Swedish In-Service Testing Program

On Emissions from Heavy-Duty Vehicles

Report for the Swedish Transport Agency

Certification & Regulation Compliance
AVL

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Content

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List of Abbreviations

CFV	Critical Flow Venturi
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity Of Production
CVS	Constant Volume Sampling
ECU	Engine Control Unit
EEV	Environmentally Enhanced Vehicle
EGR	Exhaust Gas Recirculation
ESC	European Stationary Cycle
ETC	European Transient Cycle
FC	Fuel consumption
GTL	Gas To Liquid
HC	Total hydrocarbons (THC)
HDV/HC	Heavy Duty Vehicle/ Heavy Duty
HFID	Heated Flame Ionization Detector
IUC	In Use Compliance
JRC	Joint Research Centre
LDV/LD	Light Duty Vehicle/ Light Duty
MK1	Environmental class 1
NDIR	Non-Dispersive Infrared
NDUV	Non-Dispersive Ultraviolet
NO_2	Nitrogen dioxides
NOx	Nitrogen oxides
PASS	Photo-Acoustic principle
PEMS	Portable Emission Measurement System
PM	Particulate Matter
PN	Particulate Number
SCR	Selective Catalytic Reduction
SEPA	Swedish Environmental Protection Agency
SRA	Swedish Road Administration
STA	The Swedish Transport Agency
WHTC	World Harmonized Transient Cycle
WHVC	World Harmonized Vehicle Cycle

Summary

AVL MTC AB has on the commission of The Swedish Transport Agency (STA) carried out The Swedish In-Service Testing Programme on Emissions from Heavy-Duty (HD) Vehicles. Seven vehicles have been tested on road in accordance with the PEMS (Portable Emission Measurement System) protocol which include urban, suburban, and highway driving. In addition two of these vehicles have also been tested on chassis dynamometer according to the European Stationary Cycle (ESC) and the Fige (chassis dynamometer version of European Transient Cycle (ETC)). Two of the vehicles have been tested twice, one during both summer and winter conditions and one after service of the exhaust gas recirculation (EGR) system. The selection of the vehicles was based on Euro III Euro IV and V standard.

The scope of the investigation was, beside in use compliance, to generate emission factors from commercial vehicles during a normal working day and representative driving. In addition aspects of retrofit system, alternative fuels, driving pattern and loads were taken into consideration.

The vehicles are denoted A – G in this report.

The vehicle A (90-ton) study was designed to compare emission levels from a 90 tonnes heavy duty timber truck driven empty as well as with full load. The truck is only allowed to drive on a specific route in Överkalix where it is used 24 hours per day all year long. The fuel consumption was increased with 4 litres per 10 km when carrying 60 tons of timber. The increase of emission levels was in the order of 40 – 50 %.

Vehicle B was a long distance distribution truck tested on road with different loads. The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle C was a medium sized distribution truck, equipped with a SCR system, tested on road with and without a load of 3 tons. The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle D was a small sized distribution truck, equipped with an EGR system, tested on road with and without a load of 2 tons. The emissions increased with 40 – 70 % when driving with extra load. No calculation of brake specific emissions i.e. g/kWh were possible to carry out due to the lack of ECU signal.

Vehicle E was a Euro III distribution truck tested on the road with standard Environmental Class 1 diesel as well as wit Gas To Liquid (GTL) fuel from Ecopar. It was found that the use of Ecopar fuel on an average decreased the CO emissions with 20% and the NOx emissions with 10% compared to MK1.

Vehicle F was an environmentally enhanced vehicle (EEV) tested on road as well as on chassis dynamometer. In addition, the vehicle was tested during cold start conditions. The emissions of CO and HC correlates, approximately 40 % higher levels with hot start compared to cold start. The NOx emissions are increasing by 30% during cold start and the fuel consumption with 15 %.
The CO2 emissions are increased with cold start and high load.

Vehicle G was a Euro V vehicle tested on road as well as on chassis dynamometer. In addition, the vehicle was tested during cold start conditions. The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Introduction

Sweden has been considered as for runner related to emission legislations and emission testing especially for light duty vehicles among European countries. The first emission legislation, the ECE R15, was introduced in 1971. However, decision makers did not feel comfortable with the European emission legislation and therefore Sweden introduced US federal requirements in 1975. Later, when Sweden became member of the European Union, the European regulation laid down as directive 70/220/EEC with later amendments was introduced. Together with the requirements at type approval for light duty vehicles (LDV), Sweden introduced Conformity of Production (COP) and In-use compliance testing (IUC) at a very early stage. In-use compliance testing of LDV's in normal operation and owned by private persons has been carried out by AVL MTC/MTC for more than 20 years. During the years more than 900 passenger cars and light duty trucks have been subjected to IUC testing.

The development of emission requirements for diesel fuelled engines to be used in HDV´s has not been as progressive as the ones for LDV´s. Emission requirements for type approval were introduced in Sweden by directive 88/77/EEC, but the regulation is only dealing with the engine itself and not the vehicle. Therefore, IUC testing has been a difficult task.

Historically, the responsible party for administration and implementation of emission requirements in Sweden has been the Swedish Environmental Protection Agency (SEPA) but gradually the responsibility has been transferred to the Swedish Road Administration (SRA). Since 2009 STA has the full responsibility for emissions from the transportation sector.

The emission laboratory operated by AVL MTC comprises several test cells with various capabilities and performance. One test cell is dedicated to test HDV's on a chassis dynamometer, several other test cells are dedicated to test diesel engines to be used in HDV's. IUC testing of HD engines/vehicles started as a research and development program in year 2000. The first phase of the program tried to establish correlation between vehicle testing and engine testing under stationary test conditions later also a significant number of tests was carried out under transient conditions. Later, correlation between chassis dynamometer tests and real life on-board measurement was investigated. Since year 2000 approximately 100 heavy duty engines/vehicles have been tested, and several hundreds of tests have been carried out. The results have been published in cases of public financing of projects. Based on experiences gained from testing, the focus for IUC tests of HDV's has gradually shifted towards on-board measurement. However, testing of HDV's by the use of a chassis dynamometer is still open as an alternative.

The STA has commissioned AVL MTC by a long term contract from year 2009 to perform in-service testing on HDV's operating on Swedish roads. This type of testing has for a long time been performed on LDV's, not only in Sweden but also for example in Germany, the Netherlands and Great Britain. The intention is to include HDV's in this procedure from Euro VI.

The manufacturer has a responsibility that the type approved engine/vehicle does not exceed the emission limits stated in the type approval during a specified period of time or driving distance.

Since the type approval for HDV's is related to the engine, and based on tests performed in engine test bench, it is not uncomplicated to verify emission performance for vehicles in use. Earlier studies have included dismounting the engine from the vehicle, but since the engines and associated exhaust emission control systems get more and more complicated and more electronic controlled devices are used, this is an unreasonable procedure – not at least from cost and time perspectives. The development of in-use testing for heavy duty vehicles have therefore been towards methods that are more practically accomplished.

In Europe, activities to develop suitable test methods for on-road measurements and associated test protocol have been organized and coordinated by EU Joint Research Centre (JRC). JRC launched a pilot project year 2006 where manufacturer of engines/vehicles, manufacturer of instrument, approval authorities and technical services was invited to participate. The activity is called EU-PEMS project. Several meetings have been organized by JRC and interested parties have been invited to share experiences. A common way to calculate and present results from measurement have been introduced by JRC and a standardized test protocol has been established, the PEMS-protocol.

Sweden, represented by STA, is strongly promoting the activities of JRC and the EU-PEMS project. In 2006, STA initiated a national project based on the EU-PEMS project including on-road measurement of HDV's in normal operation, as well as comparative testing on chassis dynamometer. The result from national activities carried out 2011 is presented in this report.

Test program

Seven vehicles have been tested on road by a portable exhaust measurement system (PEMS). In addition, two of these vehicles (F and G) have also been tested on chassis dynamometer. The aim of the study was not to pinpoint specific manufacturer thus, the vehicles in this report will be denoted A – G.

Selection of test vehicles

The vehicle selection has been performed in cooperation with the STA. The vehicle type choosen for testing was based on Euro III, IV and V, EEV and VI technology. The vehicles tested have been served in accordance to the manufacturer specification on a regular basis.

Table 1 EU Emission Standards for HD Diesel Engines

Emission standard	Date	Test	CO g/kWh	HC g/kWh	NOx g/kWh	PM g/kWh	Smoke m^{-1}
EEV	1999.10	ESC & ELR	1.5	0.25	2.0	0.02	0.15
Euro III	2000.10		2.1	0.66	5.0	0.10	0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5
Euro VI	2013.01		1.5	0.13	0.4	0.01	

Testing on chassis dynamometer

Chassis dynamometer test cell

The chassis dynamometer is a cradle dynamometer with 515 mm roller diameters. The maximum permitted axle load is 13 000 kg. Vehicle inertia is simulated by flywheels in steps of 226 kg from 2 500 kg to 20 354 kg. The maximum speed is 120 km/h without flywheels and 100 km/h with flywheels.

Two DC motors, each 200 kW maximum load, and separate control system serves as power absorption units. The DC motors and their computer-controlled software enable an excellent road load simulation capability. The software sets the desired road load curve through an iterative coast down procedure with test vehicle on the dynamometer.

An AVL PUMA computer system is used as a superior test cell computer for engine monitoring and also for the measurement and collection of all data emanating from the vehicle, emission measurement system and test cell.

Measuring methods – gaseous emissions

The sampling- and analysing equipment are based on full flow dilution systems, i.e. the total exhaust is diluted using the Constant Volume Sampling (CVS) concept. The total volume of the mixture of exhaust and dilution air is measured by a Critical Flow Venturi (CFV) system. For the subsequent collection of particulates, a sample of the diluted exhaust is passed to the particulate sampling system. The sample is here diluted once more in the secondary dilution tunnel, a system referred to as full flow double dilution.

According to the regulations for steady state tests, the raw exhaust gases are sampled for further gaseous analysis before the dilution in the tunnel occurs. For transient tests the diluted exhaust gases are both bagsampled and sent for further analysis *and* on-line sampled. Through the CVS system a proportional sampling is guaranteed.

The equipment used for analysing the gaseous regulated emissions consist of double Horiba 9400D systems. Hereby exists the possibility to measure both diluted and raw exhaust emissions on-line simultaneously. The sampling system fulfils the requirements of directive 2005/55/EEC and also the U.S. Federal Register in terms of sampling probes and heated lines etc.

Table 2 Measured components and measurement principles.

Component	**Measurement principle**
Total hydrocarbons (THC)	HFID (heated flame ionization detector) (190°C)
Carbon monoxide (CO)	NDIR (non-dispersive infrared analyzer)
Carbon dioxide (CO_2)	NDIR
Nitrogen oxides (NO_X)	CL (chemiluminescence)
Fuel consumption (FC)	Carbon balance of HC, CO and CO_2

Measuring methods – particle emissions

The particulate emissions were measured gravimetrically by the use of glass fibre filters. The diluted exhausts were sampled on the filters according to standard procedures. Two filters were used, mounted in series.

Test cycles

The ESC, European stationary cycle

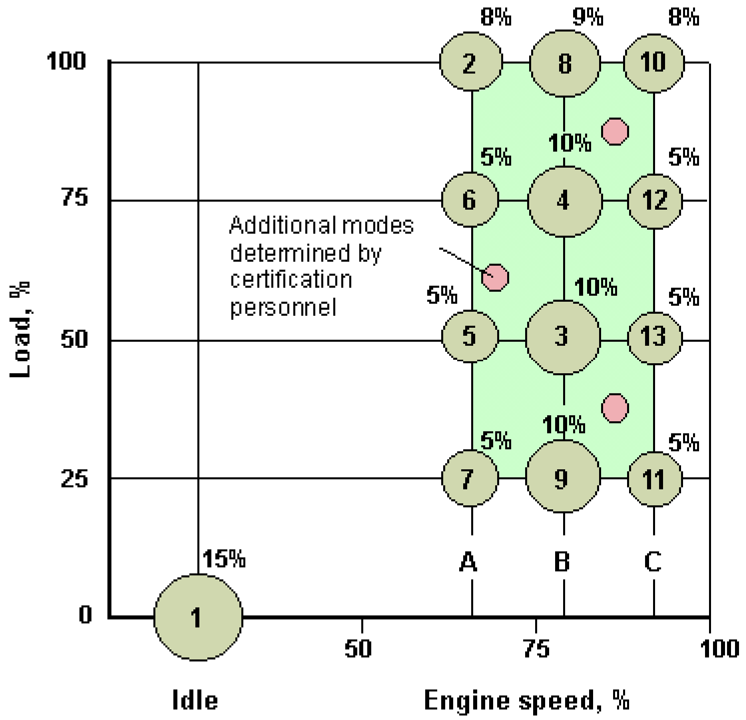


Figure 1 European Stationary Cycle (ESC), Source: Diesel Net

The ESC cycle (European stationary cycle) in combination with ELR (European Load Response) is used for certification of H-D diesel engines of EURO IV and earlier, without advanced exhaust after treatment (i.e SRC, PDF). H-D Diesel engines with advanced after treatment as well as EURO V are certified according to ESC, ELR and ETC test cycles. Gas fuelled H-D engines are certified according to the ETC test cycle. These tests are carried out in engine test bench, but the cycles could be transformed to be used also on a chassis dynamometer, testing a complete heavy duty vehicle.

