JRC Scientific and Technical Reports

Parameterisation of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes

Authors:
G. Mellios, S. Hausberger, M. Keller, C. Samaras, L. Ntziachristos

JRC Editors:
P. Dilara, G. Fontaras

JRC
EUROPEAN COMMISSION

Institute for Energy and Transport

The mission of the Joint Research Centre – Institute for Energy and Transport (IET) is to provide support to Community policies and technology innovation related both:
- to energy, to ensure sustainable, safe, secure and efficient energy production, distribution and use and
- to transport, to foster sustainable and efficient mobility in Europe.

European Commission
Joint Research Centre
Institute for Energy and Transport

Contact information
Address: Via E. Fermi 2749, I-21027 Ispra, Italy
E-mail: Panagiota.dilara@jrc.ec.europa.eu
Tel.: +39 0332 789207
Fax: +39 0332 786328

http://iet.jrc.ec.europa.eu/

http://www.jrc.ec.europa.eu/

A great deal of additional information on the European Union is available on the Internet.

It can be accessed through the Europa server http://europa.eu/

JRC 66088

EUR 24927 EN

ISBN 978-92-79-21050-1

ISSN 1018-5593

doi: 10.2788/58009

Luxembourg: Publications Office of the European Union

Printed in Italy

TABLE OF CONTENTS

AUTHORS AFFILIATION:

Giorgos Mellios: giorgos.m@emisia.com , (EMISIA: www.emisia.com)

Stefan Hausberger: (Technical University of Graz)

Mario Keller: mario.keller@infras.ch, (INFRAS: http://www.infras.ch)

Christos Samaras (EMISIA: www.emisia.com)

Leonidas Ntziachristos (Aristotle University Thessaloniki,)

Executive Summary

Background and Objectives

CO_2 emissions of new passenger cars (PCs) registered in Europe are monitored in order to meet the objectives of Regulation EC 443/2009. This calls for an average CO_2 emission of 130 g/km for new PCs registered in Europe to be met by vehicle measures in 2015. This decreases to 95 g/km in 2020. Similar regulations are gradually promoted for other vehicle categories as well, more prominently for light commercial vehicles (LCVs).

CO_2 emissions of new vehicle types are determined during the vehicle type-approval by testing over the New European Driving Cycle (NEDC). Worries have been expressed that this driving cycle is not representative of real-world driving conditions. It is considered that fuel consumption, and hence CO_2 emissions (and air pollutant emissions), measured over this cycle under-represent reality. This report uses real-world information to compare in-use fuel consumption of PCs with type-approval CO_2.

The main objective was to develop functions that may enable prediction of in-use fuel consumption values, based on vehicle specifications. The functions can then be used in inventorying tools, such as COPERT and HBEFA, to correctly allocate fuel consumption to the different PC vehicle types.

In-Use fuel consumption

In-use fuel consumption data for PCs were collected from various sources, including particular studies ordered or conducted by national organisations (ADAC in Germany and BAFU/TCS in Switzerland), measurements conducted by automotive journals (the German Auto Motor und Sport and the Swiss Automobil Revue), technical information from the FP5 Artemis project and HBEFA databases, and information from actual vehicle drivers (spritmonitor.de). The vehicle dataset collected from these sources formulated the so-called sample "All".

There were significant differences in the definition of in-use fuel consumption between the various sources, including the measurement procedure used (road or chassis dynamometer), mix of driving situations tested, vehicle mix in the sample, etc. This leads to a significant variation of the average in-use consumption values reported by each source. However, all sources report higher in-use fuel consumption than the type approval values, mostly in the range from 10% to 15% for petrol cars and 12% to 20% for diesel cars. Individual higher differences are observed in particular for one of the journals included in the dataset. Preliminary analysis showed that the excess fuel consumption as a percentage of the type-approval one increases with year of vehicle manufacture.

In order to produce a more detailed view of in-use vs type-approval fuel consumption, a smaller number of 68 vehicles was filtered from these sources, where more detailed information was available. This smaller sample was distinguished into small cars, medium cars (limousine, estate), vans, and sport-utility vehicles (SUVs). Analysis of the in-use fuel consumption, the type-approval fuel consumption and chassis dynamometer measurements for these vehicles, led to the following observations:

1. The passenger car type/size seems to have an impact on the in-use over type-approval fuel consumption ratio (e.g. 25% excess in-use fuel consumption for small gasoline cars compared to 10% for SUVs). This may be due to vehicle technology or driving style differences. It would be advisable that future studies designed to monitor driving behaviour/conditions also take into account the vehicle type(s) considered.

2. The vehicle resistance settings which are used to simulate vehicle operation on the chassis dynamometer have a significant impact on fuel consumption. It is recommended that these settings are made publicly available during the type-approval procedure. Such a practice would improve the transparency of the test and might be used to explain the gap between in-use and type-approval fuel consumption.

3. In-use fuel consumption may be parameterised on the basis of 'macroscopic' vehicle specifications, such as mass, power, size, etc. or additionally including the vehicle type-approval CO_2 value. New vehicle technologies appear which offer advanced systems to improve efficiency, such as engine start-stop functions, regenerative braking, etc. Determining fuel consumption only on the basis of 'macroscopic' properties for such vehicle technologies will be difficult. Using the type-approval fuel consumption in the function may be advantageous in this case.

Information on in-use fuel consumption from LCVs is more scarce than for passenger cars. No monitoring mechanism has been established yet, no databases with real-world consumption information are known, and there are many variants of a model type available. For example, a common European LCV is offered in 140 variants by the manufacturer, while more variants built by local dealers/garages cannot be excluded. Obtaining a realistic picture for in-use fuel consumption by LCVs is therefore much more difficult than for PCs. In order to obtain an as much as possible representative picture of the LCV sector, detailed vehicle specifications and type-approval data were collected for 19 widespread individual models from 10 manufacturers. These vehicles cover all three weight classes of LCVs and (their various variables) correspond to 90% or more of LCV sales in major European countries. These vehicles will be used for simulations to derive their expected in-use fuel consumption.

Simulations

Six 'average' passenger cars were defined for the small, medium, and SUV categories, distinguished in diesel and petrol. These 'average' passenger cars were defined taking into account mean specifications (mass, power, resistance, gearbox, etc.) from the available 68 vehicles selected. Engine consumption maps for each category were obtained from previous studies and corresponded to Euro 5 technology. The vehicle specifications and the engine maps were fed into the model PHEM to simulate fuel consumption over real-world driving cycles. PHEM is a well-known model developed by TUG that simulates longitudinal driving dynamics and comes up with fuel consumption and pollutant emissions. The model results for the six vehicles were validated for the NEDC, the IATS and the CADC driving cycles, based on measured data over the same driving cycles. The model output and the measurements have a very good agreement (within 5%) for the CADC. The model generally overestimates NEDC emissions (up to 11%). As was identified before, resistances used during the NEDC are largely unknown. Further tuning of these parameters would further improve the match between simulated and type-approval NEDC consumption. However, this would have been of limited use as real-world is what needs to be simulated by the model.

As a second step, key vehicle specifications (mass, rated power, air resistance, rolling resistance, no of gears and transmission ratios) were varied to examine their effect on CO_2 emissions. The effect of these parameters on fuel consumption depends on vehicle size and driving situation. However, fuel consumption generally changes as follows for each 20% increase in each parameter: 5% for mass increase, 10% for rated power increase, 3% for aerodynamic resistance increase, 2% for rolling resistance increase. Finally, an increase in the final transmission ratio by 10% (higher rpm for same velocity) increases fuel consumption by ~2%.

Both 'average' and individual vehicles were simulated for LCVs. The first reason is that the uncertainty in defining an average LCV is large, due to the many variants of such vehicles in the market. Second, the number of LCVs collected was not as high as for passenger cars, therefore simulating every one of them was straightforward. Third, simulating individual vehicles could make possible to develop consumption factors for each of the three weight classes per fuel. In fact, the petrol N1-III class is not relevant in Europe, therefore three diesel weight classes and two gasoline weight classes were sufficient to cover the majority of light commercial vehicles.

The simulations led to similar conclusions to passenger cars. Mean CADC fuel consumption was higher than NEDC one by 18% for petrol LCVs (both N1-I and N1-II) and 15%, 7% and 5% for diesel N1-I, N1-II, and N1-III, respectively. The simulation results were validated with measurements on three LCV vehicles included in the Artemis/HBEFA database. The match between measured and simulated data was very good at urban and rural speeds (±10%). However, this increased at higher speeds. This is probably because the aerodynamic settings might not have been identical between the test and simulation; both drag coefficient and frontal area data are difficult to obtain for LCVs.

Several of the vehicle parameters were varied within certain ranges, in order to study their impact, similar to passenger cars. The parameters studied were the mass, rated power, frontal area, drag coefficient, transmission ratio, and rolling resistance. The effect of these parameters differed according to vehicle type and fuel used. For a 20% increase in each of these parameters, the corresponding increase in fuel consumption was of the order of 5% for mass increase, 5% for aerodynamic resistance increase, 10% for rated power increase, and 2-3% for rolling resistance increase, For a 10% increase of the final transmission ratio, fuel consumption increases by ~5% but this largely depends on the vehicle category.

Models

Simple empirical models were constructed to check how well measured in-use fuel consumption of PCs can be predicted on the basis of independent variables. The models were built on the basis of linear combinations of the variables mass, engine capacity, rated power, and power to mass ratio. In addition, type-approval fuel consumption was used as an independent variable and, in some cases, the manual and automatic transmission and the vehicle emission concept (Euro standard) were used as independent variables as well. The models were first applied to all measured in-use fuel consumption data that became available to the project.

From in total 12 models tested, with different linear combinations of some or all of these variables, the best correlation coefficients (R^2 ~0,9) were found for the models including mass, rated power (or engine capacity) and the type-approval CO_2 emissions. The mass, power and/or capacity are included in the CO_2 monitoring database until 2010 and are rather straightforward to locate from other sources. Inclusion of additional variables marginally improves the correlation but disproportionally increases the complexity and limits the applicability of the model.

