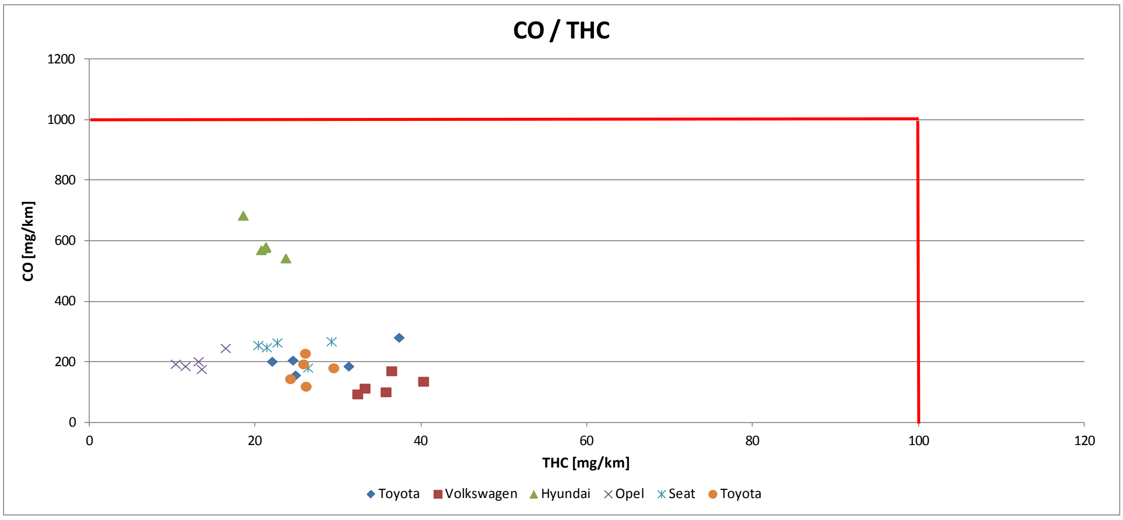

Figure 5.7: CO and HC emissions of vehicles with positive ignition during Type I test

Particle mass emissions and nitric oxide emissions of positive ignition vehicles during Type I test are shown in **Figure 5.8.**

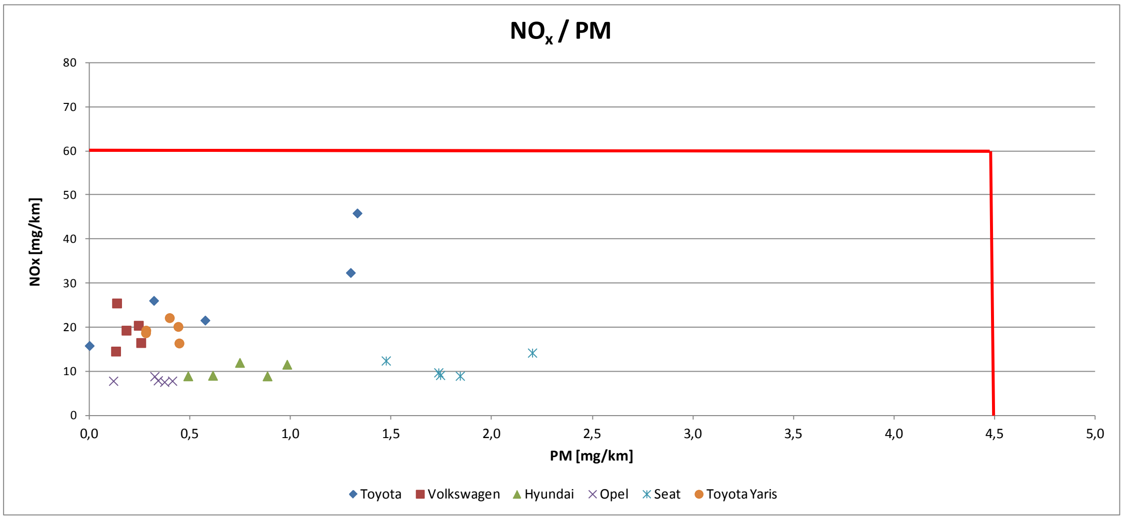

Figure 5.8: NO_x and PM emissions of vehicles with positive ignition during Type I test

In comparison **Figure 5.9** shows the Particle number emissions and nitric oxide emissions for the same vehicles.

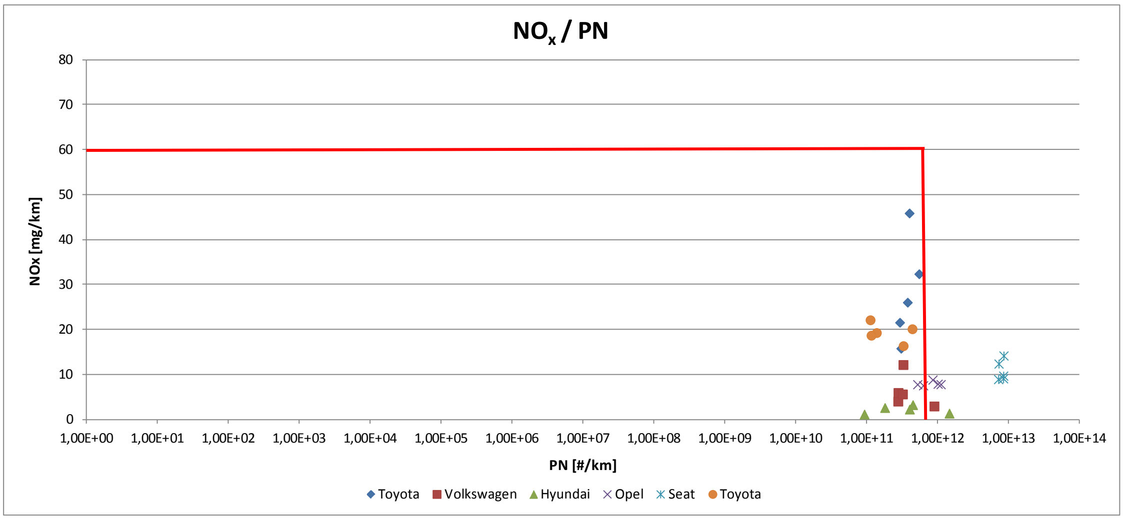

Figure 5.9: PN and NOx emissions of vehicles with positive ignition during Type I test

All tested gasoline vehicle types complied with the Euro 5 limits during Type I test and fulfilled the requirements for In-Service testing according to the statistical procedure defined with Directive 715/2007/EC.
Because all cars are type approved according Euro 5 limits they do not need to fulfil the limit for particle number that takes place for vehicles with positive ignition and direct injection with the introduction of Euro 6.

Compression ignition:

Figure 5.10 shows carbon monoxide emissions and the hydrocarbon emissions added to the nitric oxide emissions of compression ignition vehicles during Type I test.

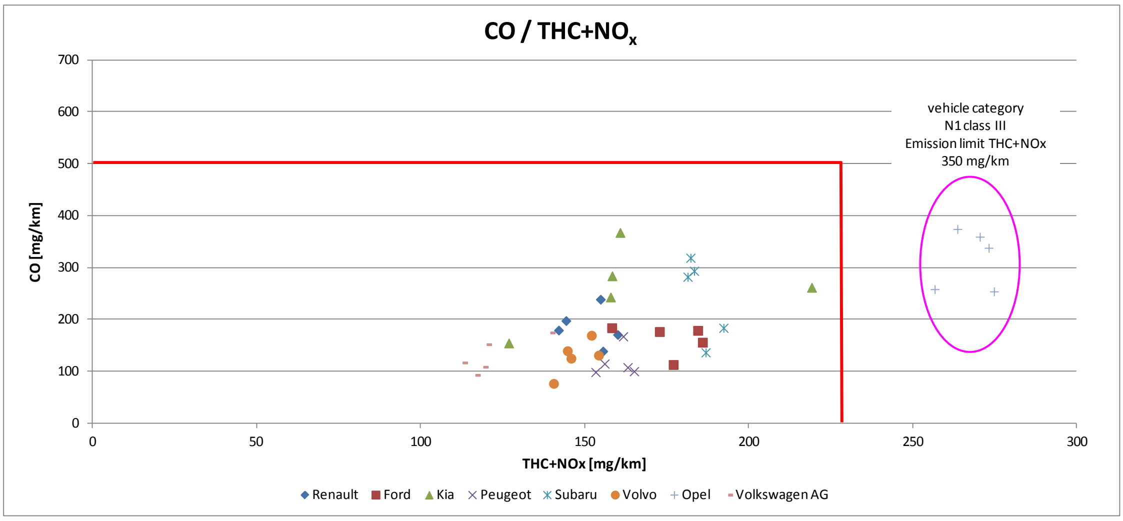

Figure 5.10: CO and THC+NOx emissions of vehicles with compression ignition during Type I test

Figure 5.11 shows Particulate mass emissions and nitric oxide emissions of compression ignition vehicles during Type I test.