The ETC/FIGE driving cycle

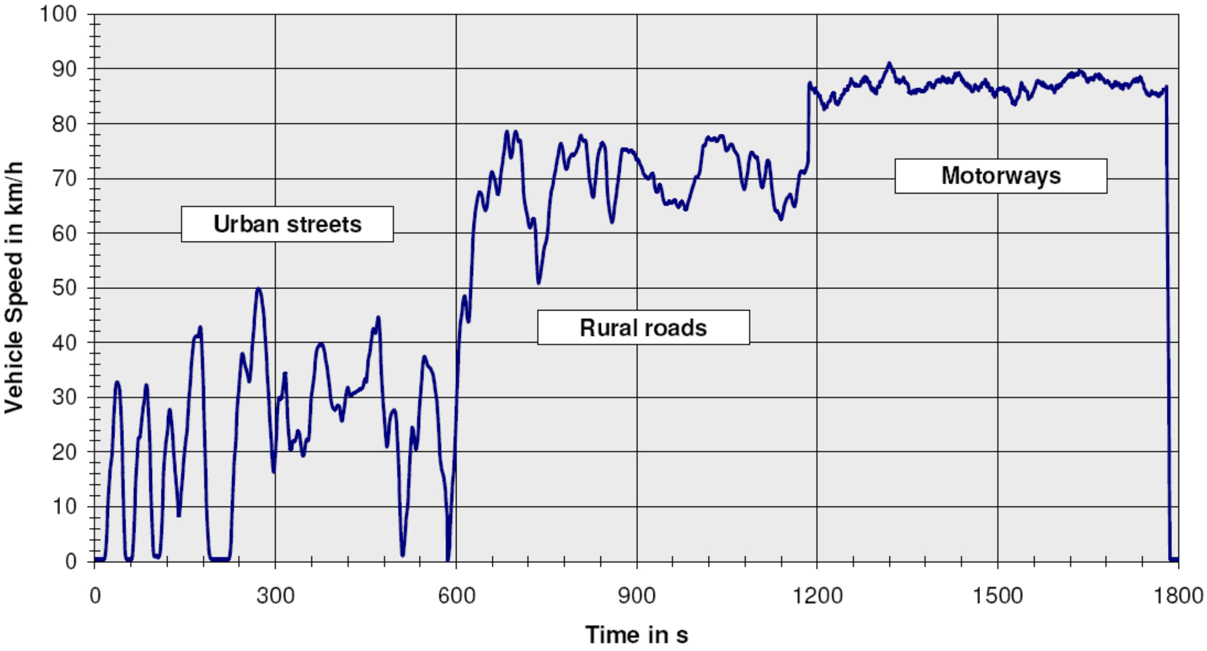


Figure 2 The FIGE driving cycle

The FIGE test cycle has been developed by the FIGE Institute, Aachen, Germany, based on real road cycle measurements of heavy duty vehicles. FIGE Institute developed the cycle in two variants: as a chassis and an engine dynamometer test. The engine dynamometer version of the test is the so called ETC cycle (European Transient Cycle) which today is used for certification purposes of diesel engines to be used in heavy duty vehicles. The chassis dynamometer version is normally referred to as the FIGE test cycle.

Different driving conditions are represented by three parts of the ETC/FIGE cycle, including urban, rural and motorway driving.

The duration of the entire cycle is 1800s. The duration of each part is 600s.

- Part one represents city driving with a maximum speed of 50 km/h, frequent starts, stops, and idling.
- Part two is rural driving starting with a steep acceleration segment. The average speed is about 72 km/h
- Part three is motorway driving with average speed of about 88 km/h.

The WHVC/WHTC test cycle

The WHTC (World Harmonized Transient Cycle) test cycle will become the future test cycle for certification of engines. The WHVC (World Harmonized Vehicle Cycle) test cycle, which can be used for testing entire vehicles on a chassis dynamometer, is the test cycle from which the WHTC was developed. The WHVC is not identical to the WHTC since it was only an intermediate step from data collection to engine test bench cycle, but it is the closest there is today.

The test procedures for chassis dynamometer testing are not identical to the procedures used for engine dynamometer testing, but the results using the WHVC test cycle can be used in order to compare the emission levels from a vehicle with the emissions levels of an engine tested with the WHTC test cycle. The emission results are presented in g/km but also converted from g/km to g/kWh using estimations of executed work during the transient test cycle.

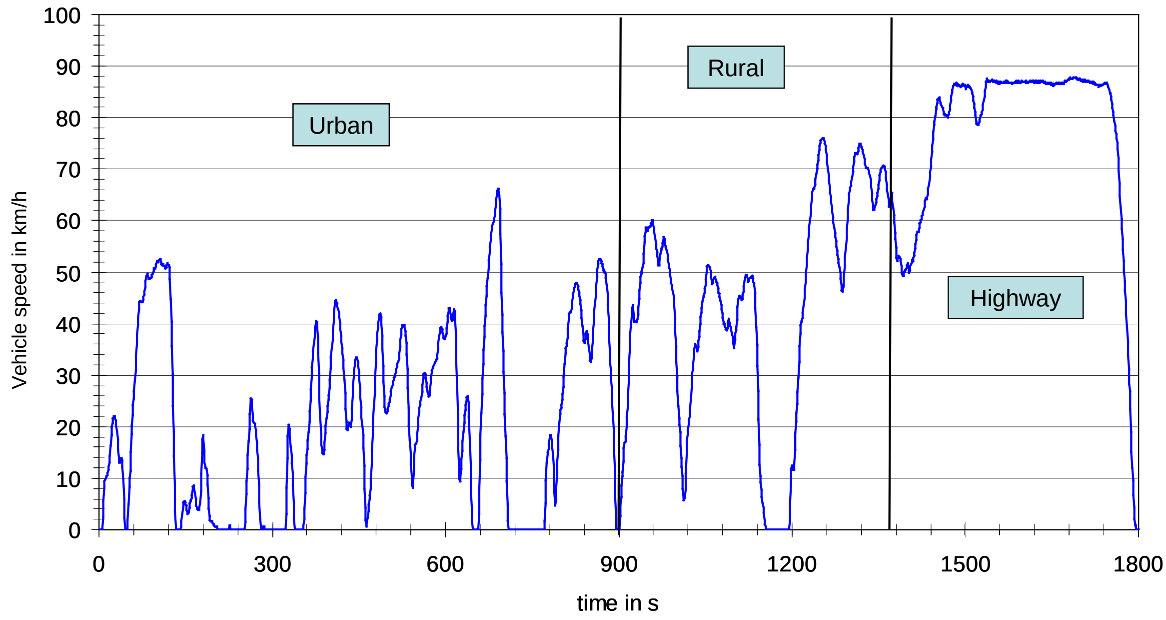


Figure 3 The WHVC test cycle

The transient cycle used in the test was the “WHVC” testcycle (unofficial).

The WHVC is a transient test of 1800 s duration, with several motoring segments.

Different driving conditions are represented by three parts of the WHVC cycle, including urban, rural and highway driving.

The duration of the entire cycle is 1800s.

- The first 900 seconds represents urban driving with an average speed of 21 km/h, maximum speed of 66 km/h. This part includes frequent starts, stops and idling.
- The following 468 seconds represents rural driving with an average speed of 43 km/h and maximum speed of 76 km/h.
- The last 432 seconds are defined as highway driving with average speed of about 76 km/h.

On-road measurement

The Semtech-DS is developed by Sensors for testing all classes of light as well as heavy duty vehicles under real-world operating conditions. The instrument is an on-board emissions analyzer and enables tailpipe emissions to be measured and recorded simultaneously while the vehicle is in operation.

The following measurement subsystems are included in the Semtech-DS emission analyzer:

- Heated Flame Ionization Detector (HFID) for total hydrocarbon (THC) measurement.
- Non-Dispersive Ultraviolet (NDUV) analyzer for nitric oxide (NO) and nitrogen dioxide (NO_2) measurement.
- Non-Dispersive Infrared (NDIR) analyzer for carbon monoxide (CO) and carbon dioxide (CO_2) measurement.
- Electrochemical sensor for oxygen (O_2) measurement.

The instrument is operated in combination with an electronic vehicle exhaust flow meter, Semtech E_xFM. The Semtech-DS instrument uses the flow data together with exhaust component concentrations to calculate instantaneous and total mass emissions. The flow meter is available in different sizes depending on engine size. A 4" flow meter was used, which is suitable for the engine size of the tested vehicles.
In addition to the Semtech instrument an AVL 483 Micro Soot Sensor was used to measure the soot emissions. The AVL 483 Micro Soot Sensor works on a photo-acoustic principle (PASS) and the cell design chosen (called the "resonant measuring cell") allows a detection limit of ≤10 µg/m³, (typically ~ 5 µg/m³).

The instrument is operated in combination with an electronic vehicle exhaust flow meter, Semtech E_xFM. The Semtech-DS instrument uses the flow data together with exhaust component concentrations to calculate instantaneous and total mass emissions. The flow meter is available in different sizes depending on engine size. A 4" flow meter was used, which is suitable for the engine size of the tested vehicles.
The program for emission calculation was supplied by JRC.

The on-road testing and calculation has for all vehicles been performed in accordance with the PEMS protocol. According to the PEMS protocol the measurements should be carried out during a normal working day representative for the vehicle type and if possible include hill climbs, segments with cruising at constant speed and segments that is highly transient in their character as well as different altitudes.

Test Fuel

Commercially available fuels fulfilling the specification of Environmental class 1 diesel (Mk1) has been used. Swedish MK1 fuel is a low sulphur diesel i.e. less than 10 ppm, and has a boiling point interval of 180-290°C. The fuel consists of 50-70% parafines, 30-45% naphtenes and 3-5% aromatics.

Test vehicle E was also tested with a gas to liquid (GTL) fuel from Ecopar.

Vehicle A

Vehicle A was a 90 tonnes heavy duty timber truck equipped with a Selective Catalytic Reduction (SCR) system.

Presentation of vehicle:

Table 1 Vehicle data.

Year model	2008
Environmental class	Euro V
Mileage, km	630 500
Date of registration	2008-11-10
Power, kW	485
Test weight, kg	20 000 – 90 000
Exhaust aftertreatment	SCR

Test route data

The vehicle was tested on roads during driving conditions and loads representing a normal working day.

Below are the test routes presented divided into driving with and without load, Figure 1 and 2.

Table 2 Test route data

Trip duration (s)	2360	3000
Trip distance (km)	41	60
Average speed (km/h)	63	74
Average altitude (m)	44	40
Altitude temperature (^{o}C)	11	10
Humidity (%)	80	72

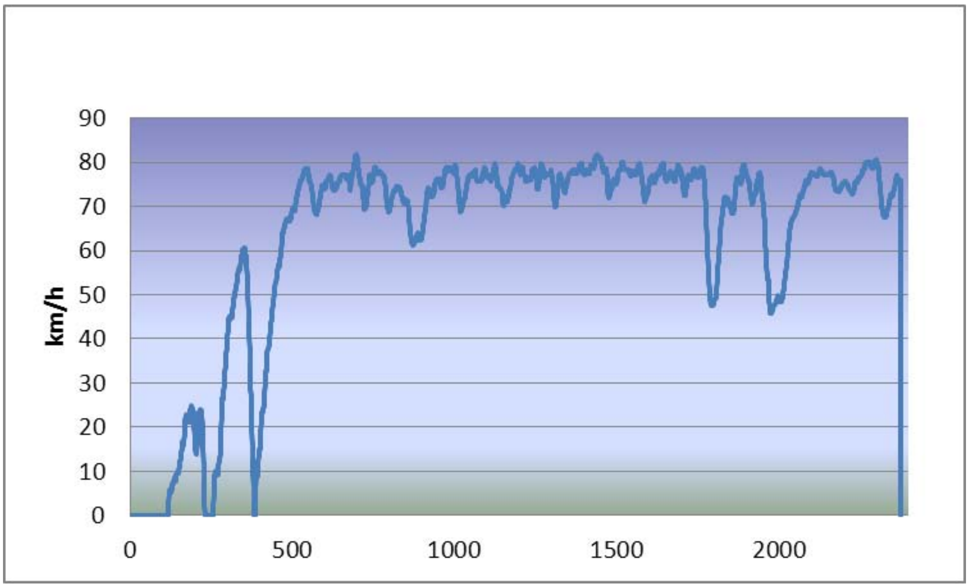


Figure 4 Driving pattern with load. Speed vs time (Sec).