An additional set of more detailed models was also developed on the basis of the limited sample of 68 vehicles and simulated "real-world" fuel consumption. One such model was developed for each of the individual vehicle classes considered (petrol and diesel cars, distinguished into small, medium, and SUVs). In addition to the parameters considered in the simplified empirical models, the new model set took into account the rolling and aerodynamic resistance parameters. Multi-variable regression analysis was then performed between linear combinations of the extended variable list with real-world fuel consumption of vehicles in this sample. Real-world fuel consumption in this case was defined as the average simulated fuel consumption over the HBEFA and IATS driving cycles, adding 5% fuel consumption to account for cold-start. This does not take into account the effect of travelling speed.

All detailed models reach very high correlation factors (R^2>0.96) of predicted with calculated fuel consumption. The set of models based on type-approval FC, only require vehicle mass in addition to predict real-world fuel consumption. Moreover, this set of models does not distinguish between vehicle types. This set of model is ideal to predict consumption of new car registrations because both vehicle mass and type-approval CO_2 are readily available from the CO_2 monitoring database. The model equations are (FC_{TA} stands for type-approval fuel consumption, *m* stands for the vehicle reference mass (empty weight + 75 kg for driver and 20 kg for fuel), and *CC* stands for the engine capacity in cm^3):

Diesel Euro 5 PCs: (E.1)

$$FC_{InUse,\,Gasoline}[l/100\,km] = 1.15 + 0.000392 \times CC + 0.00119 \times m + 0.643 \times FC_{TA}$$

Petrol Euro 5 PCs: (E.2)

$$FC_{InUse,\,Diesel}[l/100\,km] = 0.133 + 0.000253 \times CC + 0.00145 \times m + 0.654 \times FC_{TA}$$

For older vehicle technologies, for which no type approval CO_2 information is available, more technical information needs to be included (resistances and power) to predict real-world fuel consumption. For these technologies engine efficiency improvements are also proposed. A linear model to predict real-world fuel consumption of pre-Euro 5 vehicle technologies is therefore proposed, i.e.:

Diesel: (E.3)

$$FC = Fe_{Diesel,i} \times (-6.17 + 0.3 \times P_{rated}[kW] + 16.5 \times (c_d \times A) + 939.4 \times (r_0 + 18 \times r_1) + 0.0085 \times m\,[kg])$$

Petrol: (E.4)

$$FC = Fe_{Gasoline,i} \times (2.49 + 0.327 \times P_{rated}[kW] + 14.99 \times (c_d \times A) + 532.64 \times (r_0 + 18 \times r_1) + 0.01 \times m\,[kg])$$

Where P_{rated}: average engine rated power of the fleet [kW]

m: reference mass (empty weight + 75kg for driver and 20 kg for fuel)

$r_0+18\times r_1$: value for the rolling resistance coefficient at 18 m/s [-]

$c_d\times A$: aerodynamic resistance [m^2]

Engine efficiency improvements (Fe) can be obtained from the following table, for the different vehicle technologies (vintages):

	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
	Ratio of engine fuel efficiency compared to Euro 5, Fe [-]						
Gasoline	1.40	1.12	1.09	1.10	1.02	1.00	0.98
Diesel	1.49	1.42	1.33	1.18	1.02	1.00	0.95

This formulation has the advantage that it can predict in-use fuel consumption for older vehicles using new low-resistance tyres, as the rolling resistance factors are explicitly stated. On the other hand, the formulation requires many parameters which may be difficult to specify as averages for an entire fleet. In the case that such information is not available, simpler (however less accurate) formulations are given in section 4.2.

The third model category consists of models which can provide fuel consumption as a function of the speed. In this approach, fuel consumption is calculated using the brake-specific fuel consumption (be – g/kWh) and a measure that has the dimensions of acceleration (bea – m/s^2). This depends on both the driving cycle and the vehicle type. The final set of equations is (all independent variables defined in equations E.3 and E.4):

$$Fc\,[g/km] = Fe \times b_e \times 0.000278 \times [m \times (9.81 \times r_0 + 1.05 \times bea) + (v/3.6) \times m \times g \times r_1 + (v/3.6)^2 \times 0.6 \times c_d \times A] \quad (E.5)$$

with: Gasoline PC: $bea = 0.45 - 0.007 \times v + 0.000028 \times v^2$ (bea in [m/s²]; v in [km/h])

$b_e = 1339 \times v^{-0.305}$ (b_e in [g/kWh]; v in [km/h])

Diesel PC: $bea = 0.4 - 0.006 \times v + 0.000023 \times v^2$

$b_e = 1125 \times v^{-0.300}$

Gasoline LCV:

N1-I: $bea = 1.80 - 0.031 \times v + 0.00016 \times v^2$

$b_e = 1475.7 \times v^{-0.310}$

N1-II: $bea = 1.78 - 0.031 \times v + 0.00015 \times v^2$

$b_e = 460.1 \times v^{-0.140}$

Diesel LCV:

N1-I: $bea = 1.88 - 0.032 \times v + 0.00016 \times v^2$

$b_e = 481.7 \times v^{-0.202}$

N1-II: $bea = 1.73 - 0.030 \times v + 0.00015 \times v^2$

$b_e = 840.5 \times v^{-0.347}$

N1-III: $bea = 1.56 - 0.024 \times v + 0.00011 \times v^2$

$b_e = 804.2 \times v^{-0.309}$

Implementation to COPERT and HBEFA

The models developed in this report may be used to predict and/or correct fuel consumption values for passenger cars and LCVs included in HBEFA and COPERT. The exact considerations how this can be achieved are given in sections 5.2 and 5.3, respectively.

There are in principle two main ways of applying the models:

- Taking into account the type-approval CO_2: In this case the national stock vehicle specifications are compared to the specifications of the vehicles used to derive the fuel consumption factors. Application of the simplified model in this case [eqs E.1 and E.2], leads to a correction factor which adjusts the in-use fuel consumption predicted by COPERT or HBEFA to the national stock characteristics. This is straightforward and only depends on information available in the CO_2 monitoring database but misses the impact of speed (or driving situation) on the correction.

- Taking into account more detailed data: This case is useful when more detailed calculations need to be done and COPERT or HBEFA are used in situations of smaller fleets (e.g. the vehicle stock of a private company) where more technical data are known. In this case, vehicle specifications are directly used in eq. E.5 and fuel consumption as a function of speed is derived.

Various other ways of introducing these models, or other models described in sections 4.1 and 4.2, may be thought of depending on the application and data availability.

1 Introduction

1.1 Project ID

This report summarizes the outcome of the study "Parameterisation of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes", funded by the European Commission, Directorate-General Joint Research Centre. The study has been conducted by Emisia SA (in short: *Emisia*) in co-operation with the Graz University of Technology (in short: *TUG*) and INFRAS Ltd (in short: *INFRAS)*. The final report includes the input data, the parameterisation, the final results and inclusion of results in HBEFA and COPERT.

1.2 Background

The European Union has since long recognized the contribution of road transport to GreenHouse Gas (GHG) emissions. In particular, passenger cars are responsible for some 12% of EU's carbon emissions. In order to address this issue, the European Commission has been investing large efforts and resources in research, policy impact analysis and quantification of effects. A list of the relevant studies may be found at the Directorate-General Climate Action web-site (http://ec.europa.eu/clima/policies/vehicules/index_en.htm). The results of this effort are well known, starting with the Directive on car labelling for CO_2 (1999/94/EC), and the voluntary ACEA Commitment to reach 120 g/km in 2012 (Recommendation 1999/125/EC), to the recent regulation (EC) 443/2009 of April 2009 which stipulates a 130 g/km CO_2 average for new registrations by 2015 and a 95 g/km average in 2020. A legislative proposal for a draft regulation to reduce CO_2 emissions from light commercial vehicles has been adopted by the European Commission in October 2009, setting a maximum value of 175 g/km for 2016 and a long-term target of 135 g/km for 2020. These regulatory tools are expected to have a significant impact on the emissions of CO_2 by passenger cars and light commercial vehicles in the years to come.

A significant limitation of these regulations is that all targets are designed along a single driving condition, i.e. the New European Driving Cycle (NEDC). No consideration is given so far[1] to driving conditions not represented by this cycle. This is a significant limitation of the approach, as the NEDC driving cycle covers only a small portion of the vehicle engine operation in both load and speed. Just to give an indication, while a typical passenger car sold today can accelerate from idle to 100 km/h at a rate of 2.8 m/s^2, the NEDC imposes an acceleration of only 0.74 m/s^2. This is the reason that UNECE WP29 has set up a group to develop a new harmonized test protocol (WLTP) to test emissions and consumption. The effect of using the NEDC as the only driving cycle for emission and consumption assessment is evident by even not experts:many costumers recognize that the officially reported fuel consumption does not reflect the fuel consumption they experience.

The bias that NEDC introduced is even more important when seen by a policy implementation perspective. In the EU's targets towards the Kyoto commitments, it is the real-world rather than the NEDC fuel consumption that matters. Therefore, the question is, are the NEDC-based CO_2 targets equivalent to real-world reductions? For example, hybrids are known of reducing emissions in the city due to the intermittent engine operation and the high-efficiency of the electric motor in urban driving. However, hybrids are generally heavier than their conventional counterparts, because they are in need of additional components (motor, battery, power flux controller). So, it remains to be seen how much their higher efficiency counterbalances the higher weight in off-cycle operation.

[1] The situation is expected to differentiate with the adoption of the new world harmonized test protocol (WLTP) in the near future.

The inventory compiler is faced with similar questions. It is known that all national inventories should come up with calculated fuel consumption values that match the national statistics (except of cases where tank-tourism is well known and is taken into consideration). In developing the inventory, detailed fuel consumption factors are required, to correctly assess the fuel consumption of the vehicle stock. Therefore, real-world and not NEDC-based consumption factors needs to be used. These may significantly differ depending on the vehicle characteristics sold in each country.