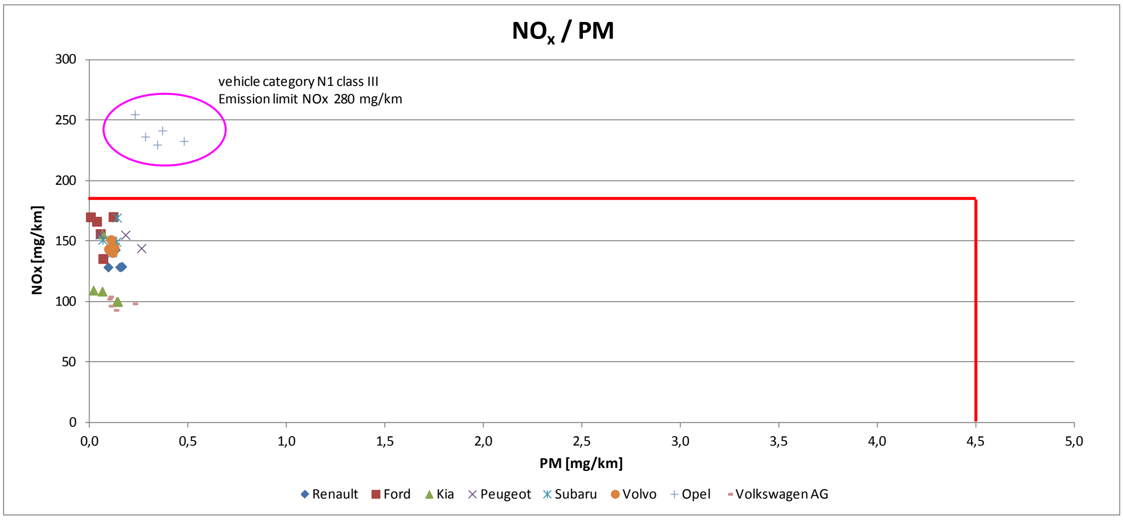

Figure 5.11: NO_x and PM emissions of vehicles with compression ignition during Type I test

Figure 5.12 shows Particulate number emissions and nitric oxide emissions of compression ignition vehicles during Type I test.

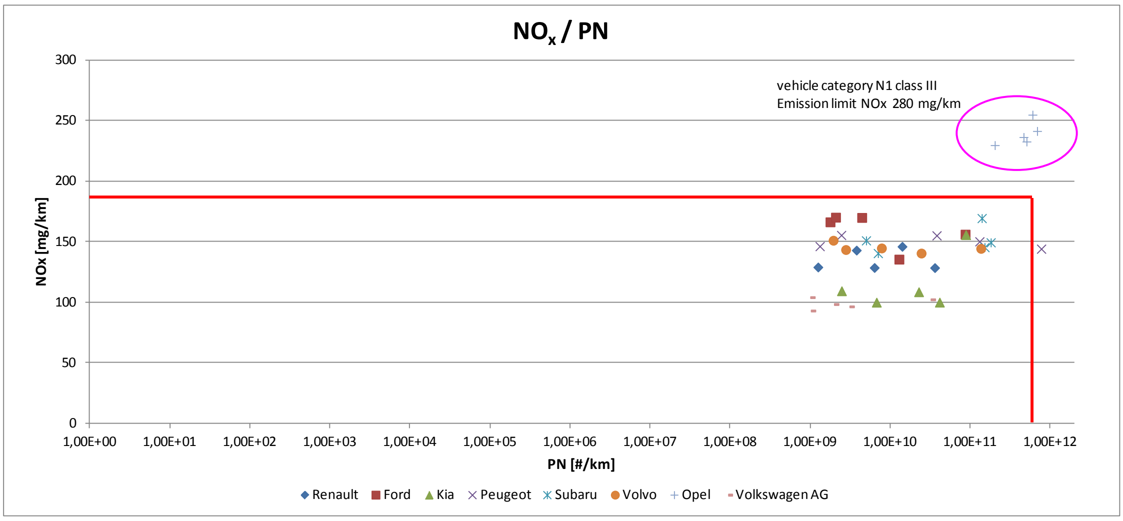

Figure 5.12: NOx and PN emissions of vehicles with compression ignition during Type I test

All tested vehicles with compression ignition were equipped with a periodically regenerating particulate trap. During type approval a factor (Ki) is used to consider the emissions during filter regeneration. The values given in this report do not consider the Ki factor. But also considering the emission during filter regeneration and the Ki factor all vehicle types with particle filter complied with the limit for particulate mass given in directive 715/2007/EC.

5.2. Categorisation of Carbon Dioxide Emissions and Fuel Consumption

Carbon dioxide is an important greenhouse gas because it transmits sunlight and strongly absorbs the infrared radiation reflected by earth. Combustion of fossil fuels increases the concentration of carbon dioxide in the atmosphere. Road traffic is a major source for man-made carbon dioxide emissions. Traffic of passenger cars contributes to 12% of man-made CO_2 in Europe, according to 2004, EU-25 figures from the European Commission.

According to Directive 80/1268/EEC, the member states are not permitted to refuse grant of the EC type approval or conformity of production with national validity for a vehicle type for reasons which are related to the emission of carbon dioxide and fuel consumption if the CO_2 emission and fuel consumption are determined in accordance with Annex I of the Directive. These values are therefore a part of the type approval. However, there are no limit values at the moment. The CO_2 and consumption declarations are for consumer information and in many EU countries used as a basis for vehicle related taxes. In Sweden for example the annual vehicle tax is a linear function of the CO_2 emissions above 120 g/km (from the 1st of January 2013 it is 117 g/km). The Directive requires that the values are contained in a document which is supplied to the owner by the manufacturer when the vehicle is purchased. If the CO_2 and consumption values are considerably exceeded, the buyer could apply warranty claims in the legal sense. The CO_2 figures will with the future CO_2 and cars regulation be even more important, when the manufactures have to fulfil 95 g/km as an average for their sold vehicles within EU. The regulation will be introduced stepwise from 2017 to have full effect from 2021.

The CO_2 emissions are measured in the "New European Driving Cycle". The fuel consumption is calculated using the measured CO_2 emissions and the other carbon-containing emissions (CO and HC). The test vehicle must be presented in good mechanical condition. For type approval it must be run-in and it must have been driven for at least 3,000 km, but for less than 15,000 km.

In **Figure 5.13** the average fuel consumption determined during the Type I test for the various vehicle types is compared to the value declared by the manufacturers.

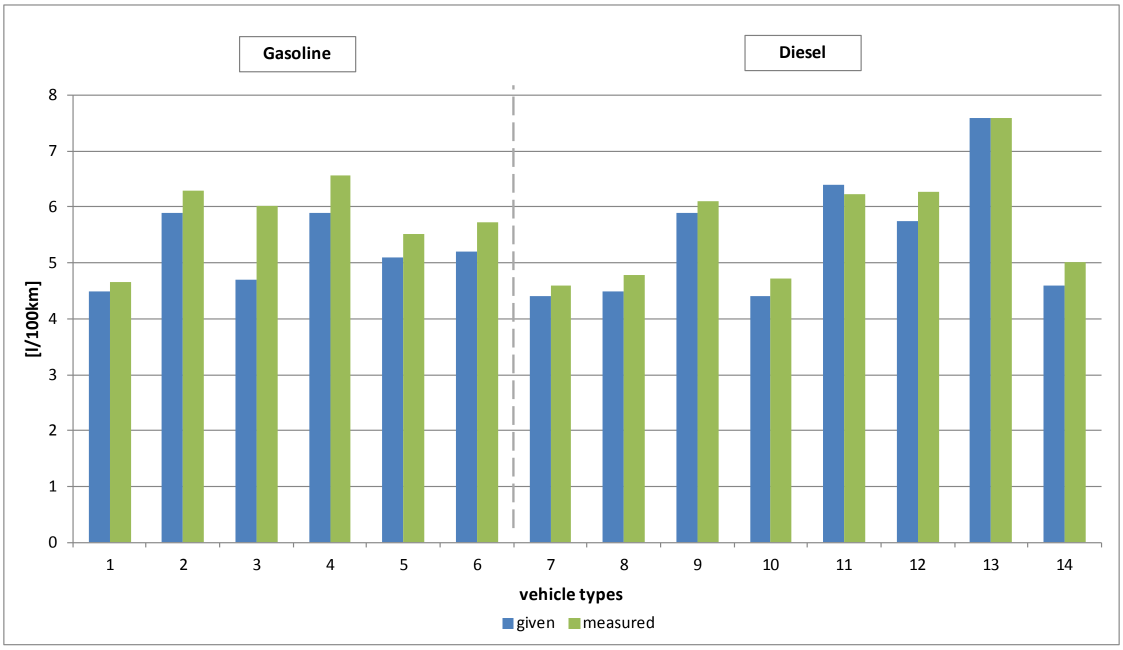

Figure 5.13: Average fuel consumption during Type I test for the different vehicle types

During the Type I test on 15 vehicles the measured average fuel consumption was higher than the fuel consumption declared by the manufacturer. For one vehicle type the deviation from the values given by the manufacturer was 25 % on fuel consumption.