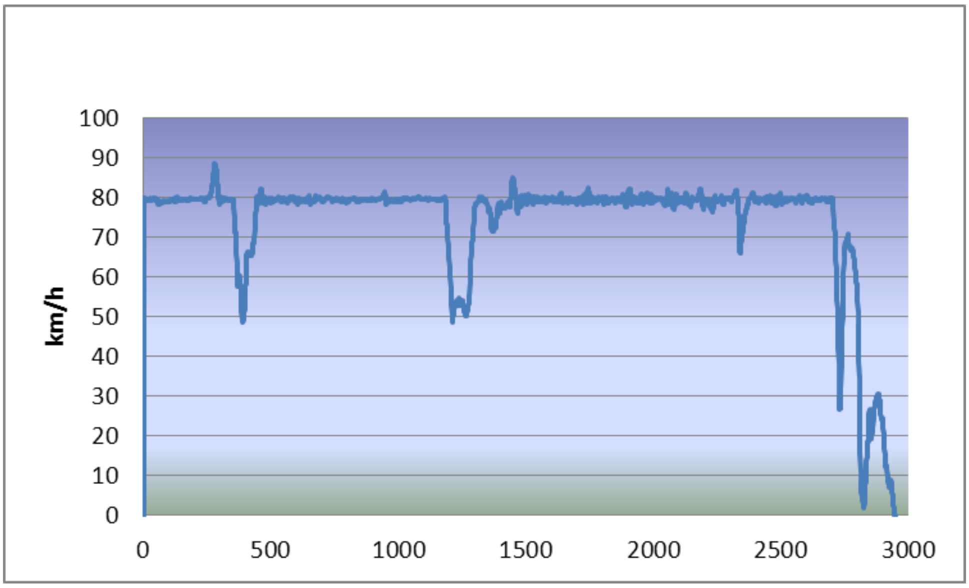


Figure 5 Driving pattern without load. Speed vs time (Sec).

Test results

Obtained test results are presented in Figure 3 – 5. From the data some general conclusions can be made. The emissions of HC are low and close to detection limit and may thus not be significant. The results of distance specific emission are in the same range compared to a 60 tonnes timber truck that was tested within the Swedish In-Service testing programme 2009.

With regard to brake specific emissions (g/kWh) the emissions are in the same order of magnitude compared to the Euro IV certification limit. As a comparison the limit values are presented in Table 2. However, it must be emphasised that PEMS measurement differs from the certification test procedure and can thus not be used as a pass or fail criteria.

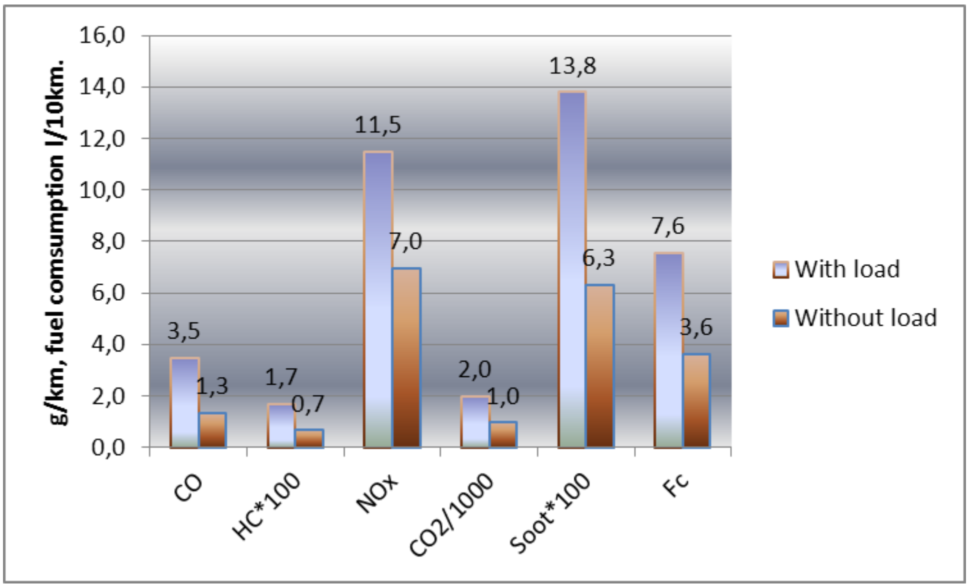


Figure 6 Distance specific mass emission.

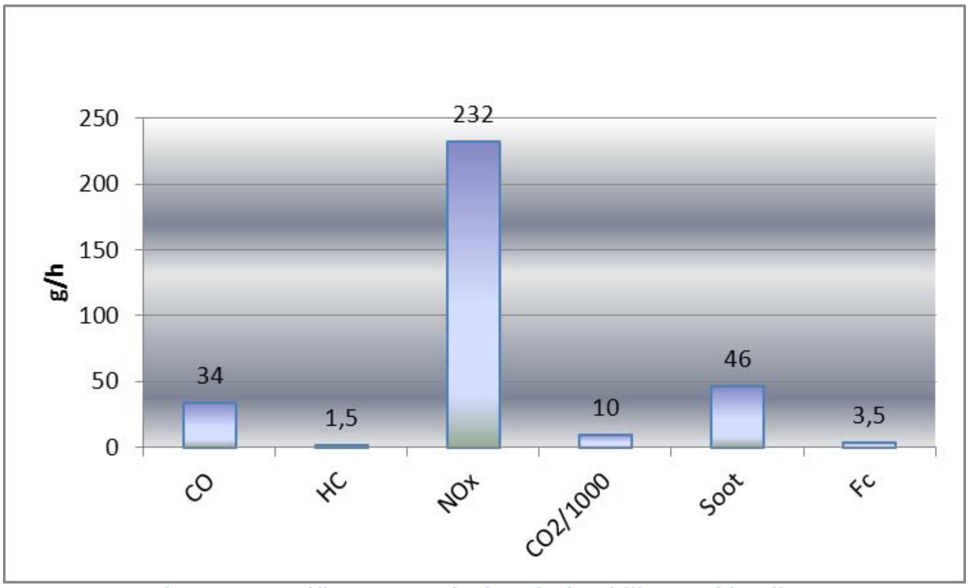


Figure 7 Specific mass emission during idling and loading.

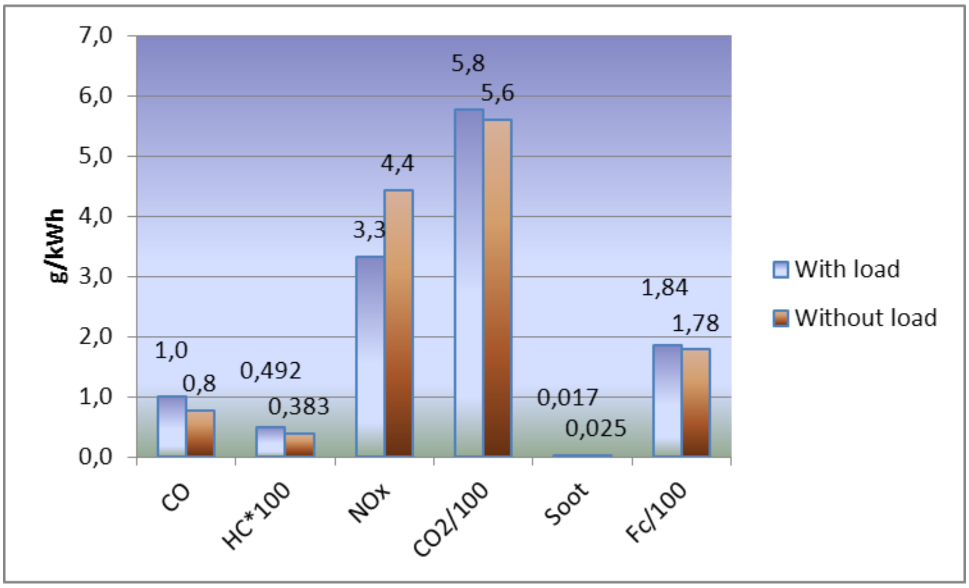


Figure 8 Brake specific emission.

Table 3 Euro V limit values, g/kWh.

CO	HC	NOx	PM
1.5	0.46	2.0	0.02

Comments

The exhaust temperature was measured after the catalyst, thus not representing the pre catalyst temperature. However, the average measured temperature during both road tests was above 320 ^{o}C. In order to have full reduction of the SCR system a temperature above 300 ^{o}C is necessary. The system start working at approximately 220 ^{o}C and no urea is injected under 200 ^{o}C. During the idling test the average temperature reached 135 ^{o}C. This might explain the relatively high levels of NOx during idling. The particulate matter (PM) values in Table 2 cannot be directly compared to the soot measurements. A rough estimate is that the PM consists of 80 % soot.

Vehicle B.

Vehicle B was a distribution truck equipped with EGR and particulate filter.

Presentation of vehicle:

Table 4 Vehicle data.

Year model	2008
Environmental class	V
Mileage, km	30 2000
Date of registration	May 2009
Power, kW	353
Test weight, kg	11 000, 22 000 and 60 000
Exhaust aftertreatment	EGR, Particulate filter

Test route data

Three on road test runs were carried out on the test vehicle. Each test run was carried out with different loads. The test route, driving conditions and loads were the same as of an approximately normal working day.

Table 5 Test route data, 11 tonnes.

Trip duration (s)	300
Trip distance (km)	4
Average speed (km/h)	37
Average altitude (m)	45
Altitude temperature (^{o}C)	22
Humidity (%)	60

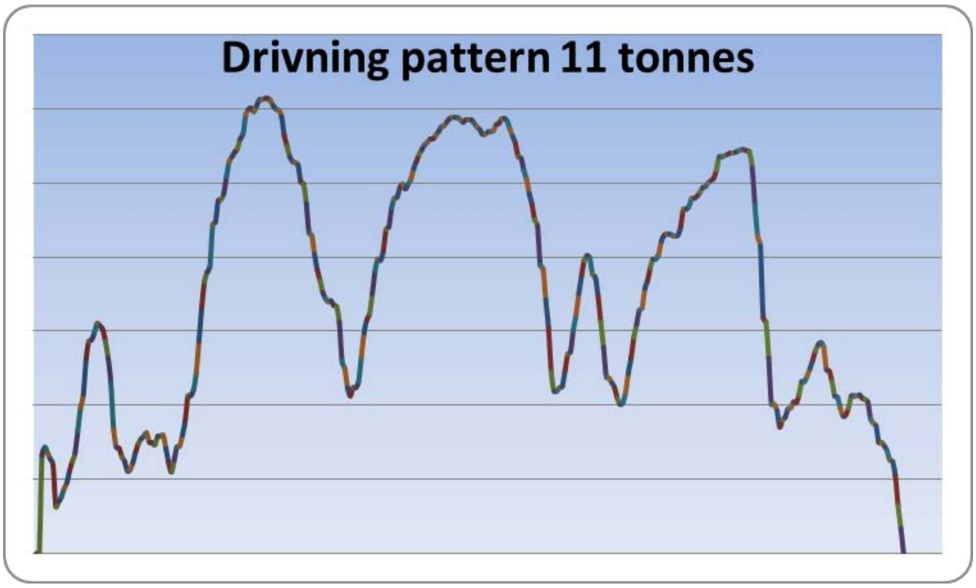


Figure 9 The driving pattern, 11 tonnes.

Table 6 Test route data, 22 tonnes.