Based on this background, two important questions have to be answered:

1. How do the real-world CO_2 emissions of new cars sold compare to the NEDC-based targets?

2. How can inventory compilers affect the fuel consumption of their stock, on the basis of the characteristics of the cars sold in each country?

The technical approach in this study responds to these two questions.

1.3 Objectives and analysis outline

The objectives of the study were the following:

1. Select databases of information on stock characteristics and fuel consumption of passenger cars and light commercial vehicles on which to base the analysis.

2. Develop the methodology, tools, and parameterisation of fuel consumption and CO_2 emissions for passenger cars and light commercial vehicles.

3. Validate the methodology, using actual measured data.

4. Make available the parameterisation results for use in emission inventorying tools.

The analysis of fuel consumption of passenger cars was performed in four levels, as follows:

1. Analysis of a large number of vehicles, driving cycles and driver performance, based on the ARTEMIS 300 database and real-world fuel consumption databases. These databases provided real-world fuel consumption values of large vehicle numbers but with limited other technical detail.

2. Analysis of selected makes and models of passenger cars from five different manufacturers. Detailed technical data of the vehicles were available in this case to assess the variability of engine and vehicle combinations and their impact on fuel consumption.

3. Simulation with the detailed consumption and emission model PHEM to calculate influences of specific vehicle and engine parameters such as the aerodynamic and rolling resistance coefficients, transmission ratios and number of gears.

4. Parameterisation of the fuel consumption using multiple regression on the PHEM output and calibration of the resulting functions against data from step 1.

The analysis of the light-commercial vehicle sector was performed in three stages, as follows:

1. Analysis of selected makes and models of vehicles from ten different manufacturers. Detailed technical data of the vehicles were made available from the manufacturers, and these were used to assess the variability of engine and vehicle configuration and their impact on fuel consumption.

2. Simulation with the AVL's CRUISE model to estimate the effect of various vehicle and engine parameters. As an initial task, CRUISE and PHEM models were compared against each other to make sure that they produce identical results when used on the same case.

3. Parameterisation of the fuel consumption using multiple regression on the CRUISE output and calibration of the resulting functions against data from the ARTEMIS 300 database.

2 Data sources and trends

2.1 Passenger Cars

The key question to address is how representative fuel consumption values measured at type approval are in respect to the fuel consumption on real-world conditions. The first step was to collect data on "real-world fuel consumption" or "in-use fuel consumption" (in short "FC InUse"). Several data sources were explored where this information is reported. It was clear from the start that the description of FC InUse is a crucial point. In addition, it soon became evident that the available datasets contain (at least publicly) only a limited set of vehicle specifications (like power, mass, capacity, etc.). Therefore more sophisticated technical information about the vehicles, such as aerodynamic resistances, had to be left out of the current analysis. At this stage, this was not considered as a drawback. The "official" datasets (like the CO_2 monitoring database) include only limited information (mass and engine capacity, and possibly rated power) in addition to the type-approval fuel consumption (in short "FC TA"). Therefore, in this section we only focus on these specifications to develop an understanding of fuel consumption as a function of vehicle attributes. The effect of more detailed vehicle specs on fuel consumption is dealt with in Chapter 4.

Therefore, in this chapter, Section 2.1.1 describes the data sources used in the analysis. Sections 2.1.2 to 2.1.7 then present the data and make first-order analysis, trying to identify dependencies between FC InUse and some vehicle specs such as mass, power, power-to-mass, capacity as well as FC TA.

2.1.1 Data sources

Data from the following data sources were collected and prepared for further analysis:

ADAC (D): Sample 1

Source: Internet (www1.adac.de): data of about 1000 vehicles are available

Available information per vehicle:

- FC InUse (= ECO-Test according ADAC2)
- Capacity
- Max power in kW
- Vehicle type (small, medium, large etc.)

Note: no information was available about FC TA in this sample. Only vehicle mass and construction year were available. Hence this data set can only be used to indicate what ADAC considers as representative fuel consumption, but no information could be provided about the ratio FC InUse / FC TA.

ADAC (D): Sample 2 (= Subset of Source 1)

Source: Internet (www1.adac.de), manually selected tests (97 vehicles)

---

[2] Definition of the ECO Test according to ADAC: 1. NEDC regular (35% weight), 2. NEDC without Coldstart but with AC (35%), 3. Special ADAC BAB (Bundesautobahn)-test (30%)

Additional available information per vehicle (compared to sample 1):

- Vehicle mass
- FC TA according to manufacturer (this information was only partially available)

TCS (CH):

Source: data made available and financed by BAFU (CH): 276 cars, from 1998-2010;

Available information per vehicle:

- FC InUse (=average FC of several TCS experts), average driving behaviour, about 3000 km/car, including city driving, rural roads and motorways, but not exactly reproducible)
- FC TA according to manufacturer, in addition: FC TA measured by TCS (lab measurement)
- Capacity
- Max Power
- Mass (according to manufacturer as well as measured by TCS)
- Year of manufacturing

AMS – Journal Auto Motor Sport (DE):

Source: internet www.auto-motor-und-sport.de; manually selected tests, 34 vehicles

Available information per vehicle:

- FC InUse (=average FC of some 3000 km/car, not exactly reproducible)
- FC TA according to manufacturer (reported by Journal)
- Capacity
- Power
- Mass

AR – Journal Automobil Revue (CH):

Source: directly received from the Journal, 272 vehicles

Available information per vehicle:

- FC InUse (average FC of several journalists, average driving behaviour, about 3000 km/car, including city driving, rural roads and motorways, but not exactly reproducible)
- FC TA according to manufacturer (reported by Journal)
- Capacity
- Power
- Mass

A300DB (EU):

Source: FP5 ARTEMIS Project WP300. This database contains the fuel consumption and air pollutant emissions measured by many European laboratories over the last ~20 years. The database was established during the FP5 ARTEMIS Project and has continuously been updated in the context of the establishment of HBEFA Version 3.1 (2010). All data are measured on test bench; hence they can be assigned to driving cycles. Most vehicles were tested over the NEDC, but many vehicles have also been tested over the so called CADC (Common Artemis Driving Cycles) which are considered as a mix of "real world driving" conditions. For this analysis the data of 217 vehicles were available.

Available information per vehicle:

- FC InUse: as a proxy for real world driving a weighted average of CADC was used (33% urban, 33% rural and 33% Motorway (The motorway cycle has two versions in the A300DB, either with a max speed at 150 km/h or a max speed of 130 km/h, depending on the vehicle power. In case that a vehicle was measured in both cycles, only the 150 km/h version is included here).
- FC TA measured by the labs
- Capacity
- Power
- Mass

SMon ("Sprit-Monitoring"):

Source: www.spritmonitor.de. In this database many vehicle owners (mostly from Germany) report their kilometres driven and the fuel consumed over a longer period. The data set used for the analysis represents the data of 3939 drivers, distributed among 61 vehicle models and makes. The data were collected and provided by TU Graz, in particular, the FC TA was added to the FC InUse.

Available information per vehicle:

- FC InUse: as reported by the drivers.
- FC TA: added by TU Graz based on type approval information
- Capacity
- Power
- Mass

The first data set (ADAC sample 1) did not allow comparisons between "FC TA" and "FC InUse" since no information about FC TA was available in the dataset. Nevertheless, this sample shows interesting average values of key attributes like power, mass and capacity for different passenger "car classes" often used (see Annex 1). All other data sources allowed this comparison. However, as it will be shown, the definition of "FC InUse" varies from source to source, hence the comparability is limited. Nevertheless, the analyses give first indications that the FC TA deviates from FC InUse to a significant extent.

CO_2 Monitoring Database:

The CO_2 emissions from new passenger cars are monitored as part of the strategy to reduce CO_2 emissions from cars. Following Article 9 of Decision 1753/2000/EC the Commission is required to submit to the European

Parliament and Council reports for each calendar year on the effectiveness of the strategy based on the monitoring data submitted by Member States. The data are published annually[3]. Figure 2-1 shows data availability per country and reporting year. The same database also includes some other interesting vehicle specification data, i.e. vehicle mass, rated power[4], and capacity. It also includes vehicle footprint, i.e the vehicle wheelbase times track. Footprint is a proxy for vehicle size – however it is not (at least) directly associated with power consumption, hence it has not been considered in the subsequent analysis. Figure 2-2 shows the evolution of the EU-wide average values of these vehicle specifications. Some values (e.g. mass before 2005) appear questionable, presumably because of errors or inconsistencies in the data reported by some member-states. The average values per country are listed in Annex 2.

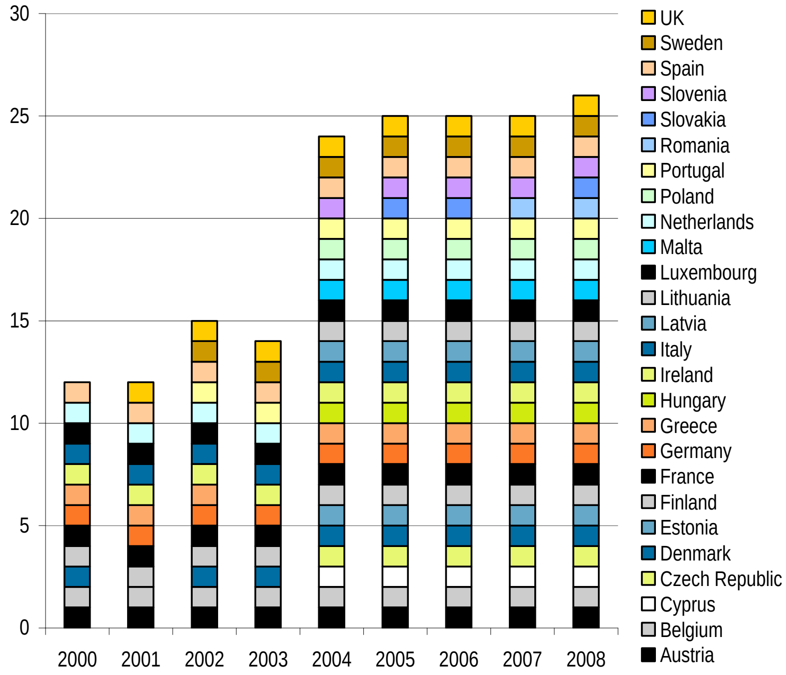


Figure 2-1: Availability of new registration data in the CO_2 monitoring database. The figure shows which country data are available in the different years (for details see Annex 2).