The average carbon dioxide emissions determined during the Type I test for the various vehicle types compared to the values declared by the manufacturers are given in **Figure 5.14 and 5.15.**

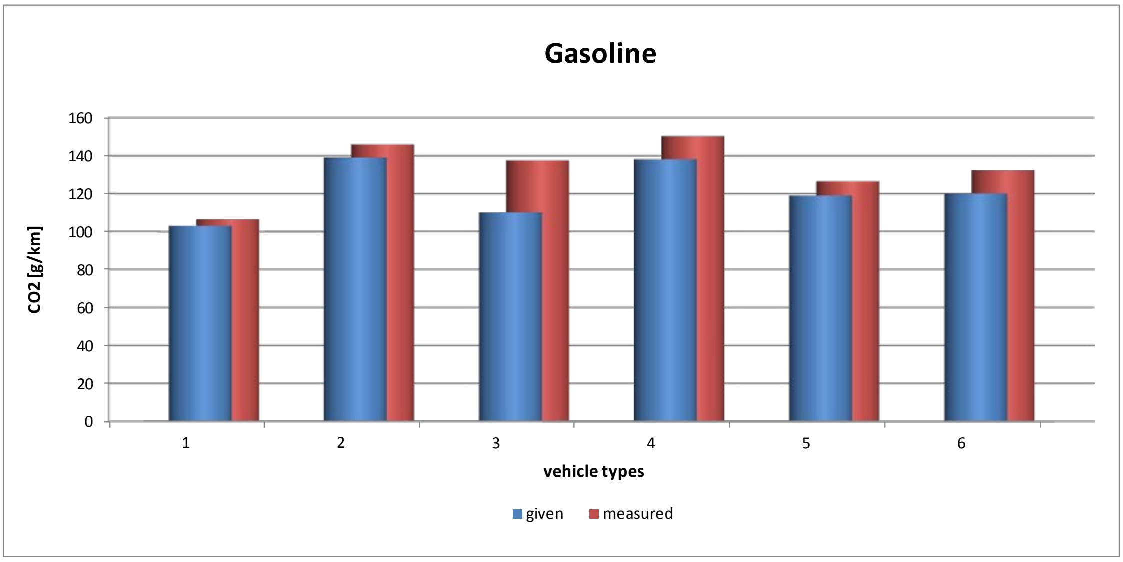

Figure 5.14: Average CO_2 emissions during Type I test for the different vehicle types with gasoline engine

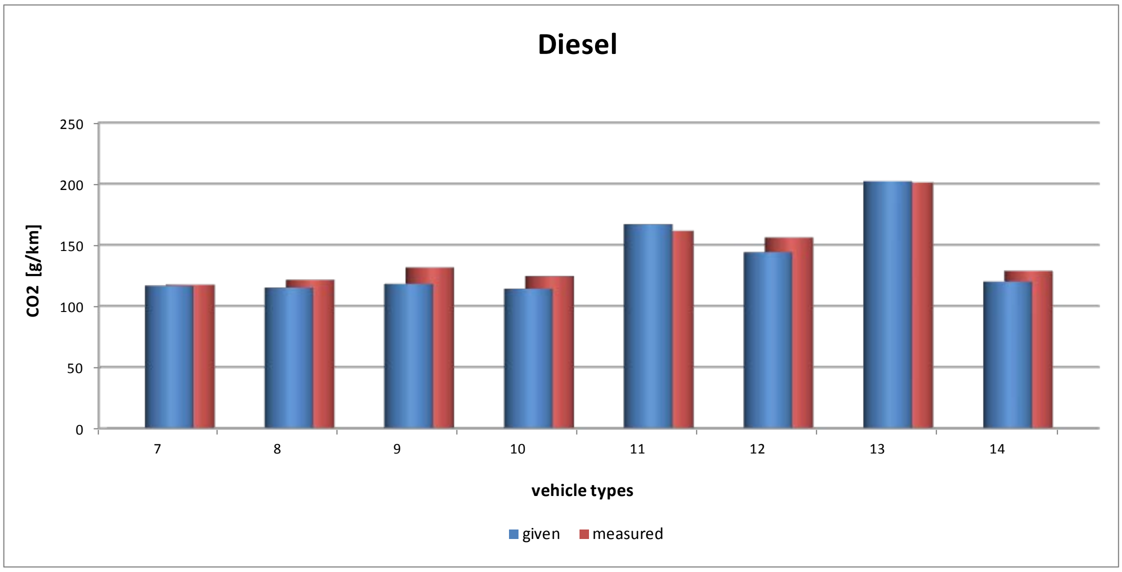

Figure 5.15: Average CO_2 emissions during Type I test for the different vehicle types with diesel engine

Figure 5.16 shows the relative deviation of the carbon dioxide emissions measured during Type I test to the value declared by the manufacturers.

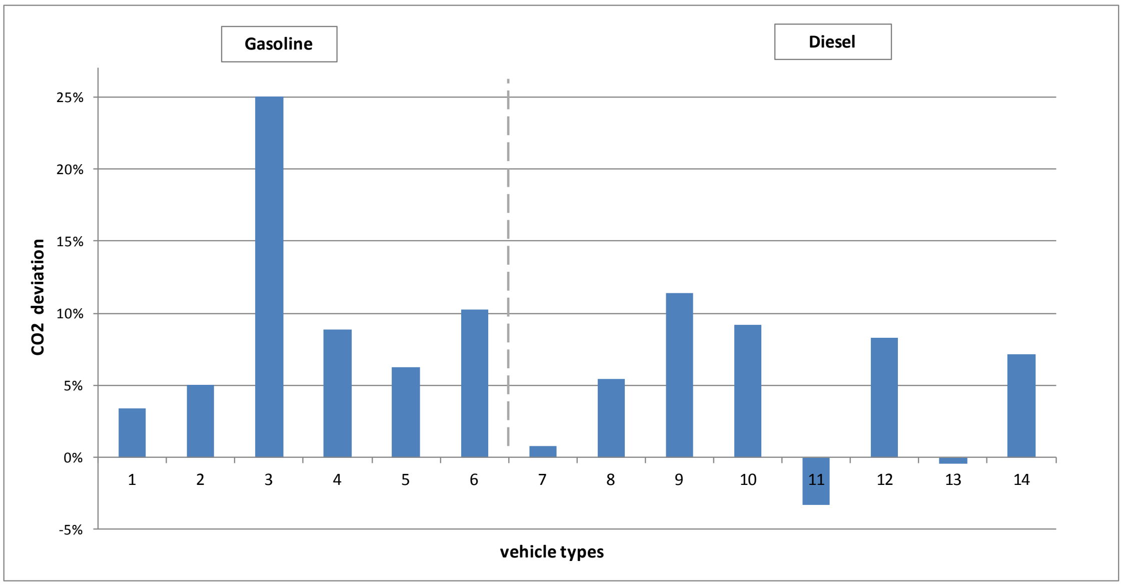

Figure 5.16: Relative deviation of the CO_2 emissions to the manufacturer's values during Type I test for the different vehicle types

For 8 types the average CO_2 emissions measured during Type I test were higher than 5% above the manufacturer's declaration. One vehicle type showed lower carbon dioxide emissions than declared by the manufacturers.

5.3. Idle Test (Type II test)

On vehicles with positive ignition engine exhaust gas concentrations are measured at idle speed. For this test the engine must be warmed up. The exhaust emissions measured at idle speed and at about 2,500 rpm are displayed in **Table 5.2**. The lambda value is calculated using the concentrations of CO, HC, CO_2 and O_2.

	Idle			
	CO [%vol.]	**HC [ppm]**	**CO_2 [%vol.]**	**λ**
Average	0,009	1,000	15,302	1,002
Limits	0,3	-	-	-
	High idle (ca. 2,500 rpm)			
	CO [%vol.]	**HC [ppm]**	**CO_2 [%vol.]**	**Λ**
Average	0,023	0,600	15,257	1,003
Limits	-	-	-	-

Table 5.2: Average exhaust emissions during Type II test

During the Type II test no emission related problems were detected on the vehicles with positive ignition engine.