Trip duration (s)	1126
Trip distance (km)	13
Average speed (km/h)	41
Average altitude (m)	47
Altitude temperature °C	20
Humidity (%)	60

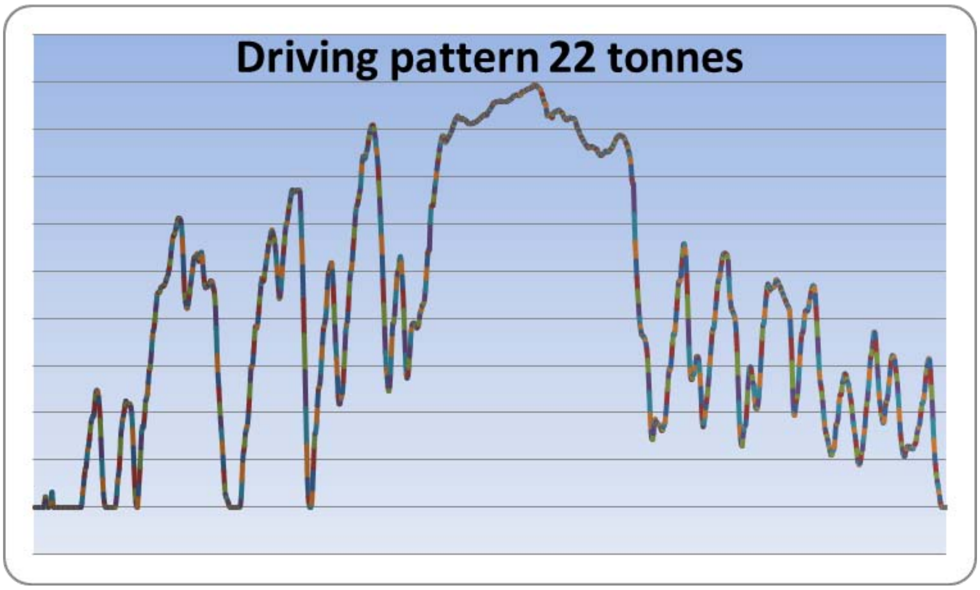


Figure 10 The driving pattern, 22 tonnes.

Table 7 Test route data, 60 tonnes.

Trip duration (s)	2280
Trip distance (km)	23
Average speed (km/h)	34
Average altitude (m)	47
Altitude temperature ^{o}C	19
Humidity (%)	80

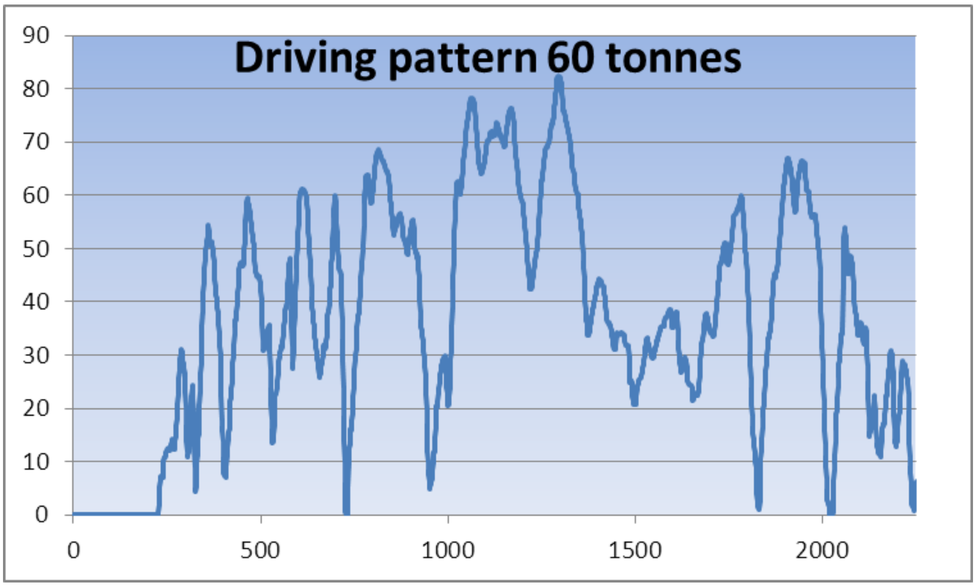


Figure 10 The driving pattern, 60 tonnes.

Test results

From Figure 12 – 13 some general conclusions can be made. The CO emissions are low and not affected by vehicle pay load. Emissions of hydrocarbons are close to detection limit thus, differences due to vehicle weight may not be significant. The emissions of oxides of nitrogen are in the order of two times higher compared to Euro V certification limits values when looking at all events. This corresponds to 6.7 – 10 g NOx per kg CO_2. The soot levels were below detection limit i.e. 5 mg/km.

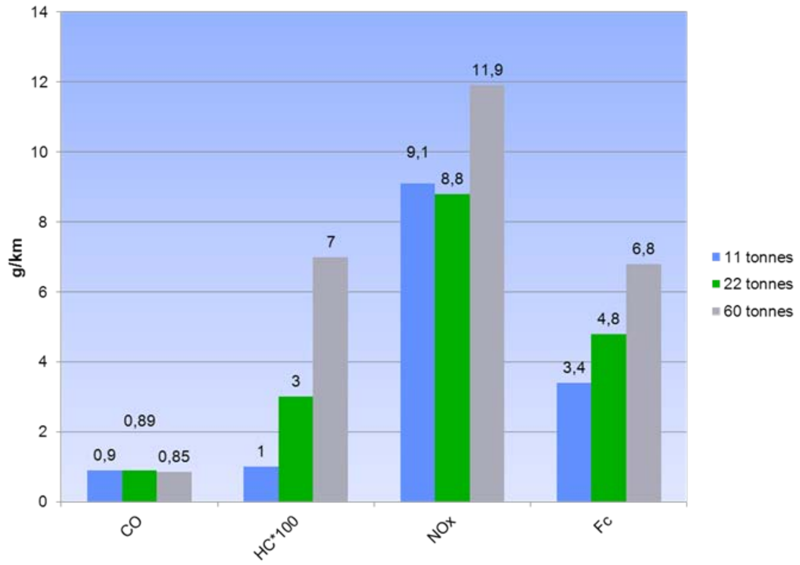


Figure 11 Distance specific mass emission.

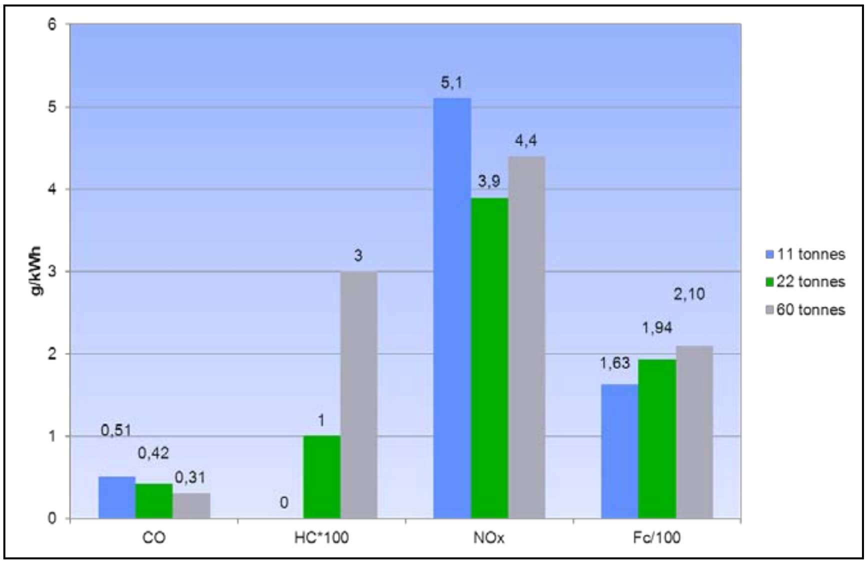


Figure 12 Brake specific emission.

Table 8 Euro V limit values, g/kWh

CO	HC	NOx	PM
1.5	0.46	2.0	0.02

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle C.

Vehicle C was a distribution truck equipped with a SCR and a particulate filter system.

Presentation of vehicle:

Table 9 Vehicle data.

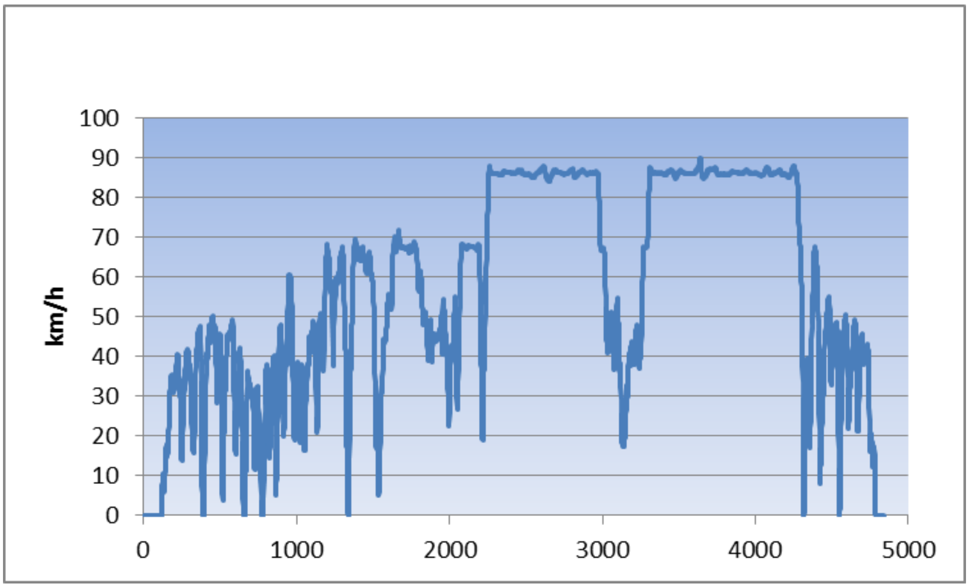
Year model	2008
Environmental class	V
Mileage, km	16 900
Date of registration	November 2008
Power, kW	185
Test weight, kg	8 500 – 11 500
Exhaust aftertreatment	SCR, particulate filter

Test route data

The vehicle was tested on roads during driving conditions and loads representing a normal working day with and without a cargo load of 3000 kg.

Table 10 Test route data

Trip duration (s)	4500
Trip distance (km)	75
Average speed (km/h)	60
Average altitude (m)	37
Altitude temperature (^{o}C)	16
Humidity (%)	79



Driving pattern with and without load.

Test results

From Figure 2 – 3 some general conclusions can be made. The CO emissions are low and not affected by more than 10% due to vehicle pay load. Emissions of hydrocarbons are close to detection limit thus, differences due to vehicle weight may not be significant. The emissions of oxides of nitrogen are in the order of 1.5 times higher compared to Euro V certification limits values when looking at all events. This corresponds to 4 – 4.3 g NOx per kg CO_2.

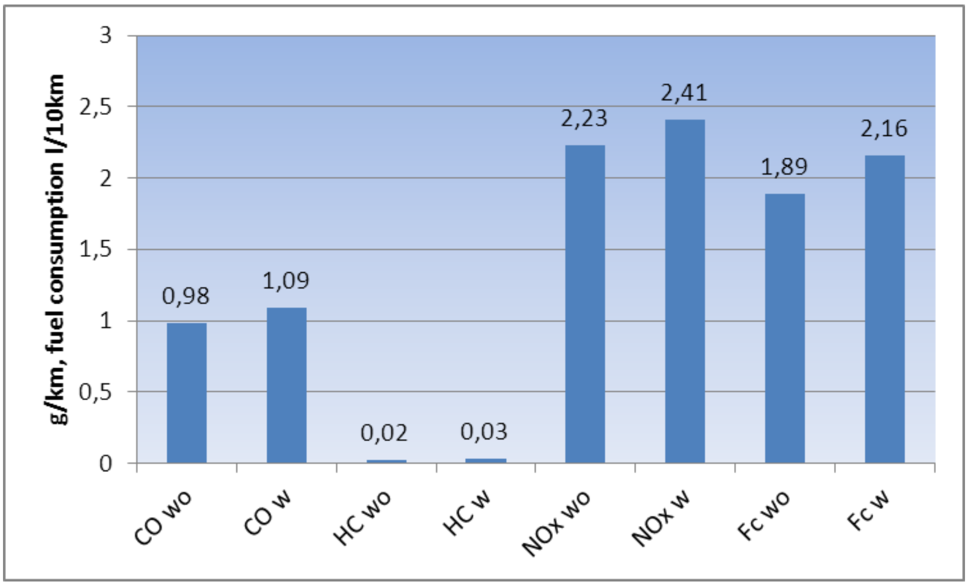


Figure 13 Distance specific mass emission, without load (wo) and with load (w)

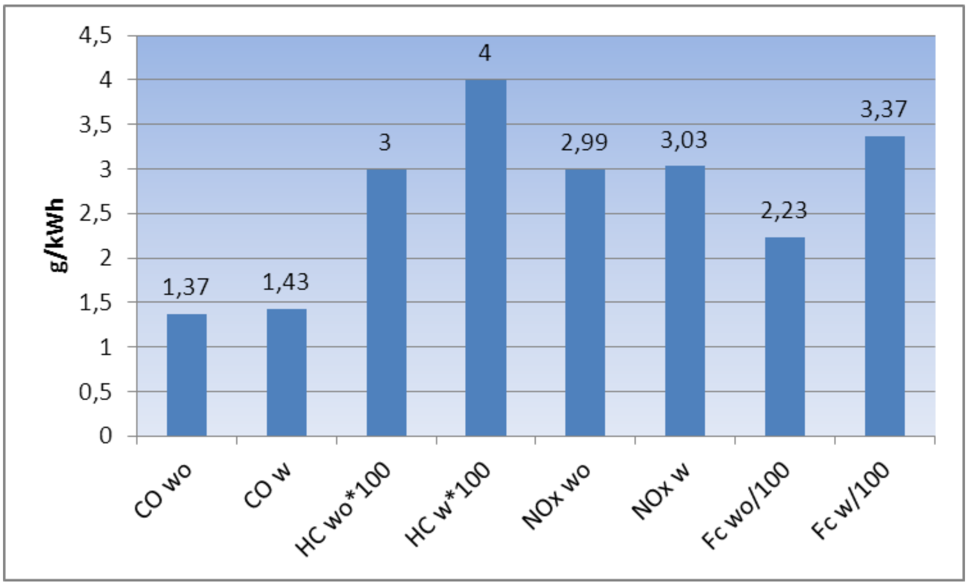


Figure 14 Brake specific emission, without load (wo) and with load (w).