[3] http://ec.europa.eu/environment/air/transport/co2/co2_monitoring.htm

[4] As from 2010, the monitoring database will not include power as a vehicle parameter.

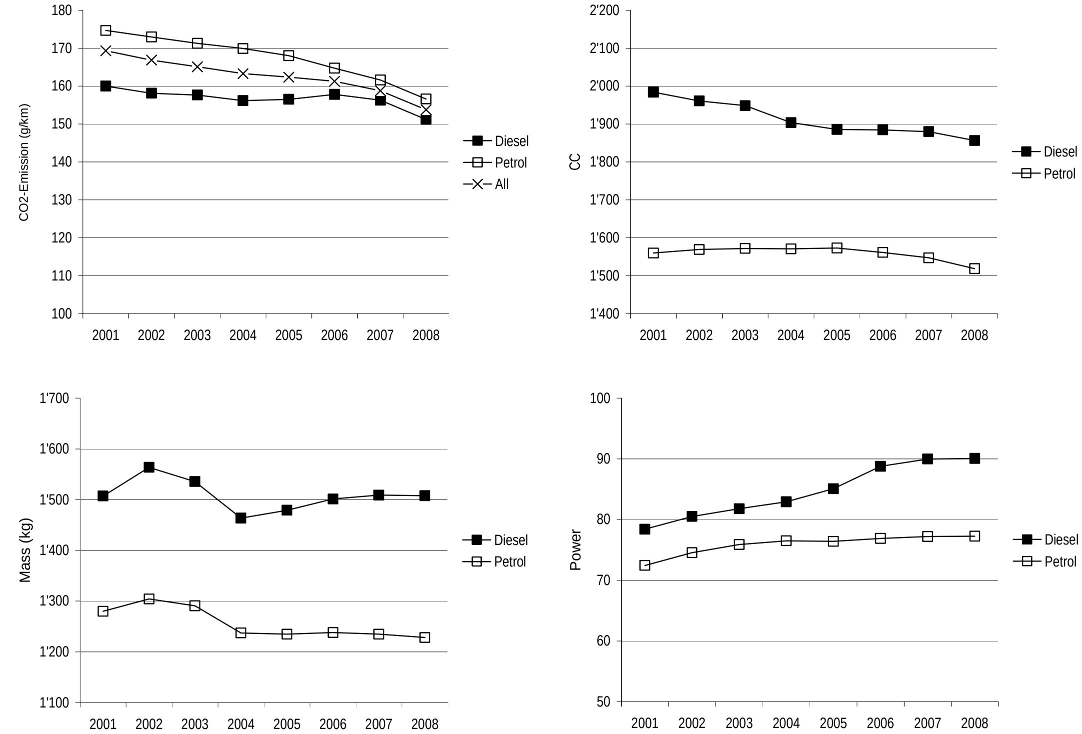


Figure 2-2: Characteristics of the EU-wide "average" new car according to the CO_2 monitoring database, weighted by vehicles (for details see Annex 2).

2.1.2 In-Use over Type-Approval fuel consumption

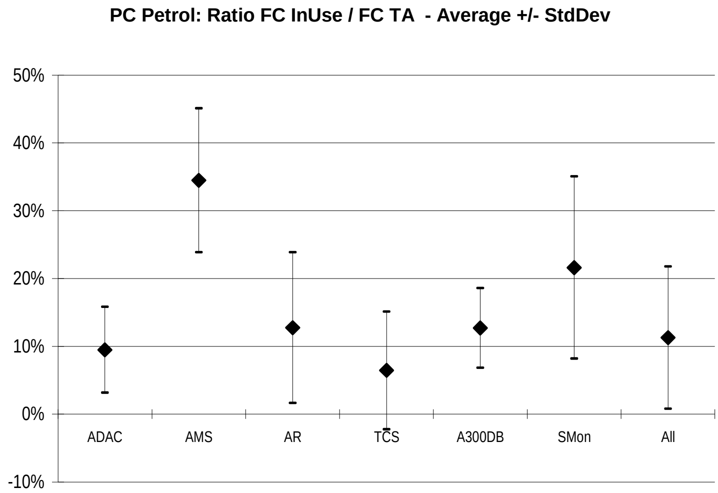
This section through section 2.1.5 analyze the data collected from vehicles in all sources presented in section 2.1.1 (sample "All" - Table 2-1). The table gives the ratio of FC InUse over FC TA and average values for vehicle specifications in the different samples (mass, power, capacity). The same specifications for the EU-wide average new passenger car (Year 2008) are also given, as derived from the CO_2 monitoring database.

Table 2-1: Ratio of "FC InUse-FC TA" over "FC TA" based on different sources[5] (Excess fuel consumption, standard deviation and sample size, separated by petrol and diesel cars). In addition, some key average sample specifications are reported.

	FuelType	ADAC	AMS	AR	TCS	A300DB	SMon	All	EU avrg
Average	D	9.8%	41.1%	18.5%	13.1%	11.8%	18.3%	16.0%	
	P	9.5%	34.5%	12.8%	6.5%	12.7%	21.6%	11.3%	
StDev	D	8.6%	11.0%	10.9%	8.9%	7.6%	8.1%	11.7%	
	P	6.3%	10.6%	11.1%	8.7%	5.9%	13.4%	10.5%	
Nr of Veh.	D	54	19	91	40	77	32	313	
	P	43	15	173	211	140	29	611	
	D+P	97	34	264	251	217	61	924	
FC TA (L/100km)	D	5.4	4.6	6.2	6.4	6.5	5.8	6.1	5.8
	P	6.9	6.5	9.0	8.1	7.8	6.9	8.1	6.7
Mass (incl 75 kg)	D	1'524	1'492	1'683	1'731	1'628	1'558	1'624	1'508
	P	1'326	1'378	1'591	1'472	1'362	1'429	1'466	1'228
Power (kW)	D	92	98	113	114	99	105	104	90
	P	86	103	175	103	85	101	118	77
Capacity	D	1'840	1'835	2'051	2'111	2'083	1'932	2'005	1'856
	P	1'510	1'690	2'579	1'928	1'690	1'703	2'012	1'518

5 The number of vehicles in the Source SMon (SpritMonitoring") refers to 61 vehicle types with a total of 3939 drivers.

The data indicate that FC InUse is higher than FC TA mostly by 10 to 15% for petrol cars and by roughly 12 to 20% for diesel cars. However, the individual differences per source are remarkably high. This is also illustrated in the following figures. In most of the samples, the ratio of diesel cars is higher than the one of petrol cars although there are also samples where the two figures are more or less equal. Compared to the European average, the samples tend to have slightly higher values, i.e. the samples contain heavier and more powerful cars than the average European fleet. This is likely due to the fact that the samples are taken from German or Swiss sources where the fleet in general consists of cars with higher average mass, power and capacity (see Annex 2).



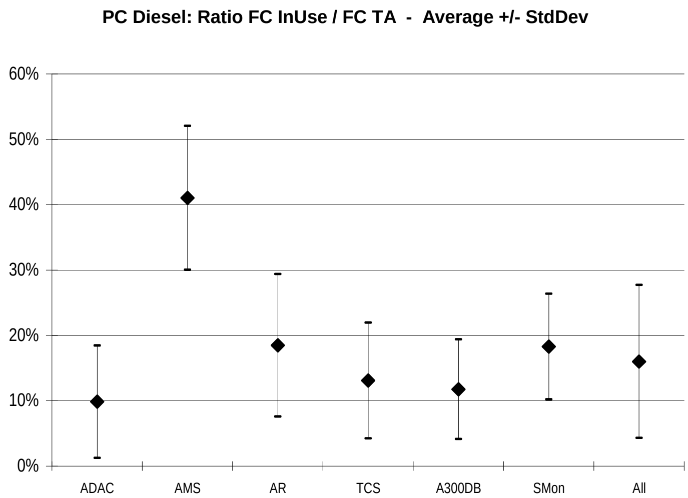


Figure 2-3: Excess fuel consumption of "FC InUse" compared to "FC TA" based on data from different sources.

2.1.3 In-Use fuel consumption and vehicle characteristics

Figure 2-4 and Figure 2-7 illustrate the FC InUse (in l/100km) as a function of different vehicle specifications, i.e. mass, power, power-to-mass and capacity, separately for petrol and diesel cars. The figures distinguish also by data source because the definition of FC InUse varies significantly between the different data sources. The figures document the generally expected fact that FC increases with increasing mass, power and engine capacity. It is interesting though that there is a huge spread of the FC InUse between vehicles with the same specifications (be it mass, power, capacity of power-to-mass). One reason may be due to the fact that FC InUse is defined differently between the samples or reported based on different circumstances. However, the differences of the gradients are limited even if the consumption level varies.