The Type II test is not relevant for vehicles with compression ignition engine.

5.4. Crankcase Emissions (Type III test)

Exhaust gases passing by the piston rings could cause environmental pollution. Therefore vehicles with positive ignition engine are equipped with a crankcase ventilation system. The crankcase gases are routed to the intake manifold and are combusted in the engine. The crankcase ventilation system is tested by measuring the pressure within the system at idle speed and at 50 km/h on the dynamometer with two different load settings. The pressure measured in the crankcase may not exceed the atmospheric pressure at different load conditions.

No crankcase emissions were emitted into the atmosphere at the Type III test on all tested vehicle types with positive ignition engine.

Measuring the crankcase emissions is not relevant for vehicles with compression ignition engine.

5.5. Evaporative Emissions (Type IV test)

If the petrol located in the fuel system is heated up, hydrocarbons evaporate. These vapours escaping into the environment cause considerable pollution. For this reason, modern vehicles with positive ignition engine are equipped with a system for retaining such fuel vapours.

For type approval testing, in addition to exhaust emissions in the driving cycle, the amount of evaporative hydrocarbon emissions escaping mainly from the vehicle fuel system is measured. For this Type IV test a Sealed Housing for Evaporative Emissions Determination (SHED) is used. The Type IV test is designed to determine hydrocarbon evaporative emissions caused by hot soaks during parking and by diurnal temperatures variation. The measurement of evaporative emissions according to Directive 98/69/EC and 715/2007/EC includes three phases:

- test preparation including a driving cycle
- hot soak loss determination
- diurnal loss determination

For measuring the hot soak emissions, the test vehicle is placed in a SHED for one hour directly after having finished a driving cycle. During the diurnal test the vehicle is placed in the SHED for 24 hours to determine the fuel-system and tank ventilation losses. The vehicle is exposed to an ambient temperature cycle which simulates the temperature profile for a summer day while the hydrocarbons released are measured. In this way, hydrocarbon emissions due to permeation and micro-leaks in the whole fuel-bearing system are considered. The results of the hot soak test and of the diurnal test are summated to a total result. The statutory limit value for the total evaporative emissions is 2 g hydrocarbons per test.

Figure 5.17 gives a detailed outline of the Type IV test procedure according directive 98/69/EC and 715/2007/EC. During this programme the vehicles were refilled with reference fuel and driven within the Common Artemis Driving Cycle before starting the SHED-procedure. On all tested vehicles the washer fluid canister was drained, purged and refilled with clear water.

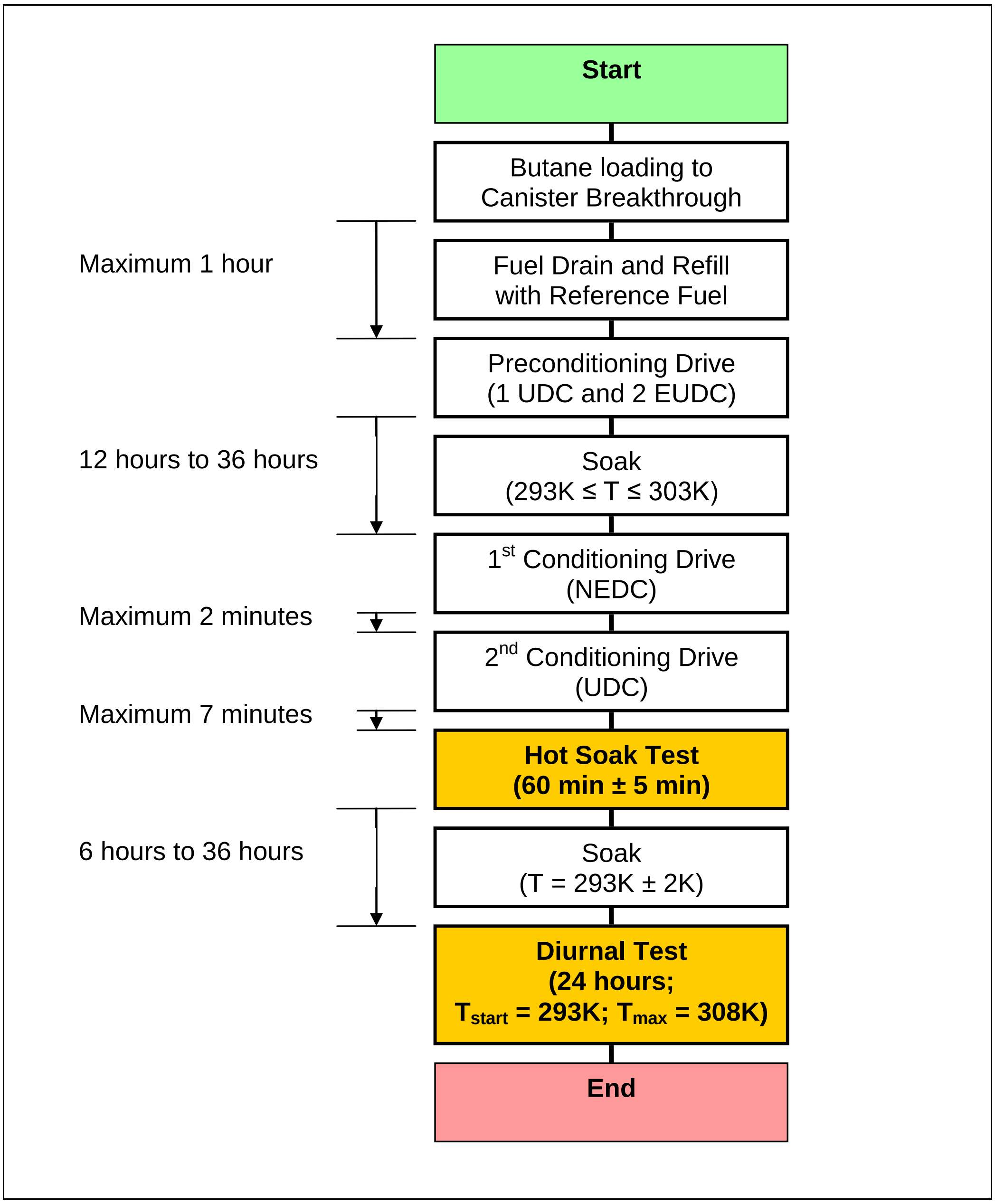

Figure 5.17: Type IV test procedure

During this In-Service Conformity testing programme, measurement of the evaporative emissions was carried out on two vehicles per type with positive ignition engine in addition to the exhaust emission measurement. The results of these measurements are summarised in **Figure 5.18**.

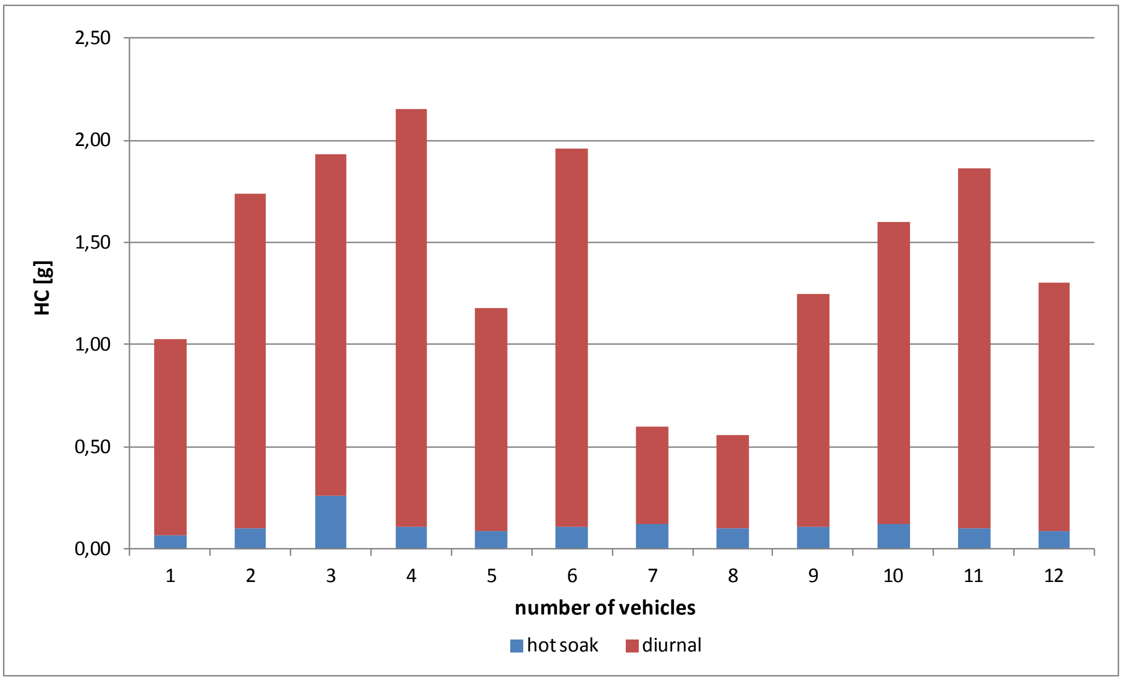

Figure 5.18: Evaporative emissions

One of the twelve tested vehicles exceeded the limit for evaporative emissions according to Directive 715/2007/EC. The second car of the same type came very close to the limit. The reason for this behaviour was not found up to the the date of this report. It was discussed with the manufacturer and the authority and there will be a retest of the EVAP System in the program of next year. All other tested cars stick to the limit given in Euro 5.