Table 11 Euro V limit values, g/kWh.

CO	HC	NOx	PM
1.5	0.46	2,0	0.02

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle D

The vehicle type chosen was a small distribution truck equipped with a EGR after treatment system.

Presentation of vehicle:

Table 12 Vehicle data.

Year model	2006
Environmental class	Euro IV
Mileage, km	16 900
Date of registration	April 2007
Power, kW	115
Test weight, kg	4000 – 6000
Exhaust aftertreatment	EGR

Test route data

The vehicle was tested on roads during driving conditions and loads representing a normal working day with and without a cargo load of 2000 kg..

Table 13 Total test route data, PEMS test route without and with load respectively

Trip duration (s)	1616 - 600
Trip distance (km)	23 - 5
Average speed (km/h)	52 - 30
Average altitude (m)	15 - 22
Altitude temperature ^{o}C	15
Humidity (%)	86

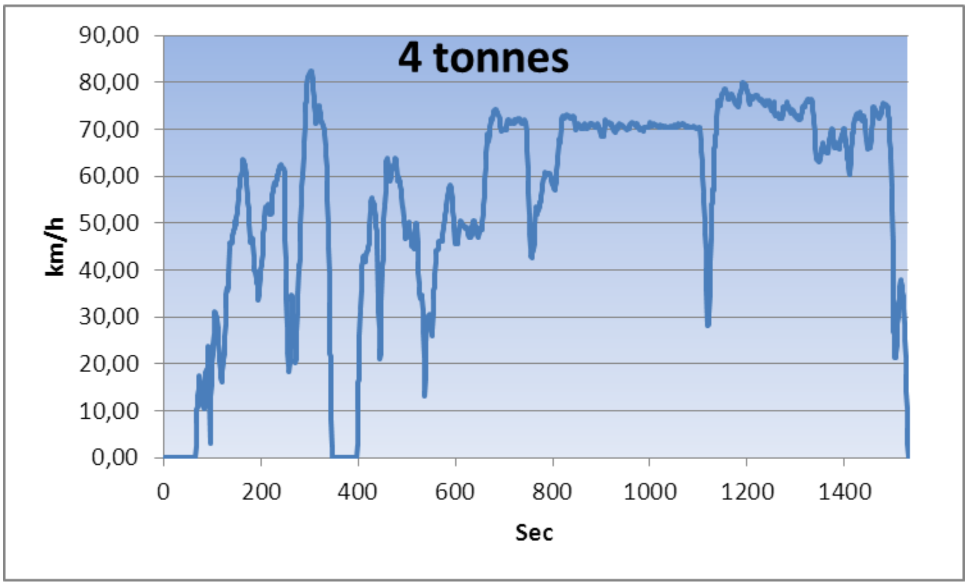


Figure 15 The PEMS test route without load.

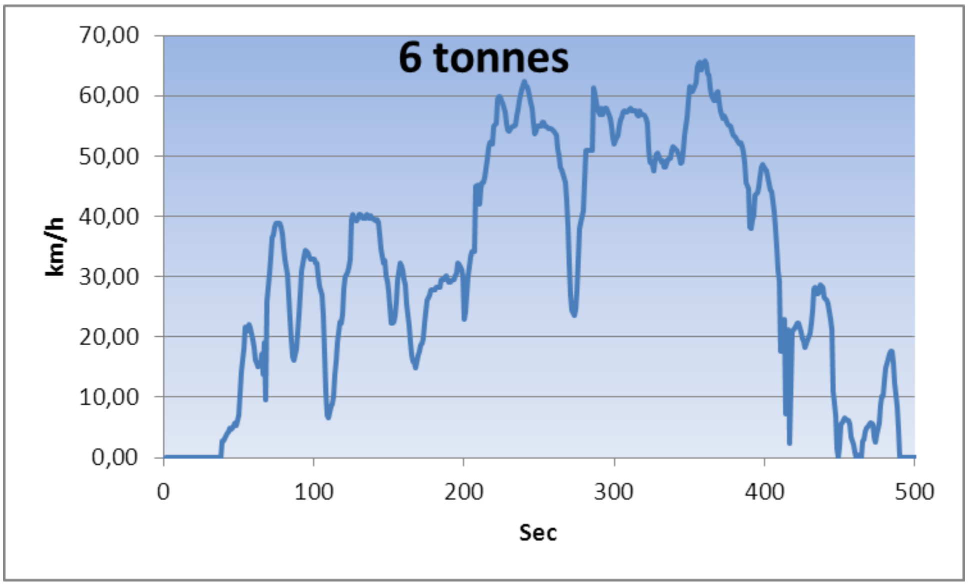


Figure 16 The PEMS test route with load.

Test results

From Figure 2 some general conclusions can be made. The emissions of CO are in the order of 70 % higher with load while HC emission increases with 40 %. The NOx and soot emission increases approximately 15 % with extra load while the fuel consumption increases with 8 %. The results correspond to 8.1g NOx per kg CO_2.

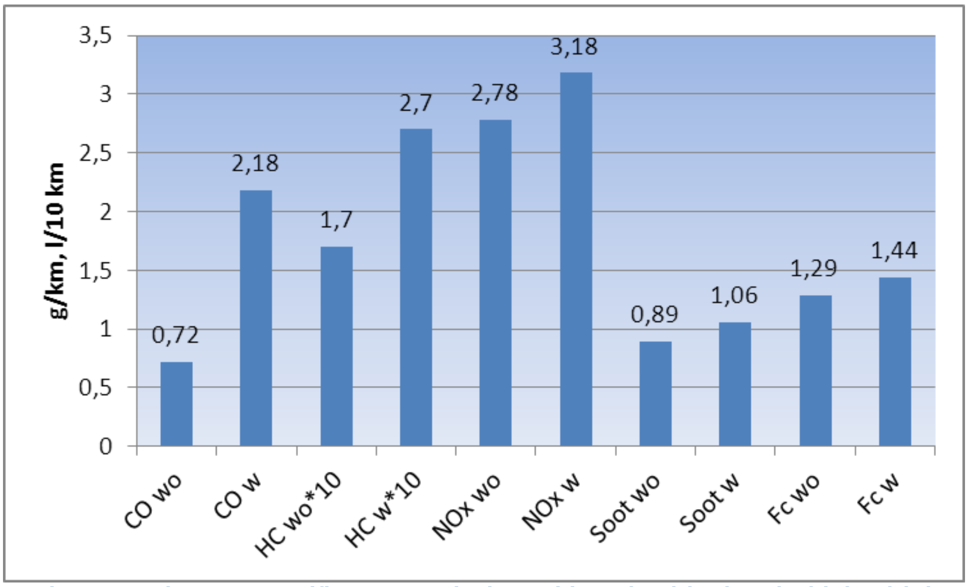


Figure 17 Distance specific mass emission, without load (wo) and with load (w)

Comments

No calculation of brake specific emissions i.e. g/kWh were possible to carry out due to the lack of ECU signal.

Vehicle E

Vehicle E was a distribution truck without any exhaust aftertreatment systems.

Presentation of vehicle:

Table 14 Vehicle data.

Year model	2000
Environmental class	III? (“MK3”)
Mileage, km	59 8000
Date of registration	1999-10-27
Power, kW	154
Test weight, kg	9680
Exhaust aftertreatment	None

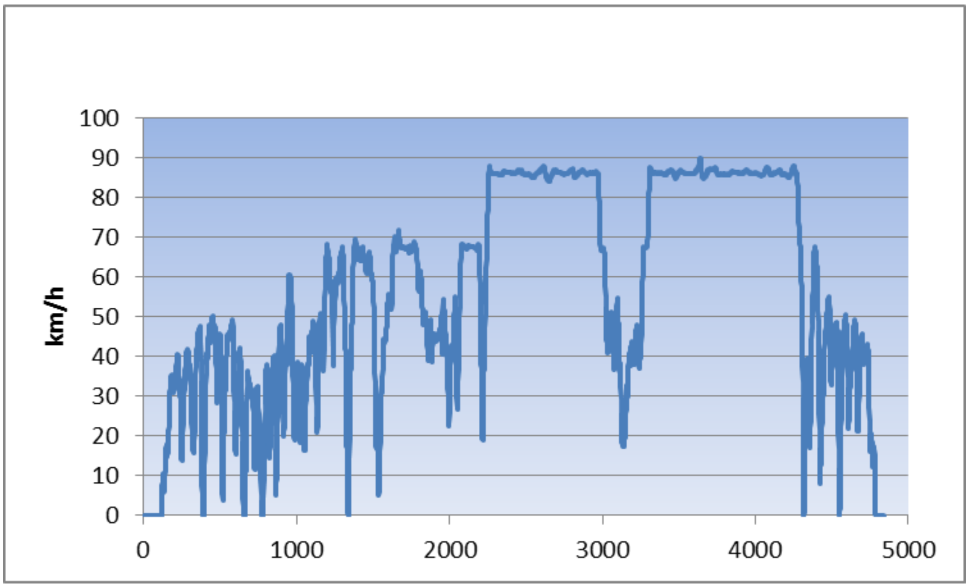
Test route data

The vehicle was tested on roads during driving conditions and loads representing a normal working day with a cargo load of 3000 kg.

The first three tests were carried out with commercially available Environmental class 1 diesel (Mk1) and the following three tests with a gas to liquid (GTL) fuel from Ecopar.

Table 15 Total test route data

Trip duration (s)	4500
Trip distance (km)	75
Average speed (km/h)	60
Average altitude (m)	37
Altitude temperature ^{o}C	20
Humidity (%)	80



Driving pattern.

Test results

From Figure 2 some general conclusions can be made. The CO emissions decreases with the Ecopar fuel with 20% compared to MK1. The emissions of NOx are also lower when using Ecopar fuel, in average, 10 %. No differences could be detected regarding emissions of soot and fuel consumption. Emissions of hydrocarbons are close to detection limit.

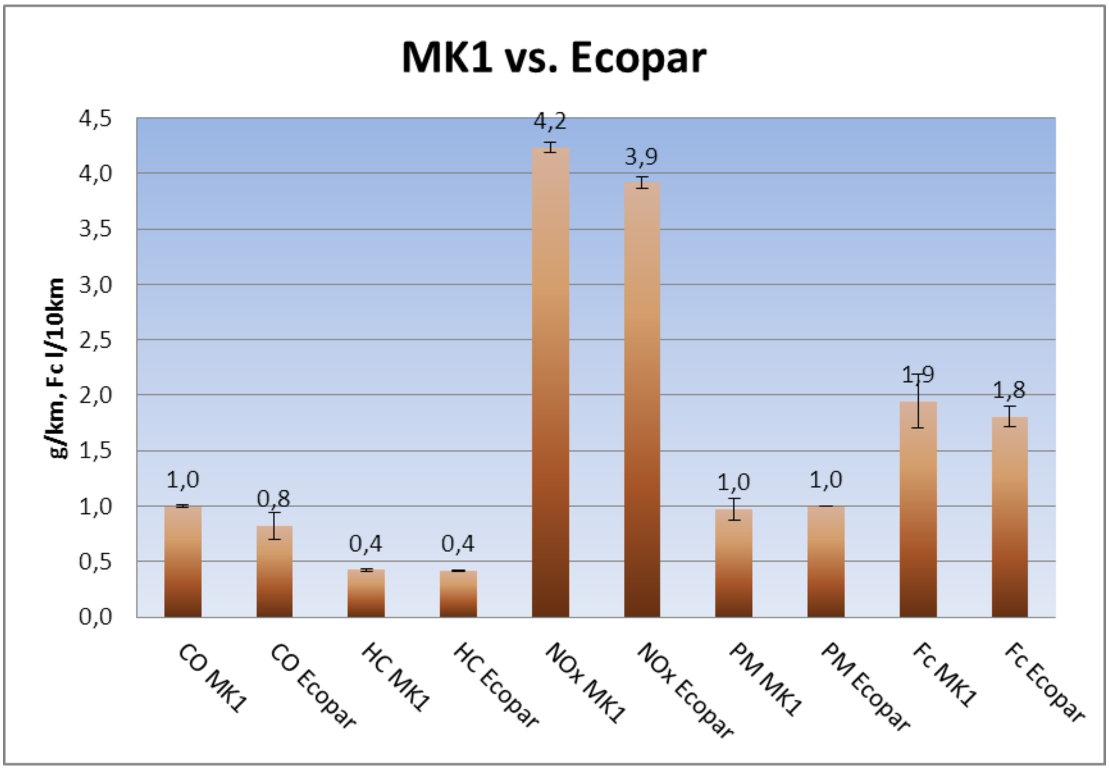


Figure 18 Distance specific mass emission.