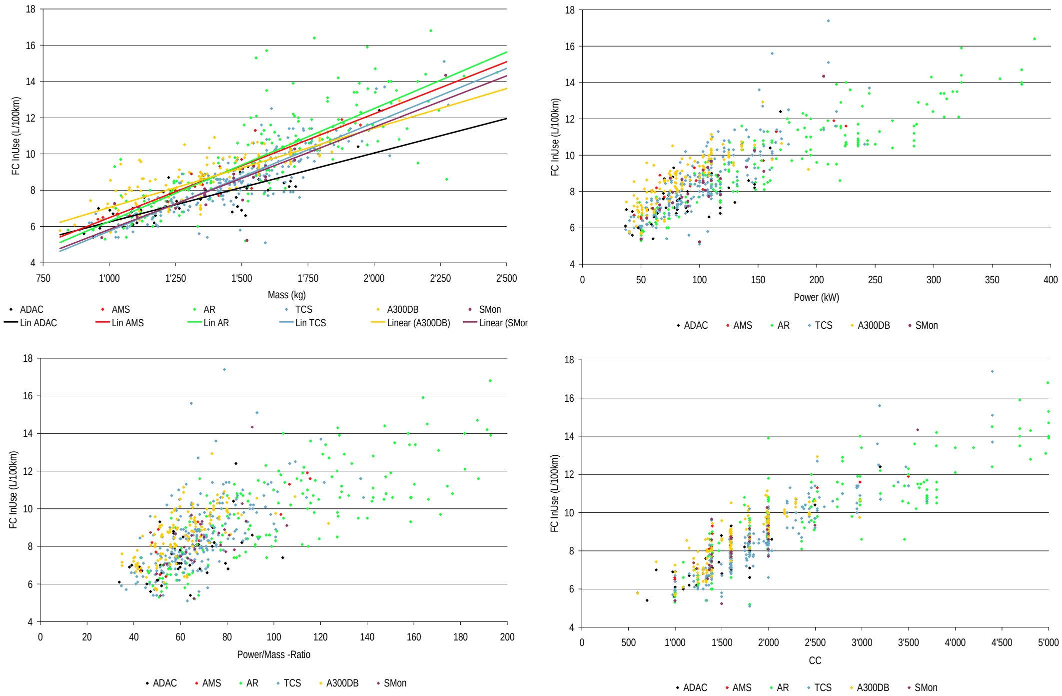


Figure 2-4: Petrol cars: Illustration of "FC InUse" as a function of different vehicle attributes (mass, power, power-to-mass, capacity). The strongest correlation is with mass[6] hence the lines are shown as a guide-to-the-eye only for this attribute. A detailed statistical analysis of the trends is described in section 4.1.

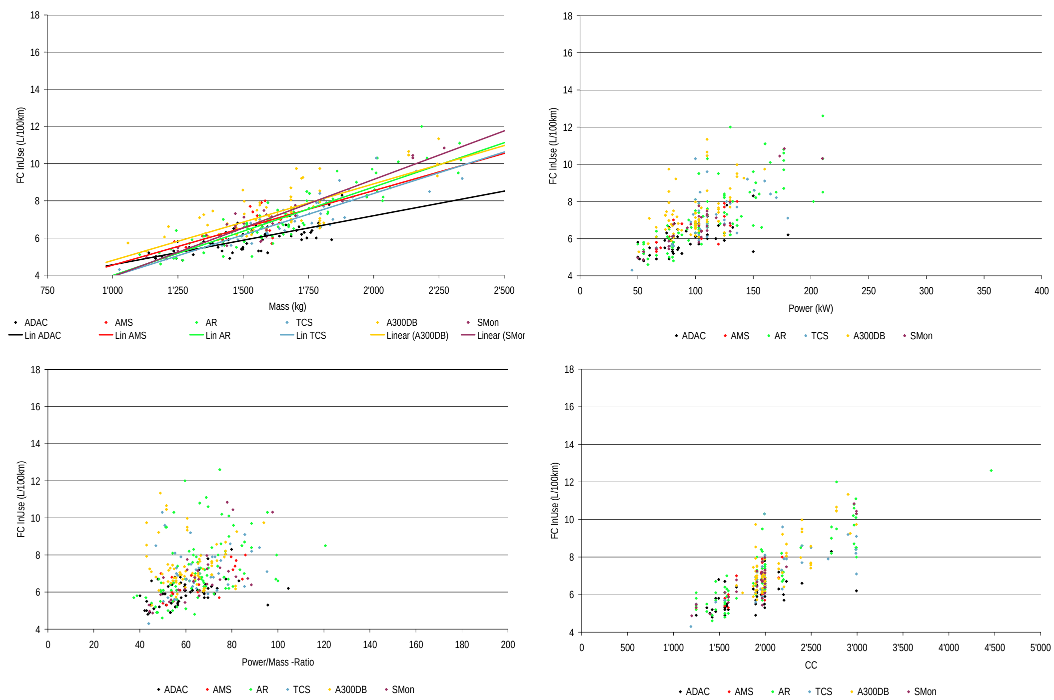


Figure 2-5: Diesel cars: Illustration of "FC InUse" as a function of different vehicle attributes (mass, power, power-to-mass, capacity). Similar to petrol cars, the strongest correlation is with mass[7] hence the lines are shown as a guide-to-the-eye only for this attribute. A detailed statistical analysis of the trends is described in section 4.1.

6 R2 (mass) = 0.71, R^2 (power) = 0.43, R^2 (power/mass) = 0.10, R^2 (CC) = 0.63
7 R2 (mass) = 0.77, R^2 (power) = 0.54, R^2 (power/mass) = 0.17, R^2 (CC) = 0.63

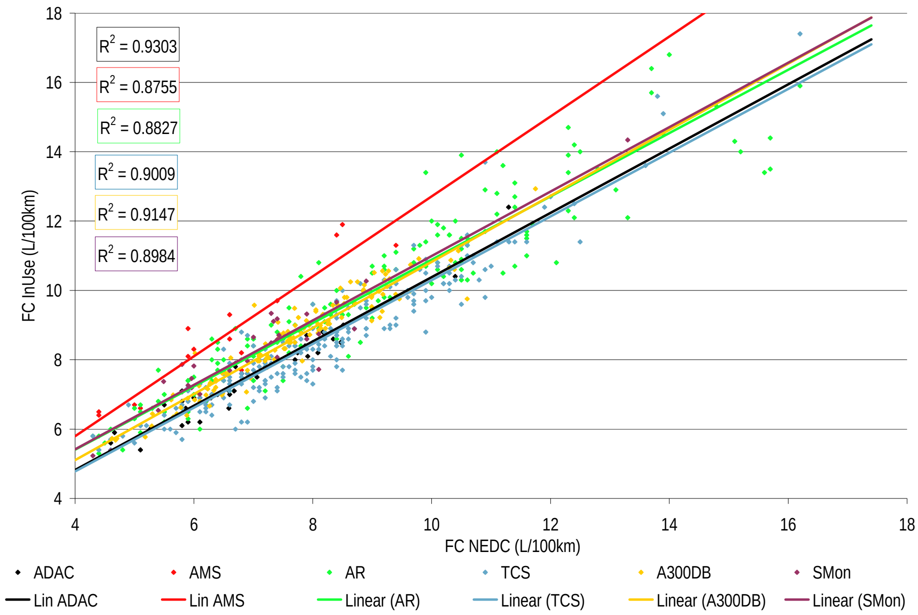


Figure 2-6: Petrol cars – Illustration of "FC InUse" plotted over "FC TA". A more in-depth statistical analysis follows in section 4.1.

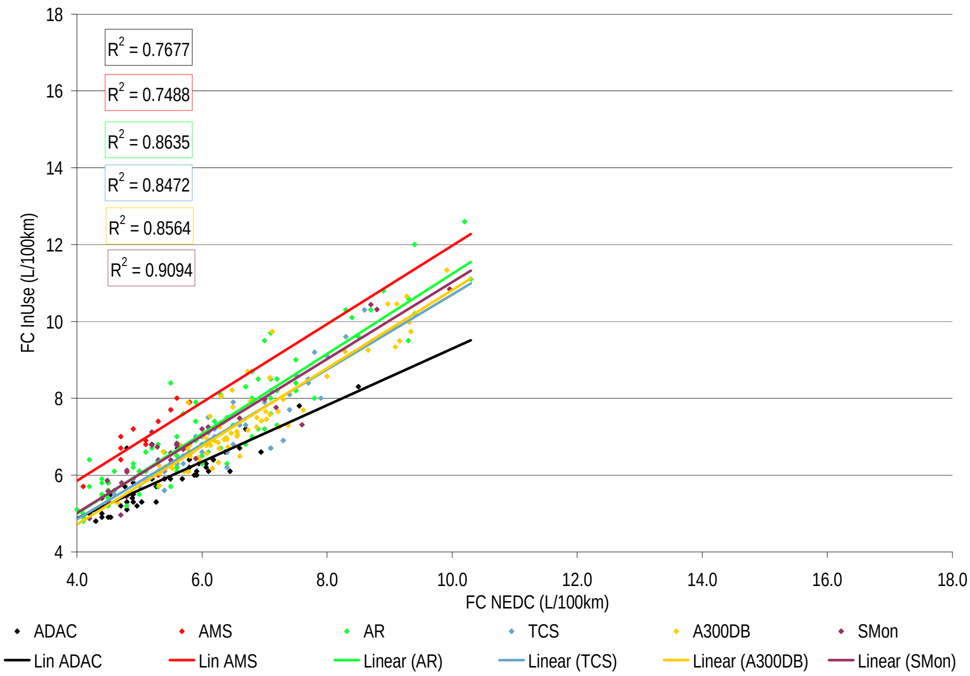


Figure 2-7: Diesel cars – Illustration of "FC InUse" plotted over "FC TA". A more in-depth statistical analysis follows in section 4.1.

2.1.4 Excess In-Use fuel consumption over Type-Approval

Based on the data presented in the section 2.1.3, the following figures show the ratio of "FC InUse" minus "FC TA" over "FC TA" (i.e. the excess fuel consumption of in-use driving compared to type-approval, again first as a function of mass, power, power-to-mass and capacity, and then as a function of "FC TA". The spread between vehicles as well as between the samples is even more pronounced in these figures.

2.1.5 General remarks

The figures indicate general trends but also considerable differences between the various data sources. In general, the smaller the vehicles the higher the relative underestimation of the real world fuel consumption by the FC TA. In absolute terms though the difference increases with the size of the car.

In particular the AMS source indicates substantially higher FC InUse (between +35% and +40%) compared to other sources. These differences are hard to explain by attributes like mass or power. Hence one might assume that AMS is defining "real world fuel consumption" in a different way. This may be because of larger shares of high-consuming traffic situations, such as high speeds in German motorways, or stop and go driving, or particular sportive driving styles to measure the performance of the car.