Vehicle No.	Evaporative emissions [g HC]		
	Hot Soak	Diurnal	Total
1	0,07	0,96	1,03
2	0,10	1,64	1,75
3	0,26	1,67	1,94
4	0,11	2,04	2,15
5	0,09	1,09	1,18
6	0,11	1,85	1,96
7	0,12	0,48	0,61
8	0,10	0,46	0,56
9	0,11	1,14	1,25
10	0,12	1,48	1,60
11	0,10	1,76	1,86
12	0,09	1,21	1,31
Average			
	0,12	1,32	1,43
Limit			
	-	**-**	**2.00**

Table 5.3: Evaporative emissions

Results presented in **Table 5.3** show that evaporative emissions during the diurnal test generate the major fraction of the total result.

5.6. Emissions at low Temperatures (Type VI test)

Directive 98/69/EC introduced an exhaust emission test at low ambient temperatures for vehicles with positive ignition engine. Also in directive 715/2007/EC the test at low temperature is mandatory. The test includes a cold start at -7°C and the urban part of the NEDC. The purpose of this Type VI test is the adaptation of type approval testing to realistic driving conditions. Carbon monoxide and hydrocarbon emissions are limited by the Directive. During this In-Service Conformity testing programme, two vehicles per type with positive ignition engine were tested at low ambient temperatures.

Table 5.4 and 5.5 show the Type VI test results compared to the Type I test results of the positive ignition vehicles tested at low ambient temperatures.

Vehicles with positive ignition engine		**Exhaust Emissions**			
Test	**Driving Cycle**	**CO [mg/km]**	**THC [mg/km]**	**NOx [mg/km]**	**CO_2 [mg/km]**
Type I test	UDC	448,689	64,417	31,795	181,586
	EUDC	182,397	1,657	7,483	107,935
	NEDC	280,742	24,463	16,430	135,064
Limit	**NEDC**	**1000**	**100**	**60**	**-**
Type VI test	UDC	3117,095	711,276	36,277	212,333
Limit	**UDC**	**15000**	**1800**	**-**	**-**

Table 5.4: Exhaust emissions during Type VI and Type I of vehicles with positive ignition engine and EURO 5 emissions standard tested at -7°C

Figure 5.19 shows the exhaust emissions measured during Type VI test. During the exhaust emission test at low ambient temperatures, all tested vehicles complied with the limits according to Directive 98/69/EC / 715/2007/EC.

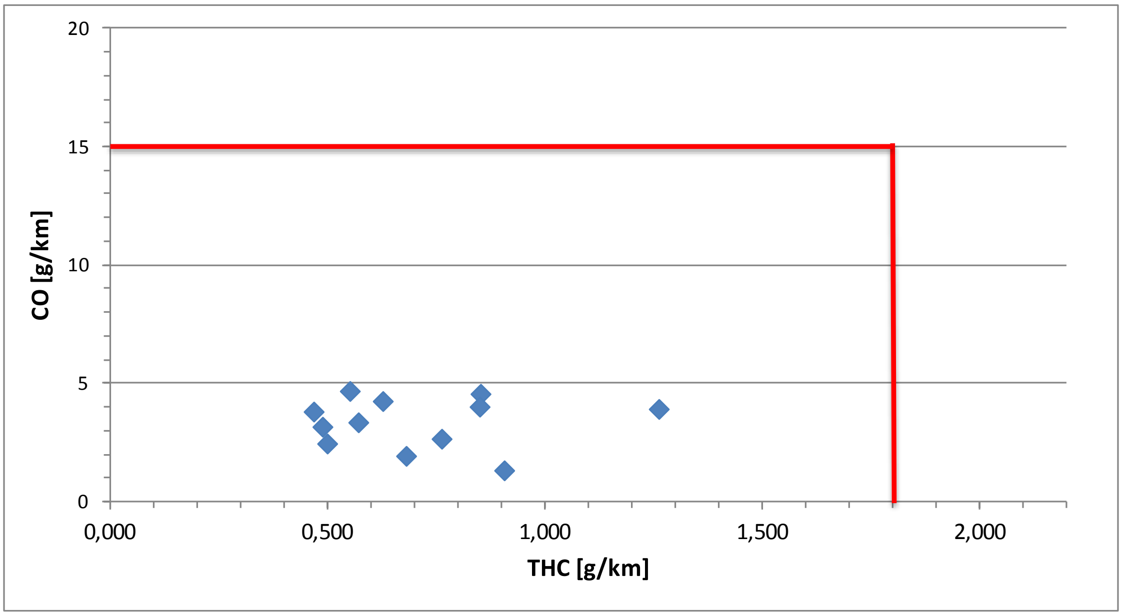

Figure 5.19: Exhaust emissions at low ambient temperatures

Figure 5.20 illustrates the HC emissions during Type I test and Type VI test.

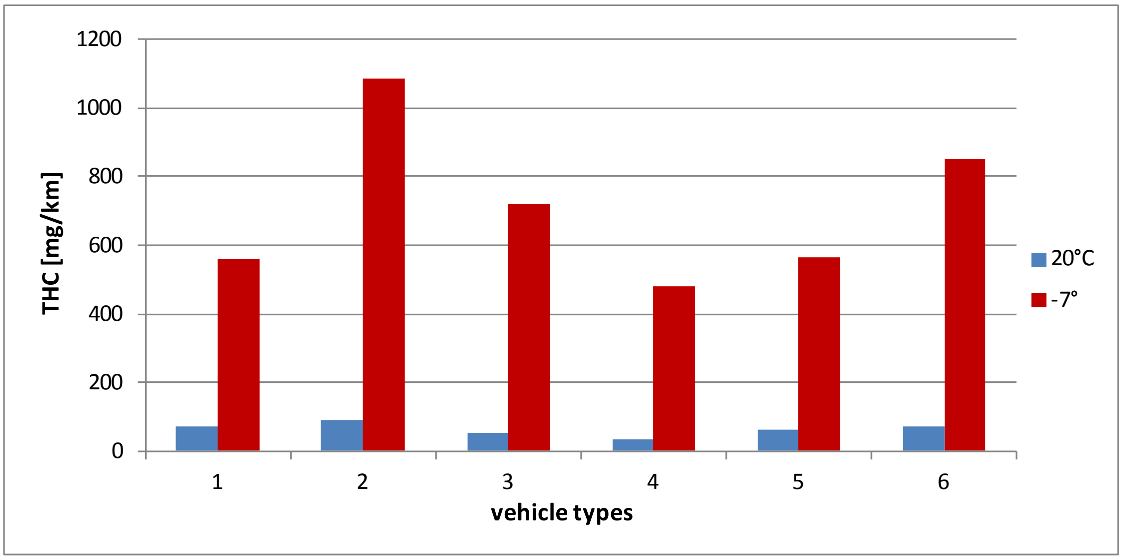

Figure 5.20: Hydrocarbon emissions during Type I and Type VI test

Hydrocarbon emissions during UDC at low ambient temperature (-7°C) exceeded the exhaust emissions at ‘normal’ ambient temperature (20°C up to 30°C according to the directive) by a factor of 10.

5.7. OBD System

With the Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars was introduced and resumed by directive 715/2007/EC. The aim of introducing the OBD system was to achieve a significant upgrade in emission performance over the useful lifetime of vehicles in service. The OBD is an electronic system designed to detect failures of anti-pollution devices immediately, monitor critical functions of the engine and emission control systems, store additional information about deviations and assist during maintenance with fault diagnosis and fault rectification. OBD is required for vehicles with positive ignition engine registered since the 1. January 2001 and for vehicles with compression ignition engine registered since the 1. January 2004.
During this project the OBD-data were registered. In addition, some emission relevant defects were simulated to control the function of the OBD system at one of the vehicles per type. Different failures like electrical disconnection of intake air pressure sensor, disconnection of throttle position sensor, misfire, electrical disconnection of injector, disconnection of oxygen sensor (before and after catalyst) were implemented depending on the power train of the vehicles tested.

All simulated failures were detected by the OBD system.