Comments

No calculation of brake specific emissions i.e. g/kWh were possible to carry out due to the lack of an engine control unit (ECU)

Vehicle F

Vehicle G was a container vehicle equipped with a SCR exhaust aftertreatment system. The vehicle has been tested both on chassis dynamometer and on road.

Presentation of vehicle:

Table 16 Vehicle data.

Year model	2011
Environmental class	*V*
Mileage, km	4 500
Date of registration	2011-06-01
Power, kW	*537*
Test weight, kg	13 000, 16 000 and 21 000
Exhaust aftertreatment	SCR

Chassis dynamometer testing

On chassis dynamometer the road load was 17 000 and the average ambient temperature was 22 ^{o}C.

The Chassis dynamometer tests were:

1 WHVC (World harmonized vehicle chassisdynamometer test)
1 Fige (chassis dynamometer version of ETC – European Transient Cycle)

Test route data-on road

On road, the vehicle was tested during driving conditions and loads representing a normal working day and the average ambient temperature was 8 ^{o}C.

Three test runs, two with hot start at different loads and one cold start, were carried out. The on-road testing and calculation has been performed in accordance with the PEMS protocol.

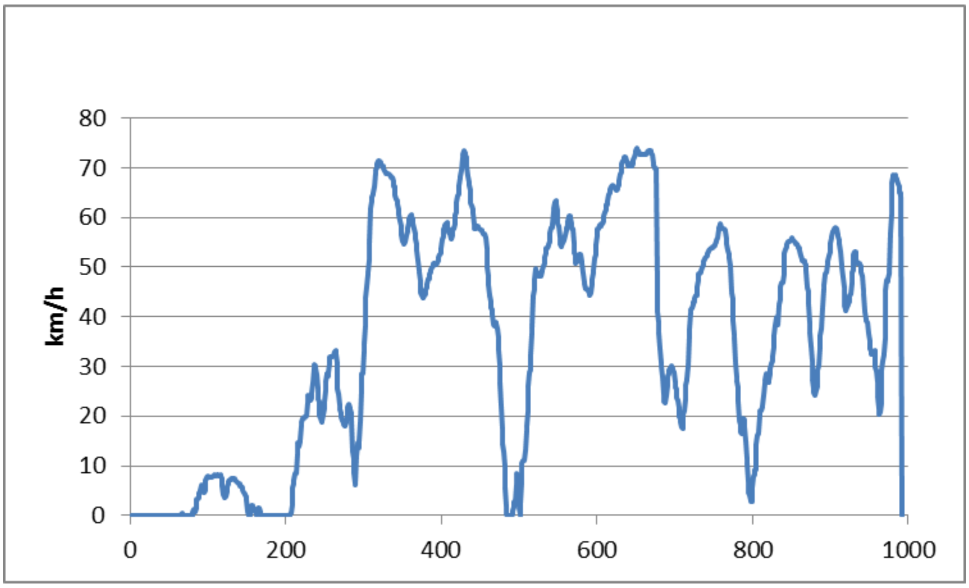


Figure 19a: *The PEMS test route number one*

Table 19a. Total test route data, PEMS test route number one.

Trip duration (s)	1000
Trip distance (km)	9.6
Average speed (km/h)	35
Average temperature (C)	8
Average humidity (%)	63

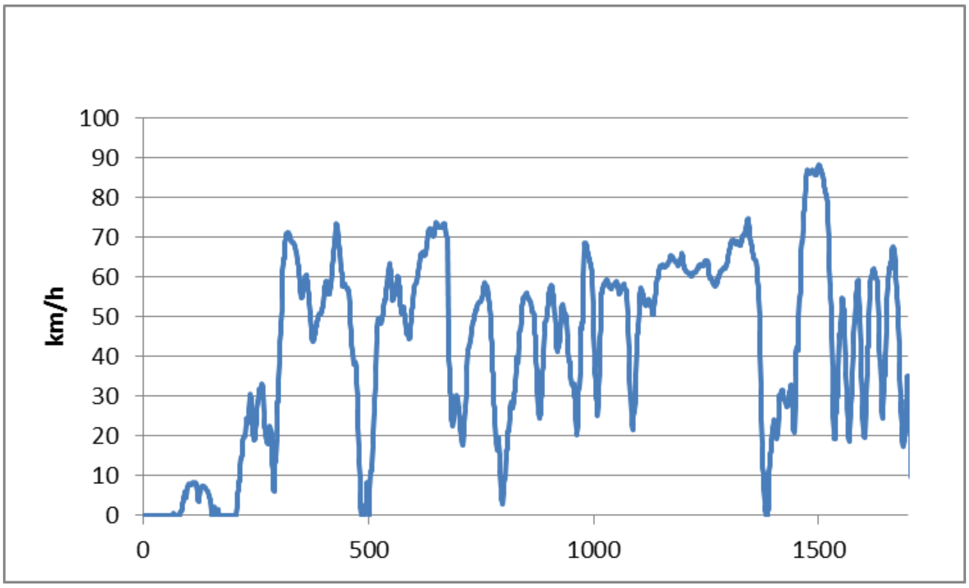


Figure 19b: *The PEMS test route number two*

Table 19b. Total test route data, PEMS test route number two.

Trip duration (s)	700
Trip distance (km)	7.8
Average speed (km/h)	39
Average temperature (C)	10
Average humidity (%)	33

Test results

From Figure 2 – 7 some general conclusions can be made. In Figure 2, the engine temperature vs. time during cold start testing is plotted. It can be seen that the normal engine working temperature i.e. 80 ^{o}C is reached after 22 minutes when the ambient temperature is 8 ^{o}C. According to the proposed regulation, measurement must be started after maximum 20 minutes, in this case 77 ^{o}C. Below are the test results from hot engine and cold start testing at 80 ^{o}C and 8 ^{o}C respectively and as comparison, the Fige and WHVC chassidynamometer test expressed as g/km, Figure.

The emissions of CO and HC correlates, approximately 40 % higher levels with hot start compared to cold start. However, it must be emphasized that the HC levels are close to the detection limit. The NOx emissions are increasing by 30% during cold start and the fuel consumption with 15 %. The CO2 emissions are increased with cold start and high load.

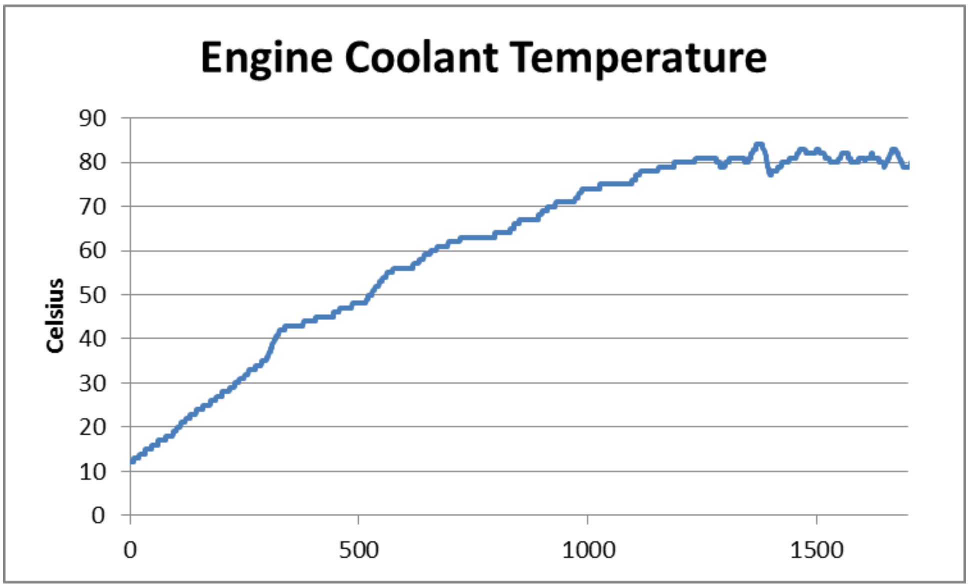
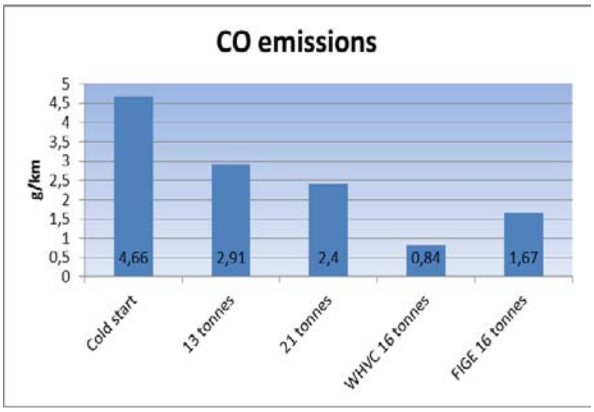


Figure 20. Engine coolant temperature during cold start test.



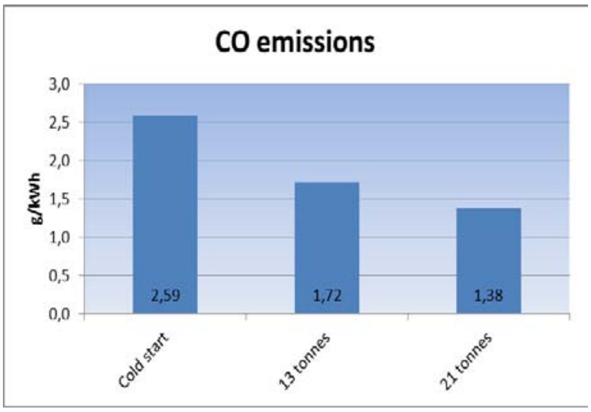


Figure 21a. Distance specific CO mass emission. **Figure 21b**. Brake specific CO mass emission.

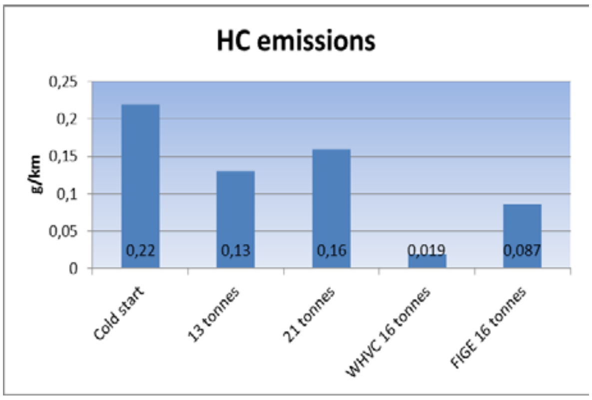


Figure 22a. Distance specific HC mass emission.

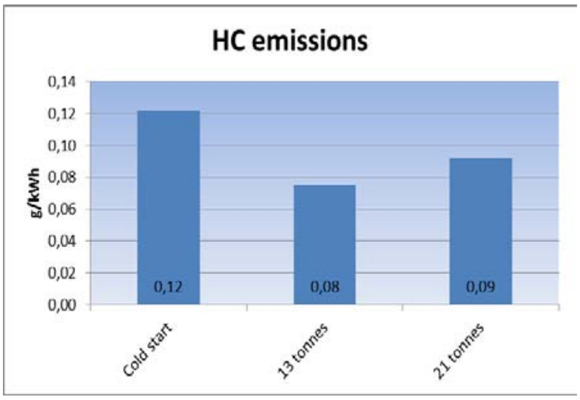


Figure 22b. Brake specific HC mass emission.