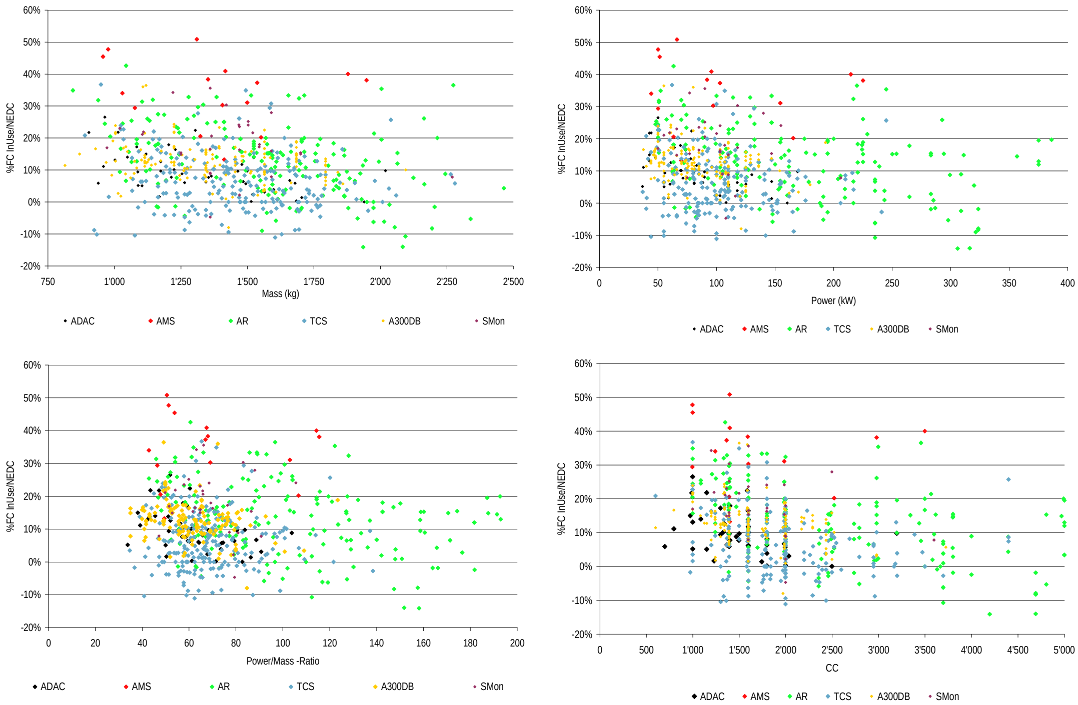


Figure 2-8: Illustration of the excess fuel consumption of the "FC in use" compared to "FC TA" of petrol cars as a function of different parameters (mass, power, power-to-mass, capacity). A more in-depth statistical analysis follows in section 4.1.

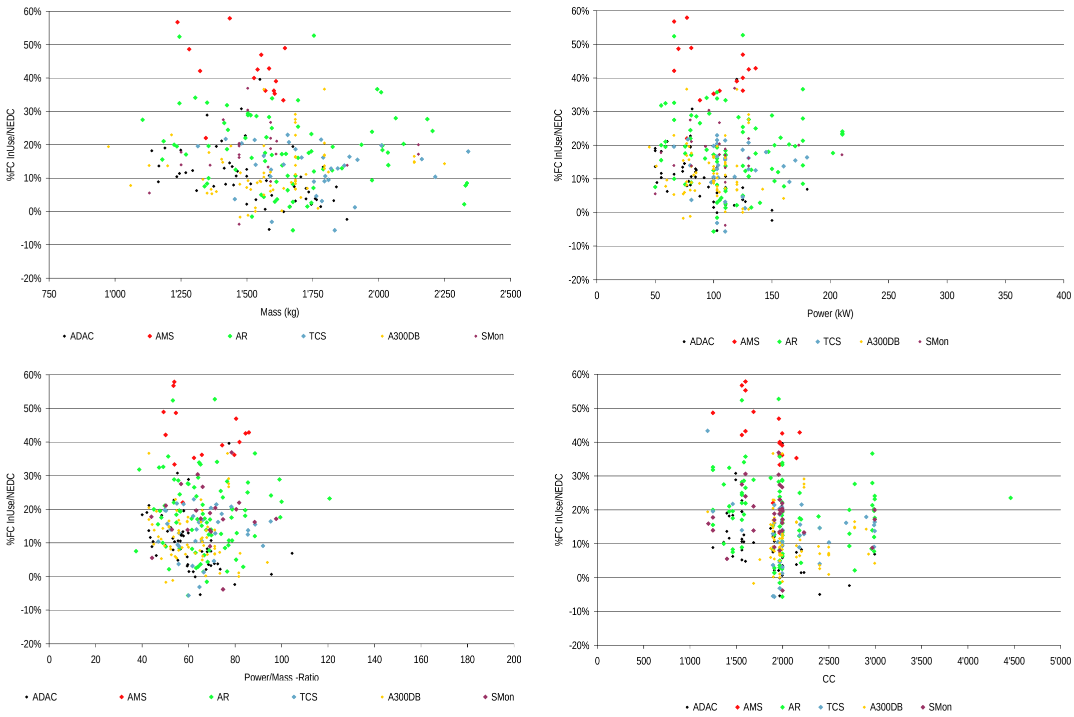


Figure 2-9: Illustration of the excess fuel consumption of the "FC in use" compared to "FC TA" of diesel cars as a function of different parameters (mass, power, power-to-mass, capacity).

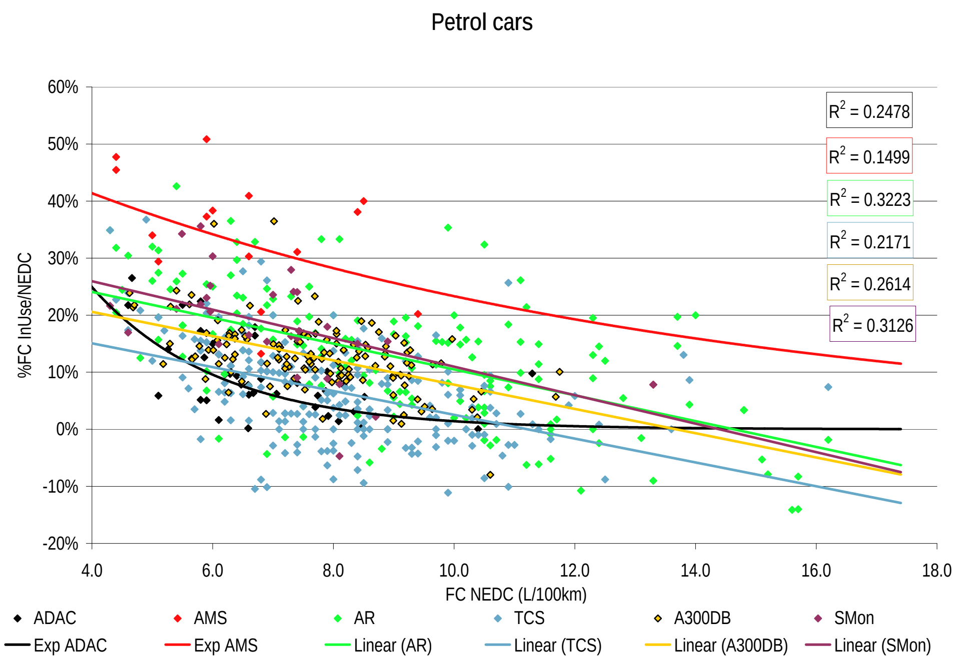


Figure 2-10: Petrol cars – Illustration of the excess fuel consumption of the "FC in use" compared to "TA FC" as a function of "TA FC". A statistical analysis follows in section 4.1.

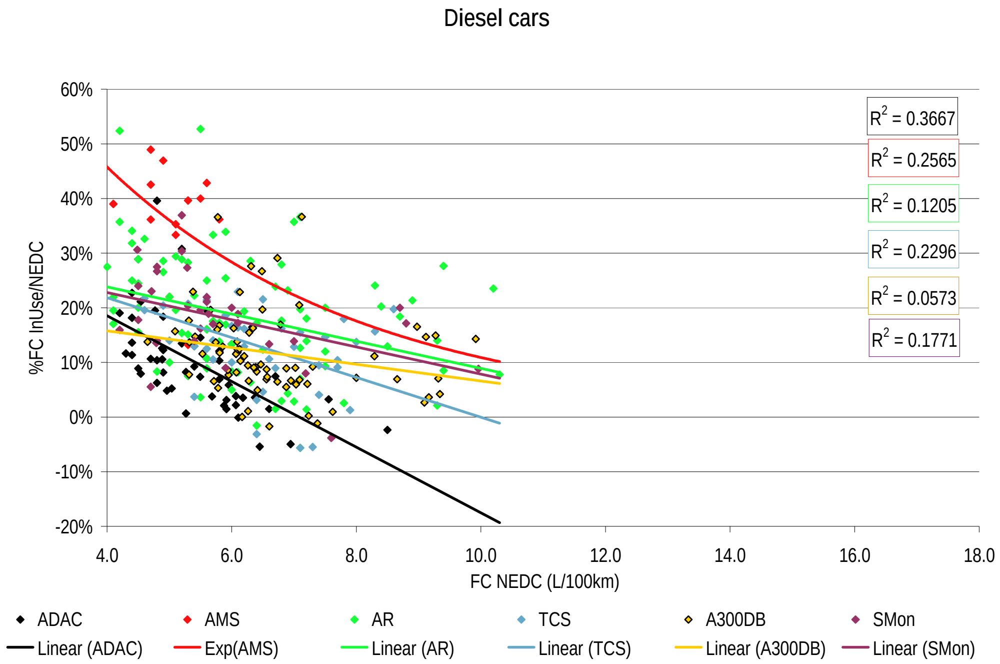


Figure 2-11: Diesel cars – Illustration of the excess fuel consumption of the "FC in use" compared to "TA FC" as a function of "TA FC". A statistical analysis follows in section 4.1.