5.8. Exhaust Emissions during the Common Artemis Driving Cycle (CADC)

The CADC was created to reproduce actual driving conditions in road traffic. It includes higher speed and stronger acceleration than the NEDC used for type approval testing. The second-by-second exhaust emissions are used for emission modelling. The CADC is not part of the European type approval legislation. Therefore, there is no limit for the exhaust emissions during the CADC. For the CADC the same inertia and load setting as for the Type I test were used.

To gain as much data as possible the urban part of the CADC was driven twice: with cold start conditions (CADC urban cold) and after warming up the engine to 80°C by driving constant speed on the dynamometer (CADC urban hot).

Figures 5.21 and **5.22** present the hydro carbon emissions measured second-by-second one time with cold start and one time with warm engine on the same vehicle. It is obvious, that the emissions emitted before the catalyst reaches its light-off-temperature compose the major fraction of the total exhaust emissions.

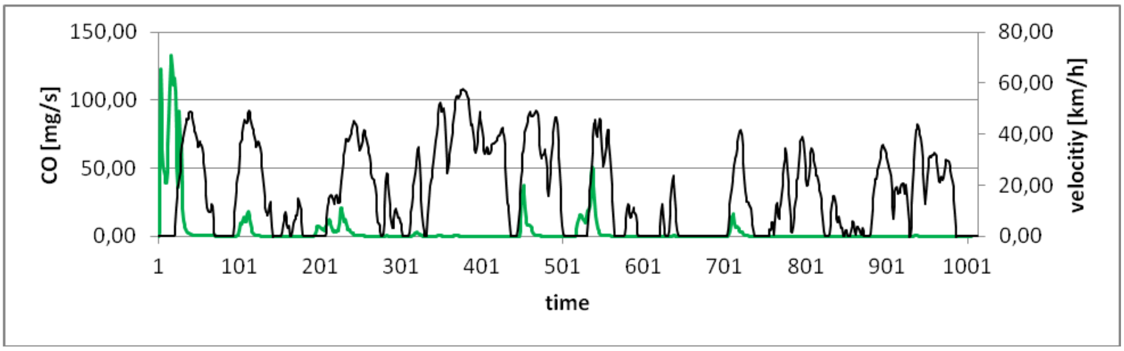

Figure 5.21: CO emissions during the CADC urban with cold start of a Euro 5 vehicle with positive ignition engine

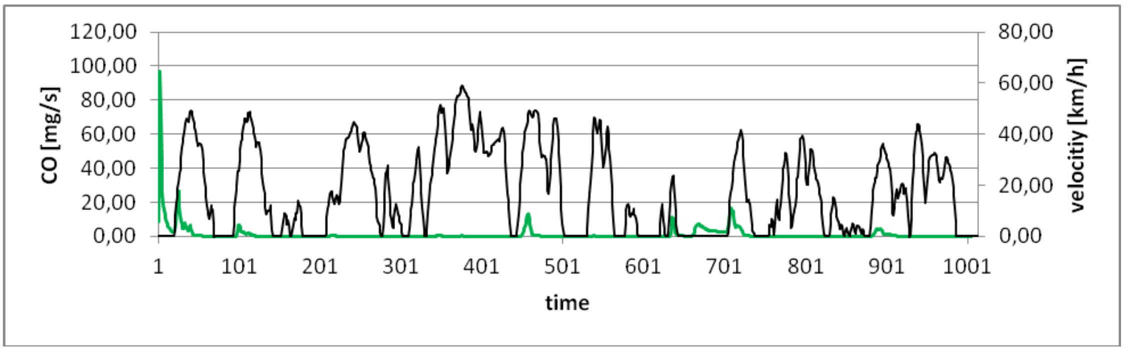

Figure 5.22: **CO emissions during the CADC urban with warm start (80° engine temperature) of a Euro 5 vehicle with positive ignition engine**

Compression ignition vehicles show totally different emission behaviour on nitric oxides than positive ignition vehicles. In **Figures 5.23 and 5.24** the NOx emissions during the CADC road of a gasoline vehicle and a diesel vehicle with similar engine capacity and reference weight are illustrated.

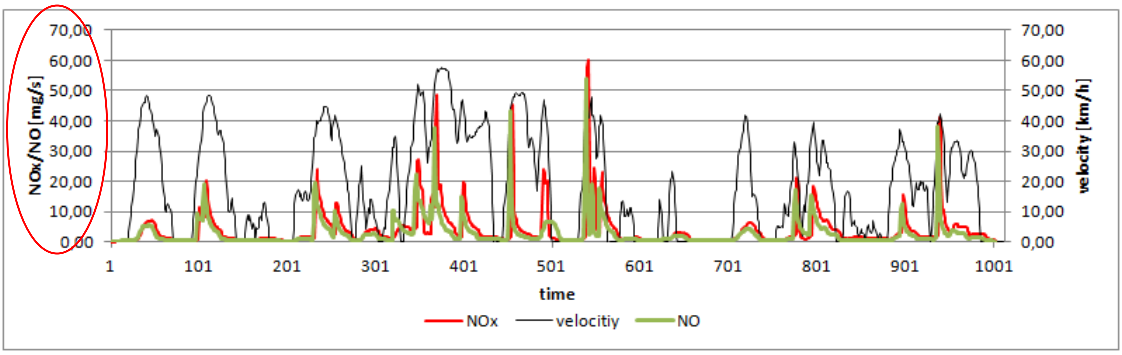

Figure 5.23: **NOx and NO emissions during the CADC urban (CI)**

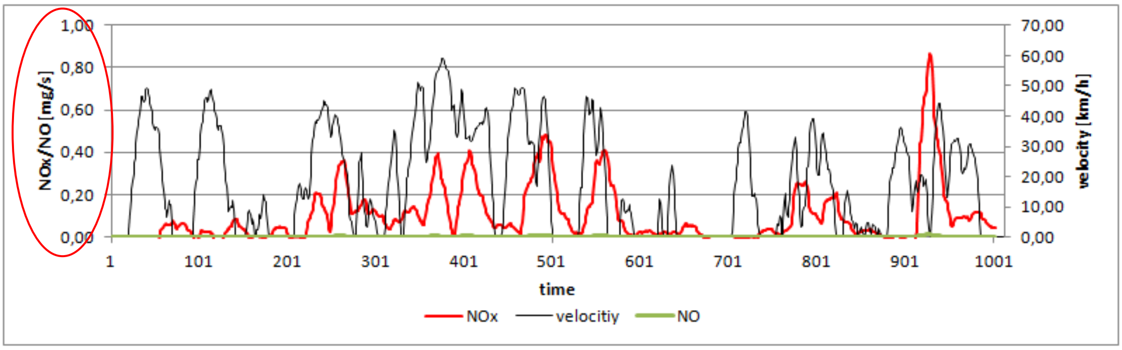

Figure 5.24: **NOx and NO emissions during the CADC urban (PI)**

Due to a surplus of oxygen in the air-fuel mixture and a lack of exhaust after-treatment on nitric oxides, NOx emissions of compression ignition vehicles are much higher than on positive ignition vehicles.

In **Figure 5.25 and 5.26** the average gaseous exhaust emissions of all vehicles tested during CADC are illustrated.

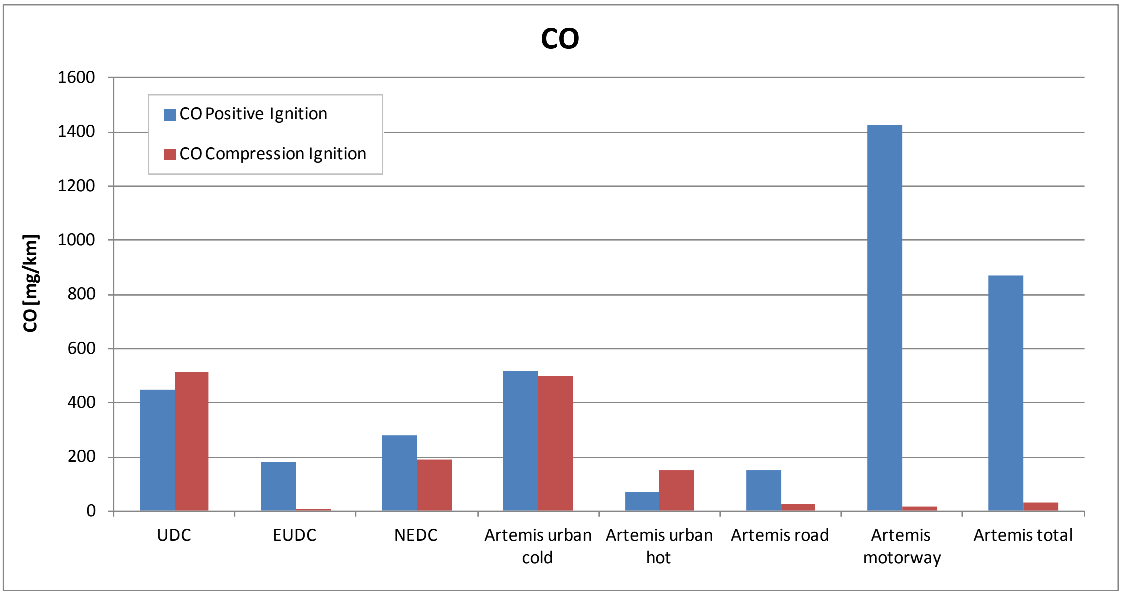

Figure 5.25: Average CO emissions under different driving conditions

Due to cold start conditions during the NEDC and the CADC urban cold high carbon monoxide emissions were measured especially on vehicles with positive ignition engine. The figures demonstrate that the major fraction of CO and HC within the New European Driving Cycle is emitted during the Urban Driving Cycle including cold start. High load and high speed during the CADC motorway cause increasing carbon monoxide emissions on positive ignition engine vehicles. The high average CO emissions during CADC motorway of positive ignition vehicles were caused by a few cars with small engines that showed extremely high emissions.