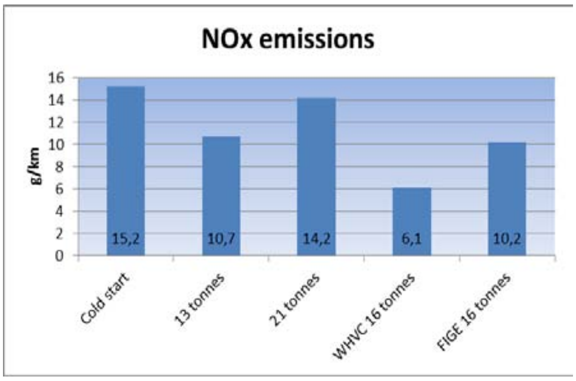


Figure 23a. Distance specific NOx mass emission.

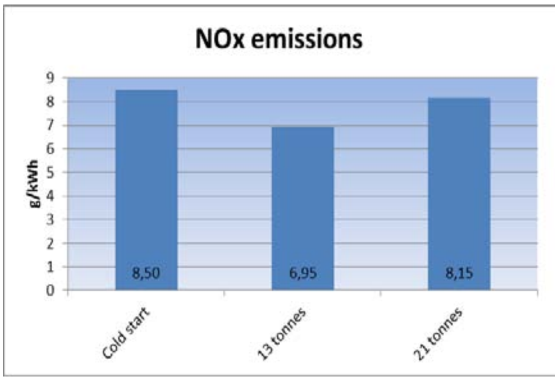


Figure 23b. Brake specific NOx mass emission.

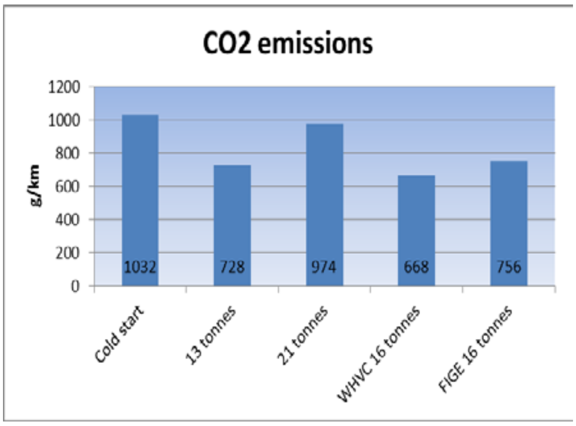


Figure 24a. Distance specific CO2 mass emission.

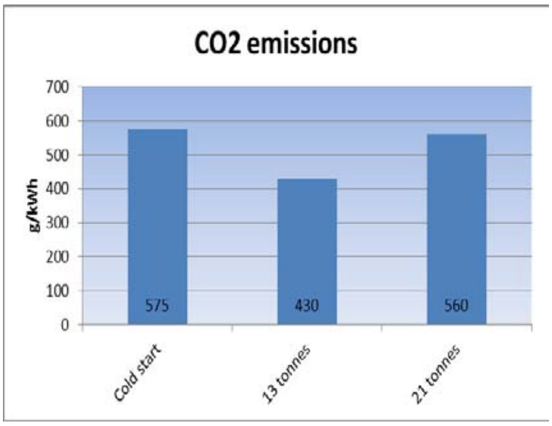
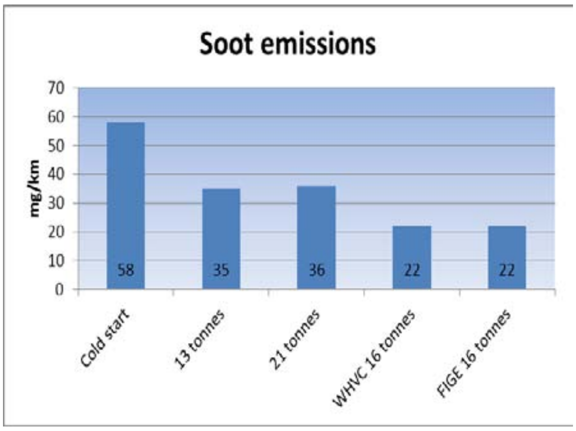


Figure 24b. Brake specific CO2 mass emission.



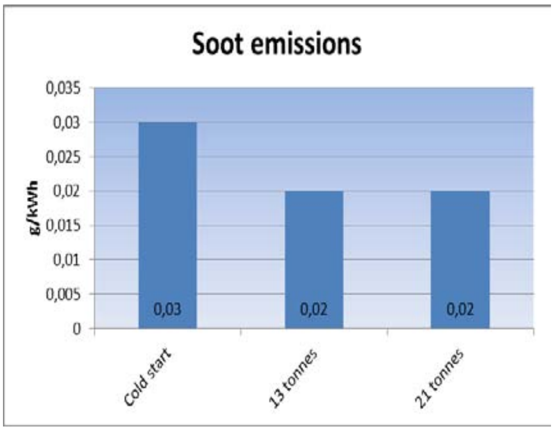


Figure 25a. Distance specific soot mass emission. **Figure 25b**. Brake specific soot mass emission.

Table 20 EEV limit values, g/kWh.

CO	HC	NOx	PM
1.5	0.25	2,0	0.02

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.

Vehicle G

Vehicle G was a distribution truck equipped with a SCR exhaust aftertreatment system. The vehicle has been tested both on chassis dynamometer and on road.

Presentation of vehicle:

Table 2117 Vehicle data.

Year model	2011
Environmental class	V
Mileage, km	12 500
Date of registration	2011-03-11
Power, kW	217
Test weight, kg	11 900
Exhaust aftertreatment	SCR

Chassis dynamometer testing

On chassis dynamometer the road load was 16 000 kg and the average ambient temperature was 22 ^{o}C.

The Chassis dynamometer tests were:

1 WHVC (World harmonized vehicle chassisdynamometer test)
1 Fige (chassis dynamometer version of ETC – European Transient Cycle)

Test route data (on road)

On road, the vehicle was tested during driving conditions and loads representing a normal working day with a cargo load of 3000 kg. The average ambient temperature was 7 ^{o}C.

Two test runs, one with hot start and one cold start, were carried out. The on-road testing and calculation has been performed in accordance with the PEMS protocol.

Test results

From Figure 2 – 11 some general conclusions can be made. In Figure 2, the engine temperature vs. time during cold start testing is plotted. It can be seen that the normal engine working temperature i.e. 80 ^{o}C is reached after 35 minutes when the ambient temperature is -7 ^{o}C. According to the proposed regulation, measurement must be started after maximum 20 minutes, in this case 70 ^{o}C. Below are the test results from hot engine start (80 ^{o}C), cold engine start (-7 ^{o}C) and as comparison, the first 20 minutes of the cold start test presented, Figure 3 - 11.
The emissions of CO and HC correlates, approximately 40 % higher levels with hot start compared to cold start. However, it must be emphasized that the HC levels are close to the detection limit.
The NOx emissions are increasing by 30% during cold start and the fuel consumption with 15 %.

The brake specific emissions (g/kWh) correlate with distance specific emissions and are below the certification limit values during ESC testing.

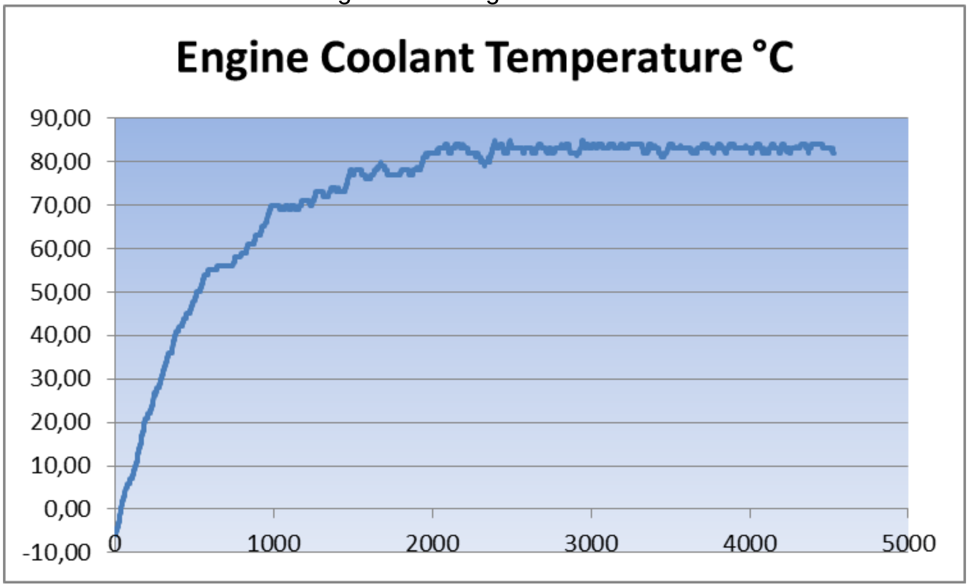


Figure 26. Engine coolant temperature during cold start test.

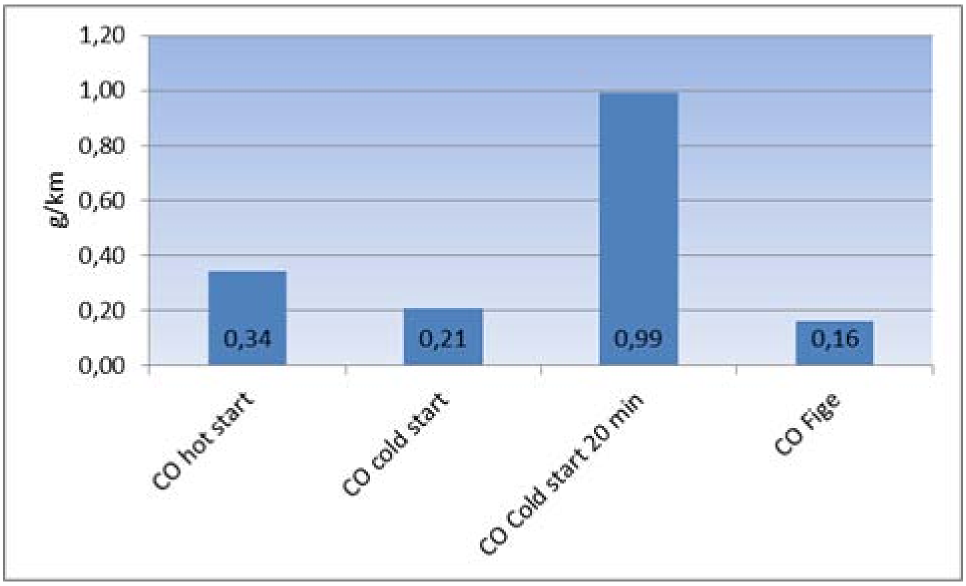


Figure 27. Distance specific CO mass emission.