A crucial difference lies in the fact that the FC InUse is defined differently in the samples: While AMS, AR, TCS and SMon report FC values based on "real world driving" (though hardly reproducible), the data of ADAC and A300DB rely on values measured on test benches. In general, the driving resistances used in tests rely on manufacturers' data, which do not necessarily reflect real world driving resistances. These may be higher due to imperfect road surfaces, wet weather conditions, suboptimal tyre pressures, suboptimal air resistances due to roof racks, etc. As will be shown in section 2.1.7 this influence can be very important. Therefore, for further analysis, a sub sample (sample A) had to be created where the data of these two sources will be excluded.

Uncertainties are not only induced by the definition of the FC InUse. Also the FC TA assigned to different vehicle types has some uncertainty. Only one source (TCS 2008) included both fuel consumption reported for vehicle type-approval and measured over the NEDC, by an independent measurement (Figure 2-12). The correspondence between the measured and the reported consumption values is good on average in this case (R^2 values of 0.91 for diesel and 0.96 for petrol cars). However, the ratio may be distorted in individual vehicles contributing to additional uncertainty.

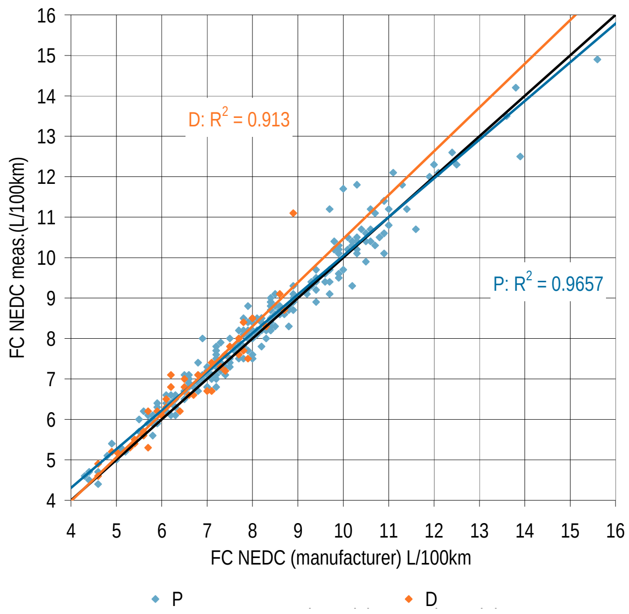
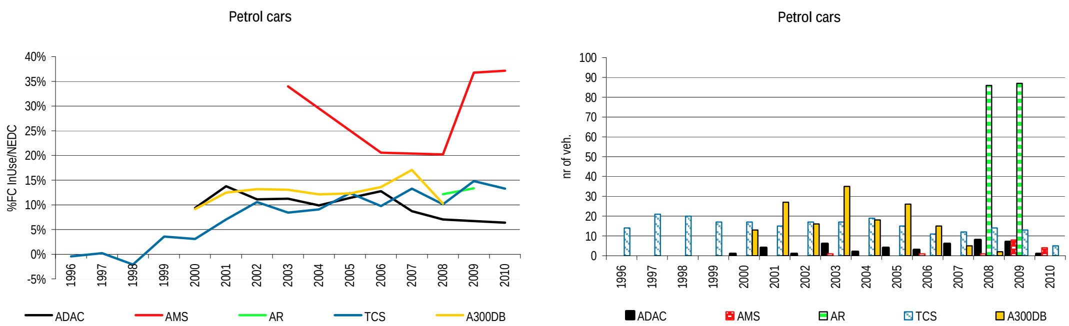


Figure 2-12: FC measured over the NEDC compared to "TA FC" reported by manufacturers (source: TCS Data- see section 2.1.1).

With regard to the actual levels reported, the samples of "AR" (Automobil Revue), "spritmonitor.de" and "A300DB" provide comparable values (see in particular Figure 2-10 and Figure 2-11) while ADAC is lower. TCS also tends to be comparatively low. However, the low values of TCS can be explained by the manufacture year of the vehicles: As Figure 2-13 illustrates, the ratio tends to increase over time (see particularly the TCS curve of petrol cars in Figure 2-13): the older cars, i.e. <2002 have much smaller ratios of FC InUse over FC TA. One hypothesis may be that the TA FC information got more and more important in the last years (due to climate change discussions and the policy regulations aiming to reduce it). Hence it is likely that the TA FC has been optimized without necessarily having the same effect in real world. This trend is not equally obvious for diesel cars. However one should take into consideration that the number of vehicles is considerably lower in this case, and does not allow for definitive conclusions.

Because the difference in FC TA and InUse TA seems to be affected by year of manufacturing, the TCS data before the year 2005 will be ignored in the "sample A". This also would imply that a correction function should include a temporal component. However, only the TCS data allowed such an analysis. Hence this temporal component has to be neglected in this study.



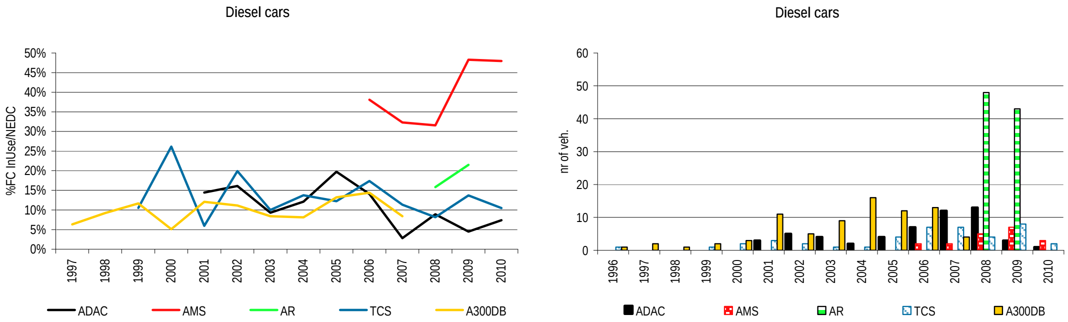


Figure 2-13: "FC InUse" compared to "FC TA" as a function of year of manufacture and sample size.

The AR sample is a particular one, due to the fact that the power of the vehicles tested is on average very high (i.e. a considerable number of high-power cars like Porsche, Lamborghini etc. are included in the sample). Hence, sample A will be constructed by limiting the power of vehicles to 230 kW in order not to bias the representativity of the sample with high-power vehicles.

2.1.6 Analysis on a filtered dataset: Sample "A"

In order to provide a more consistent and hence more representative sample, based on the total available information in section 2.1.1, sample "A" was created. This only included vehicles from AMS, AR, SMon, for which fuel consumption was measured during on-road driving and non on the dynamometer. Second, this was limited to vehicles with max power of 230 kW, not to bias the sample with a non-representative number of high power vehicles. Third, TCS data with year of manufacture later than 2005 were only included.

Table 2-2 shows the key parameters of sample "A". Compared to sample "All", sample "A" leads to closer FC values to the EU-wide average. In fact, sample "A" average consumption is close to the average FC TA of new diesel cars in Europe (6.0 l/100 km compared to 5.8 l/100 km), while it includes somewhat larger/more powerful petrol cars (7.5 l/100 km compared to 6.7 l/100 km). However, both values are closer to TA than sample "All" is which is good evidence that this is a better representation of the average new passenger car fleet in Europe.

Sample "A" vehicles demonstrate a 20% difference between FC InUse and FC TA for diesel cars and 14.6% for petrol cars. Figure 2-14 and Figure 2-15 show the excess FC InUse as a function of FC TA for petrol and diesel cars, respectively. The graphs generally replicate the trends of sample "All".

Table 2-2: Ratio of excess in-use over type-approval fuel consumption based on data from different sources. The full sample ("all") as well as sample "A" is shown. Also, key parameters of the different samples are given.

	FuelType	ADAC	AMS	AR	TCS	A300DB	SMon	All	EU avrg	Sample A
Average	D	9.8%	41.1%	18.5%	13.1%	11.8%	18.3%	16.0%		20.0%
	P	9.5%	34.5%	12.8%	6.5%	12.7%	21.6%	11.3%		14.6%
StDev	D	8.6%	11.0%	10.9%	8.9%	7.6%	8.1%	11.7%		12.5%
	P	6.3%	10.6%	11.1%	8.7%	5.9%	13.4%	10.5%		12.0%
Nr of Veh.	D	54	19	91	40	77	32	313		172
	P	43	15	173	211	140	29	611		283
	D+P	97	34	264	251	217	61	924		455
FC TA (L/100km)	D	5.4	4.6	6.2	6.4	6.5	5.8	6.1	5.8	6.0
	P	6.9	6.5	9.0	8.1	7.8	6.9	8.1	6.7	7.5
Mass (incl 75 kg)	D	1'524	1'492	1'683	1'731	1'628	1'558	1'624	1'508	1'651
	P	1'326	1'378	1'591	1'472	1'362	1'429	1'466	1'228	1'460
Power (kW)	D	92	98	113	114	99	105	104	90	111
	P	86	103	175	103	85	101	118	77	119
Capacity	D	1'840	1'835	2'051	2'111	2'083	1'932	2'005	1'856	2'015
	P	1'510	1'690	2'579	1'928	1'690	1'703	2'012	1'518	1'886

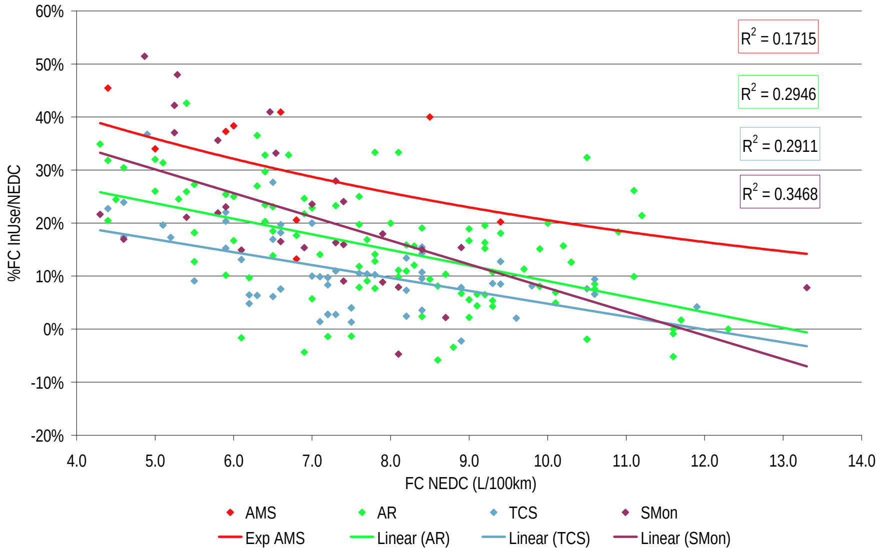


Figure 2-14: Petrol cars in sample "A"– Ratio of excess in-use fuel consumption over type-approval as a function of "TA FC". A statistical analysis follows in section 4.1.