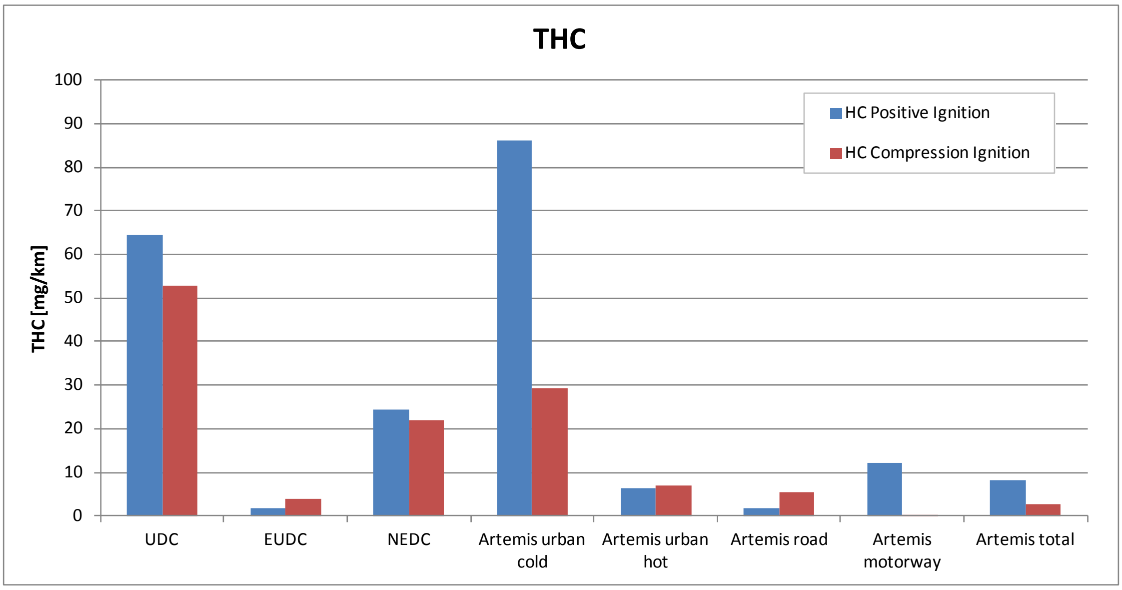

Figure 5.26: Average HC emissions under different driving conditions

Both carbon monoxide and hydro carbon emissions are products of incomplete combustion. Therefore CO and HC are emitted at the same driving conditions. Especially at cold start conditions before the catalyst has reached its light-off-temperature and at high load with a rich air fuel ratio carbon monoxide and hydro carbons are emitted because they cannot be converted. Due to a surplus of oxygen in the air fuel mixture, carbon monoxide and hydrocarbon emissions of vehicles with compression ignition engine are lower than of vehicles with positive ignition during all different test cycles.

Figures 5.27 demonstrate the different behaviour of compression- and positive-ignition with the look on NOx emissions.

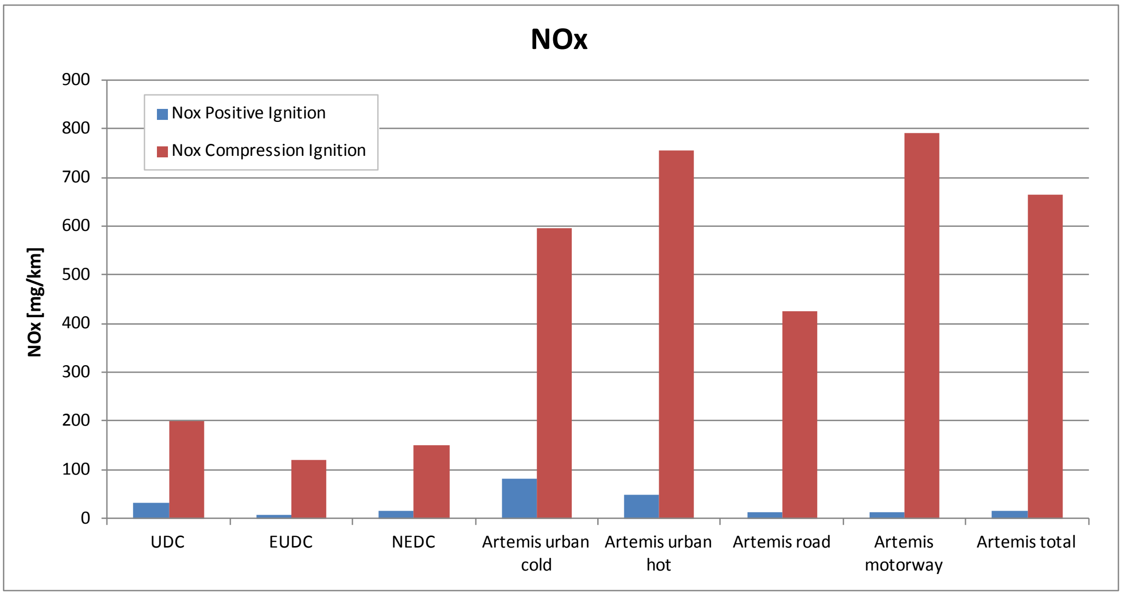

Figure 5.27: Average NO_x emissions under different driving conditions

The major environmental exposure caused by compression ignition vehicles is nitric oxide and particulate emissions. **Figures 5.27** illustrate that NO_x is emitted by compression ignition vehicles especially during the CADC motorway cycle. This is due to the high temperature inside the combustion chamber at high engine load combined with a surplus of oxygen within the cylinder.