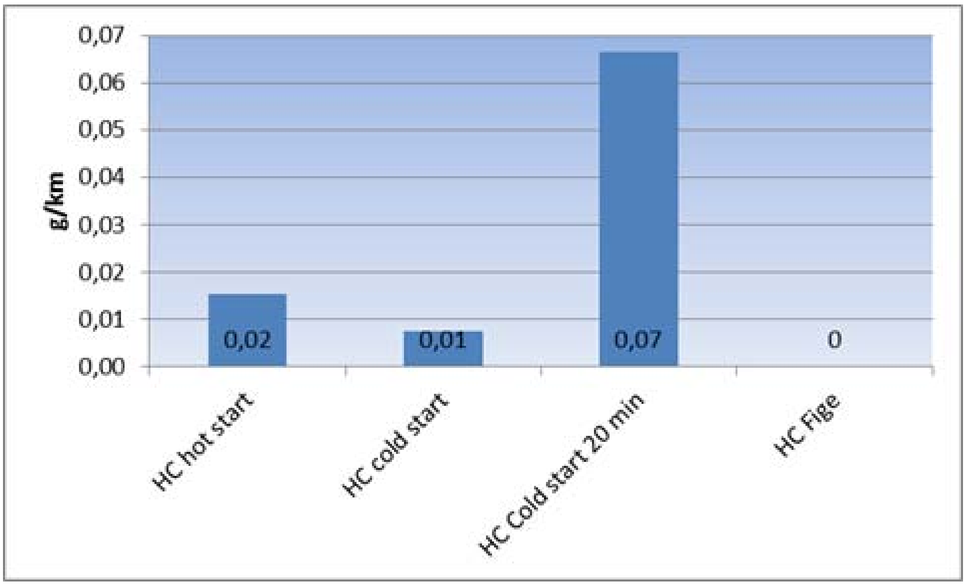


Figure 28. Distance specific HC mass emission

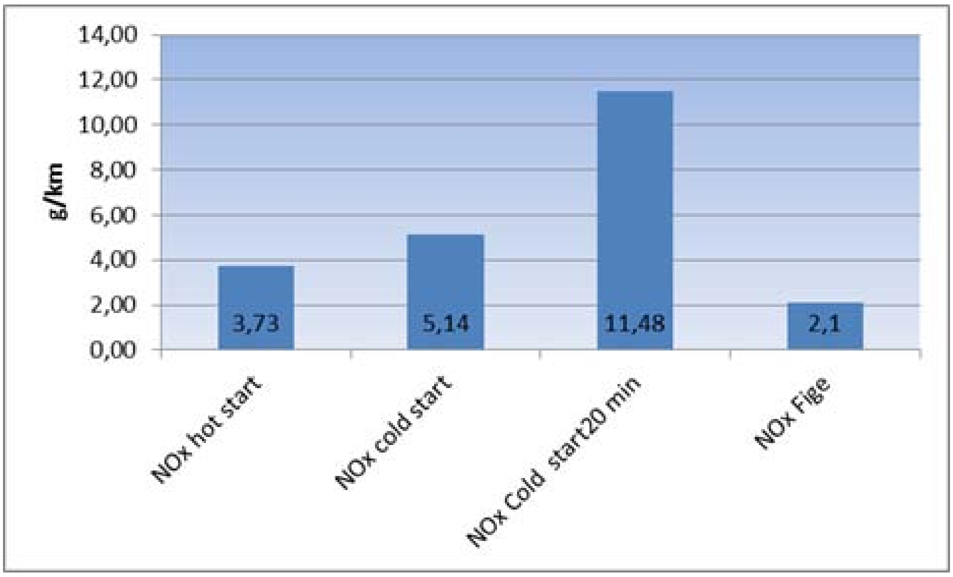


Figure 29. Distance specific NOx mass emission

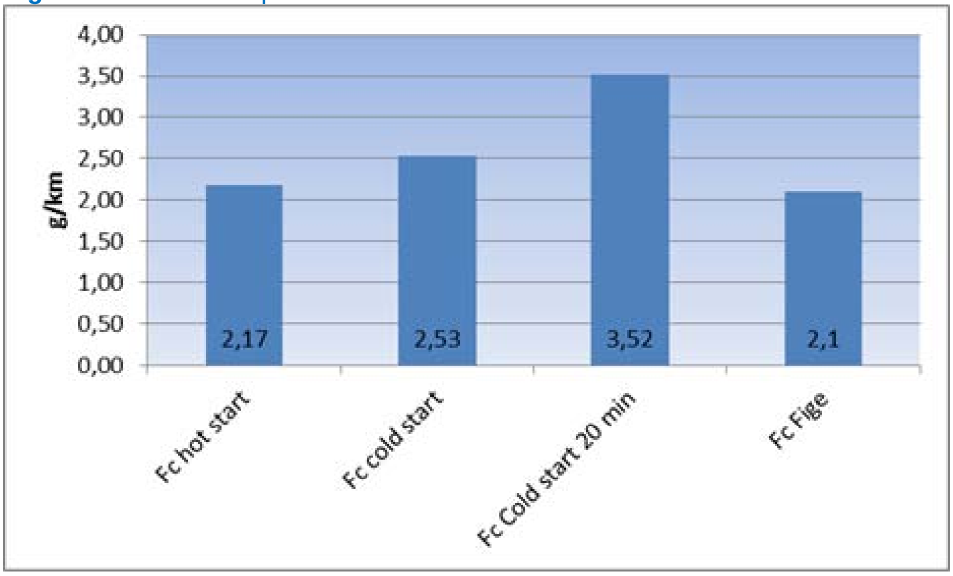


Figure 30. Distance specific fuel consumption.

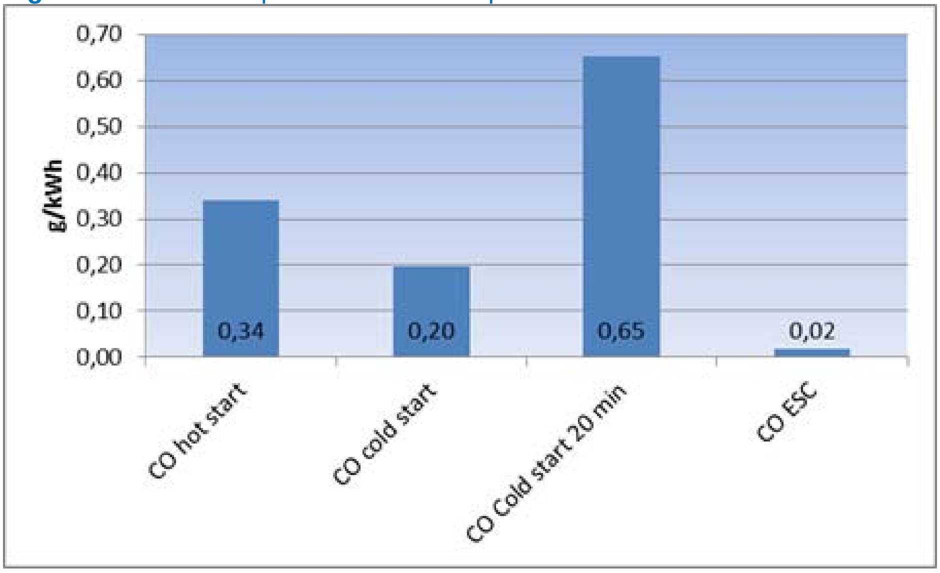


Figure 31. Brake specific CO emission.

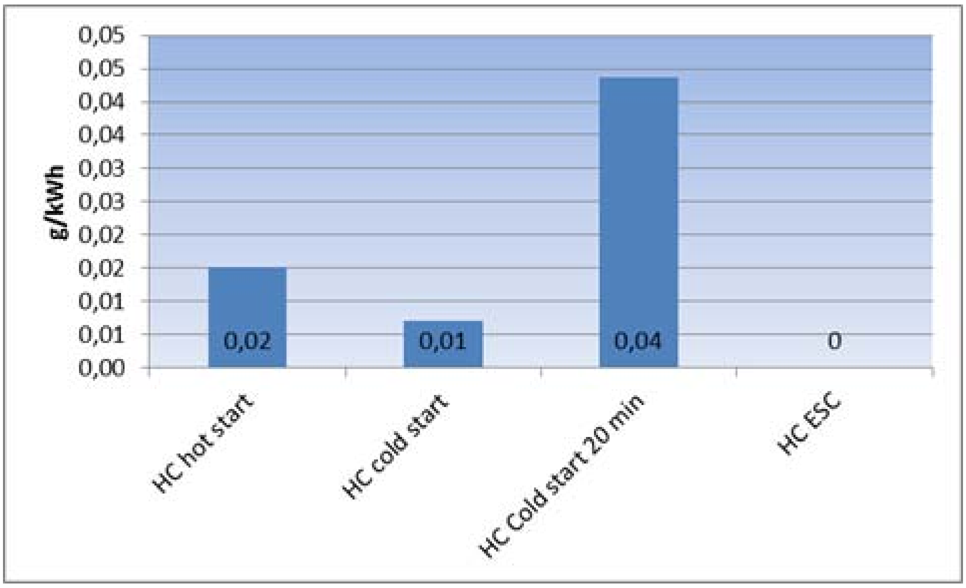


Figure 32. Brake specific HC emission.

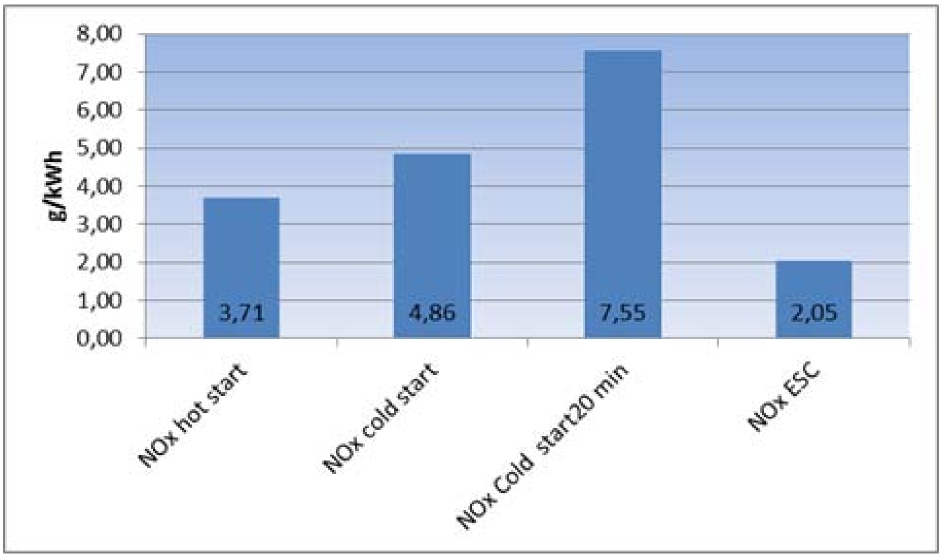


Figure 33. Brake specific NOx emission.

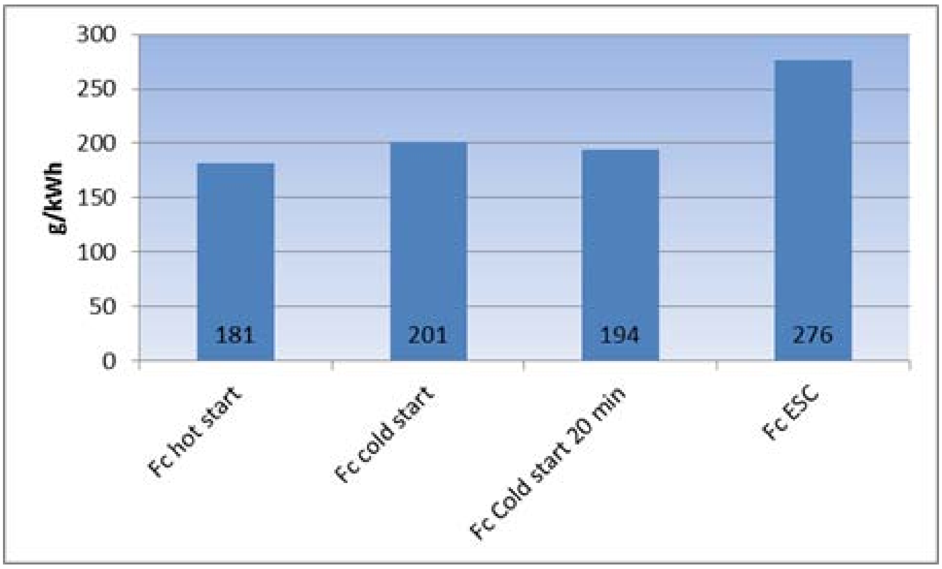


Figure 34. Brake specific fuel consumption.

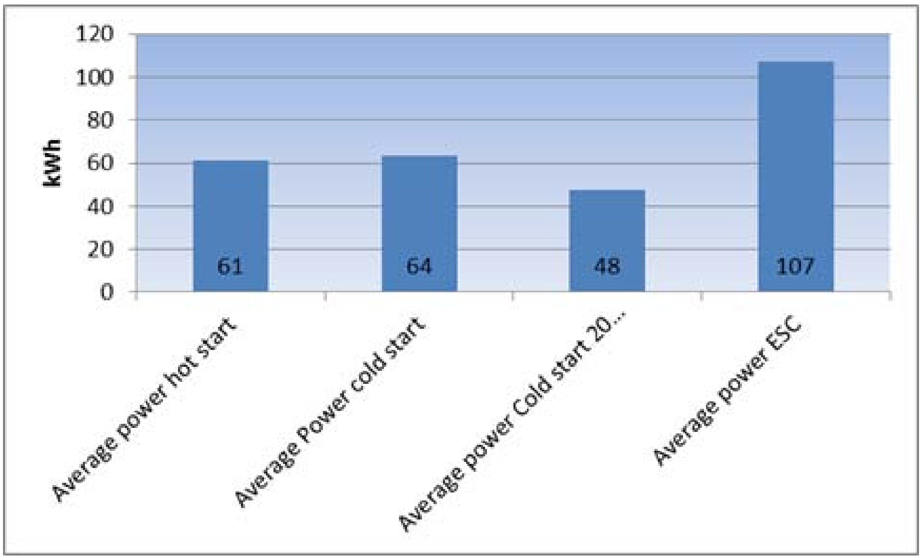


Figure 35. Average power.

Table 2 VI limit values, g/kWh.

CO	HC	NOx	PM
1.5	0.25	2,0	0.02

Comments

The overall impression of the vehicle emission performance is good and no mil light indicated exhaust after treatment failure.