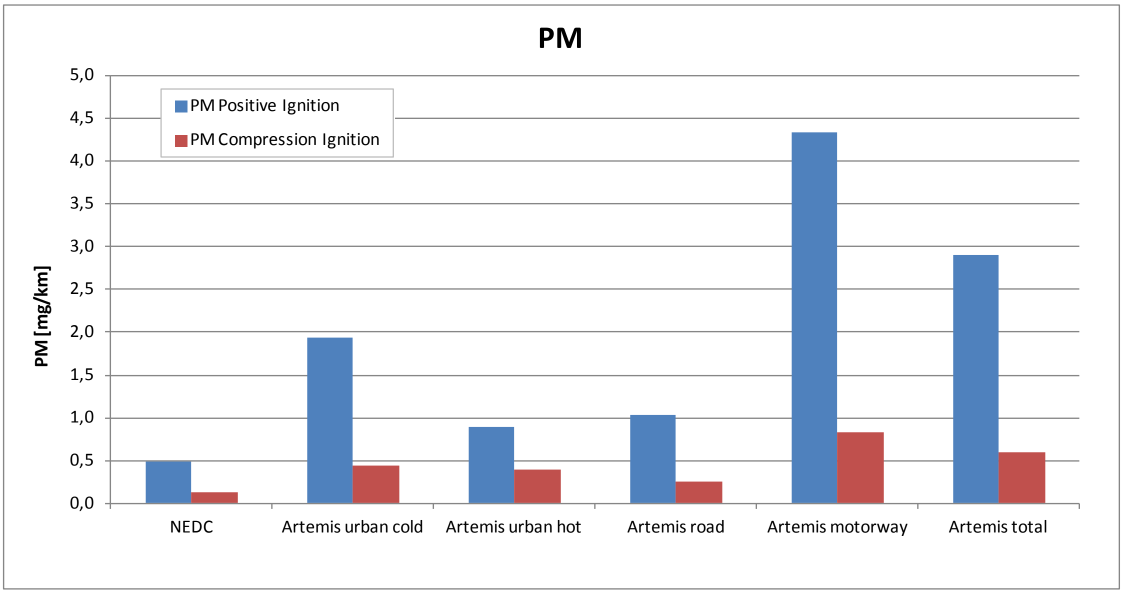

Figure 5.28: Average particle mass under different driving conditions

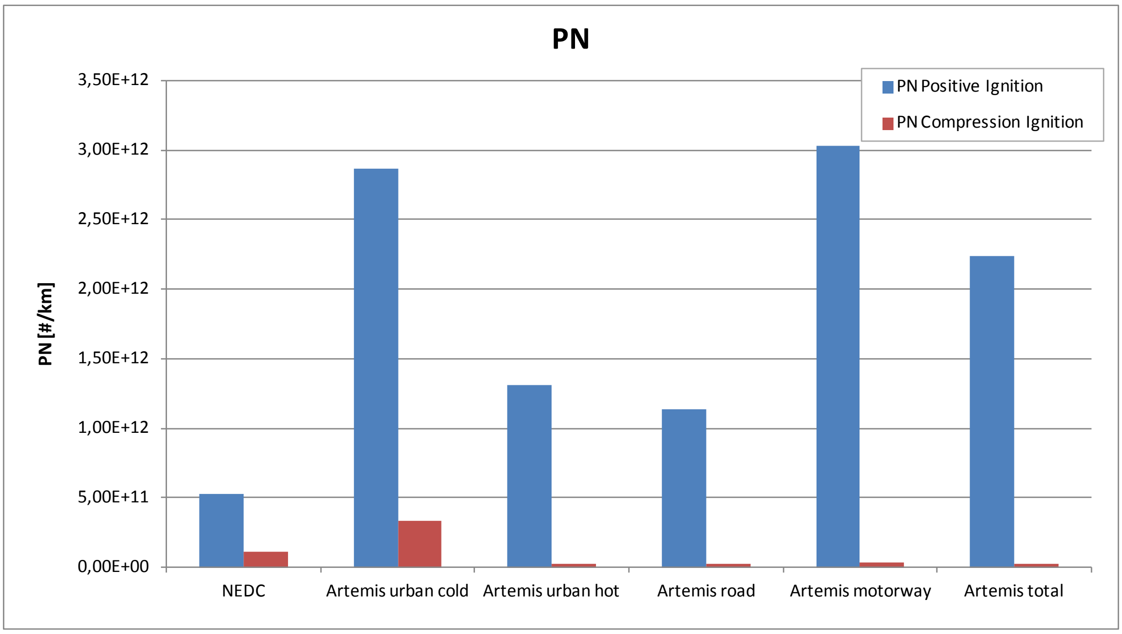

Figure 5.29: Average particle number under different driving conditions

During this programme particle emissions were measured both on diesel and on gasoline vehicles. **Figures 5.28 and 5.29** demonstrated that particle mass on positive ignition vehicles is much higher than on compression ignition vehicles with particle filters. Most tested cars with positive ignition use a direct injection system. This causes a high mass and number value of particles. With EURO 6 the limt of 6,0 x 10^{11} will be valid for compression and positive ignition. Up to now the vehicles show a much higher level of particle - so equipping positive engine cars with a filter trap could be one solution for the future if this disadvantage of the direct injection system could not be solved by development.

Figures 5.30 and 5.31 illustrate the fuel consumption measured at different driving conditions in relation to the value given by the manufacturer for the New European Driving Cycle. The average fuel consumption is given for all positive ignition and compression ignition vehicles tested during CADC.

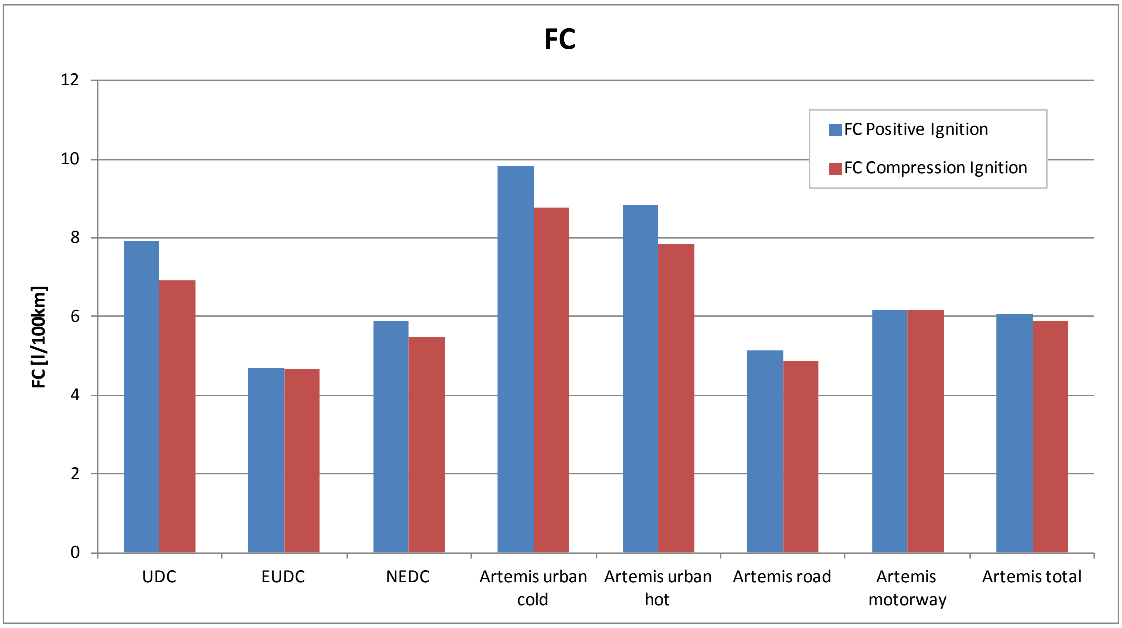

Figure 5.30: Average fuel consumption under different driving conditions

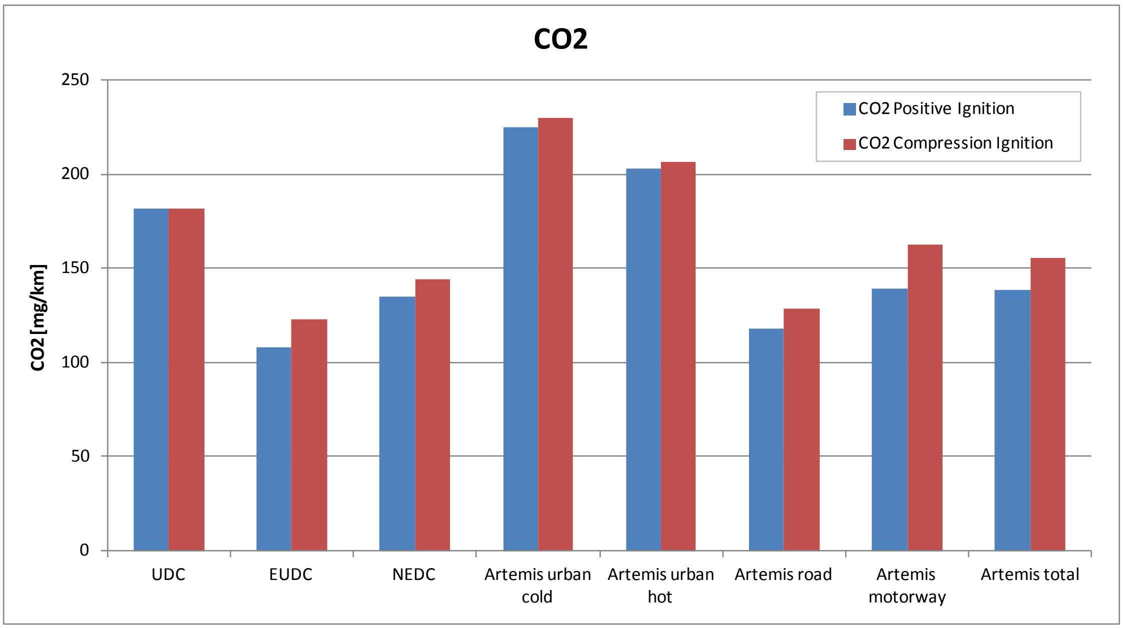

Figure 5.31: Average CO2 emissions under different driving conditions

Figures 5.30 and 5.31 demonstrate the influence of driving conditions and driving behaviour on the fuel consumption of different engine concepts. It is obvious that dynamic driving with strong accelerations at urban conditions gives the worst fuel consumption for vehicles with combustion engines. Positive ignition engines suffer from cold start more than compression ignition engines. Smoothly running traffic with moderate speed and acceleration gives the lowest fuel consumption.

6. References

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