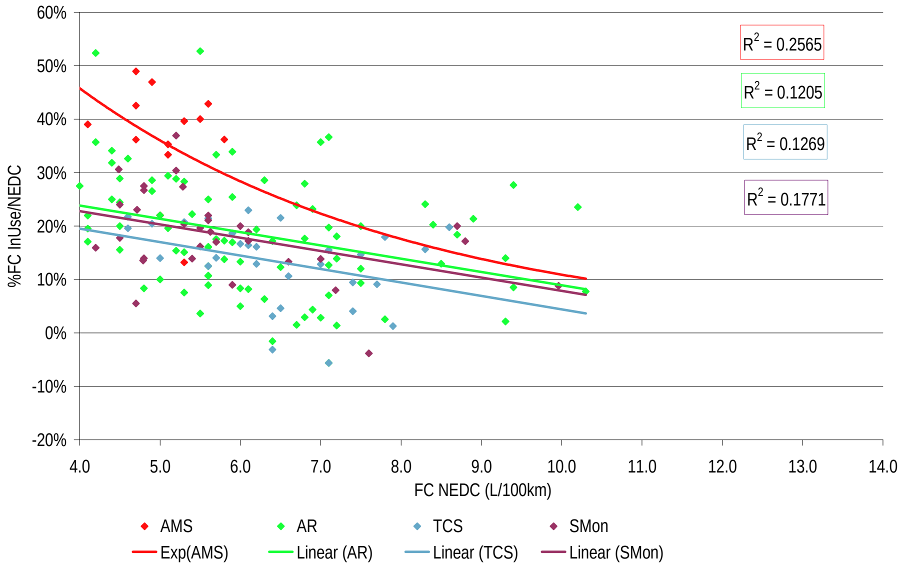


Figure 2-15: Diesel cars in sample "A"– Ratio of excess in-use fuel consumption over type-approval as a function of "TA FC". A statistical analysis follows in section 4.1.

2.1.7 Sample used for parameterisations: Sample "B"

Both samples "All" and "A" were useful to understand FC InUse effects for a large vehicle sample. However, not all of these vehicles could be used for more detailed analysis and parameterisations of the models to be used for the simulation. The reason was that several detailed data were missing for these vehicles. In addition, an independent variation of parameters like vehicle mass, engine power, cylinder capacity and frontal area would not have been possible because typically strong autocorrelations exist between these parameters (high vehicle mass is typically correlated to higher engine power and cylinder capacity and to larger car bodies).

Therefore, an even smaller sample of 68 vehicles (sample "B") from five manufacturers was built (details in Annex 3). The vehicles were classified to different categories, from small car to SUV. This dataset was used to parameterise a vehicle longitudinal–motion and emission model (PHEM) to simulate the effect on FC from variations in vehicle specifications, within each single vehicle category. Different model versions (e.g. different engine capacity and engine power as well as special fuel efficient versions) were included for each vehicle type.

Together with the basic specifications, such as engine rated power, swept volume, vehicle weight and official fuel consumption from the type approval, the following data were also collected for most of these sample vehicles:

- Driving resistance values (from real world coast down tests and from type approval).
- Fuel consumption in the CADC.
- Fuel consumption from in use tests.
- Transmission ratios.

These additional data were not available for some of the selected vehicles. Additionally, it was not always clear if the FC TA was measured applying real-world driving resistances or using the type-approval values. Furthermore the model names were not always unambiguous in the data sets. Thus some values may have not been attributed correctly. However, in total, the data collected should give a reasonable picture of the actual passenger car technology (Euro 5). The basic vehicle classification with the average vehicle data is shown in Table 2-3.

Table 2-3: Average values of parameters found from the vehicle classification applied in the detailed vehicle database.

Type	Type-code	Mass (kg)	Power (kw)	Capacity (cm^3)	TA FC (l/100km) **
Small car	1	1213	70	1386	5.0
Limousine*	2	1423	98	1768	5.9
Estate*	3	1513	103	1880	6.1
Van*	4	1575	97	1706	6.8
SUV	5	1887	148	2412	8.8

* The categories Limousine and Estate were merged together as "medium cars" in the later simulation runs since they demonstrate very similar characteristics. For vans the database with detailed technological data was rather small and the available data indicated that the fuel consumption values from Vans show a similar dependency on the vehicle mass, engine power and drive train characteristics as medium cars. Thus this category was not included in the sensitivity runs with the model PHEM.

** Average of diesel and gasoline over all single makes and models.

Impact of rolling resistances

One important factor in determining actual real-world fuel consumption on the chassis dynamometer is whether real-world resistances or type-approval resistances were used in the dynamometer. Tests with real-world driving resistance values were available from TUG. In the framework of emission factor development projects, the tested vehicles sometimes were coasted down on a road in the area around Graz/Austria. In such "real world" coast down tests the vehicles were used as delivered by the owner; only the tyre pressure was checked and corrected to the value proposed by the manufacturer. Additional equipment, such as roof racks, was not used in the tests. These measurements should correspond to real-world driving resistances of a well maintained and tuned car. On the other hand, the coast down test in type approval corresponds to the ideal condition (best tyres combined with best road surface at optimal ambient conditions). Therefore, the NEDC conducted with "real world" driving resistance values typically results in higher fuel consumption than stated in type approval data. Zallinger (2010) measured on average 17% (from +9% to +24%) higher fuel consumption over the cold-start NEDC, when real-world driving resistances were used instead of type approval ones. In a "real world mix" consisting of CADC, IATS and urban cold start, a higher FC of +21% (from +13% to +28%) was recorded on average, compared to the type approval one. The IATS cycle and the related database are described in detail in (Zallinger, 2010-2). Since only six vehicles were tested in that study, the average result may not be representative of all vehicle stock. However, it can be concluded that the higher driving resistances in real world than in type approval are a dominating factor for excess in-use consumption.

Figure 2-16 shows the ratios in FC between the NEDC tests measured with real-world resistances and the type approval values from the Zallinger (2010) study. The trends in Figure 2-16 show a different behaviour than the analysis in section 2.1. Here smaller cars have lower relative increase than larger cars, which is opposite to section 2.1. Besides the limited sample, also the effect of gear shift behaviour could explain this discrepancy. Since small cars typically have engines with rather lower torque at low engine speeds, the drivers may use lower gears than in large cars. This leads to higher engine speeds at small car engines in real world driving and shifts the engine operation points towards areas with lower fuel efficiency. This effect is not visible in the type approval cycle, where the gear shift points are fixed. Therefore, for small cars, the higher in-use fuel consumption may depend more on the engine operating at distinctively different portion of the map in real-world than the higher resistances.

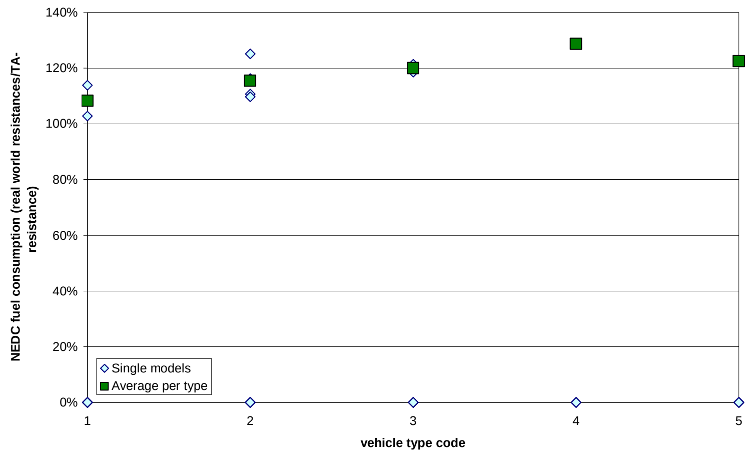


Figure 2-16: Ratio of fuel consumption measured in the NEDC with driving resistance data obtained from "real-world" coast down tests compared to the fuel consumption from the type approval (data from 10 vehicles).

We may therefore recommend that at least the coefficients of the driving resistance polynomial should be made available in the future, together with the official fuel consumption in an EU database, since the driving resistance values significantly influence the fuel consumption values. This also assists in checking the transparency of the type-approval measurement and CO_2 emissions reported by the manufacturer.

For the vehicles in sample "B", the fuel consumption values reported from in use tests from 3978 drivers in "Sprit monitor" were analysed. These data seemed to give a good average of all in use data sources analysed in section 2.1. In "Sprit monitor" the owners of the vehicles report the kilometres driven and the fuel consumed over a longer period. Figure 2-17 shows the data set for three different models, as an example. The fuel consumption values are influenced by the driving style and conditions. This is also the case in reality and the large number of driver/vehicle combinations hopefully gives a reasonable average for each make and model. However, when these FC InUse values are compared to results from real world test cycles a major source of uncertainty is the fact, that different vehicle models most likely are driven in reality in quite different styles and regions (e.g. small gasoline car and large diesel estate).

The average FC InUse values were compared to the fuel consumption given for the corresponding make and model in the type approval data. On average 16% higher values show up in real world in use (Figure 2-18). Therefore, the ratio of FC InUse over FC TA is similar to the ratio of NEDC FC with real world driving resistance values over FC TA. This indicates that the NEDC is not necessarily insufficient to depict real world fuel consumption because of its low dynamics, but rather that the driving resistance values used in type approval do not represent reality.

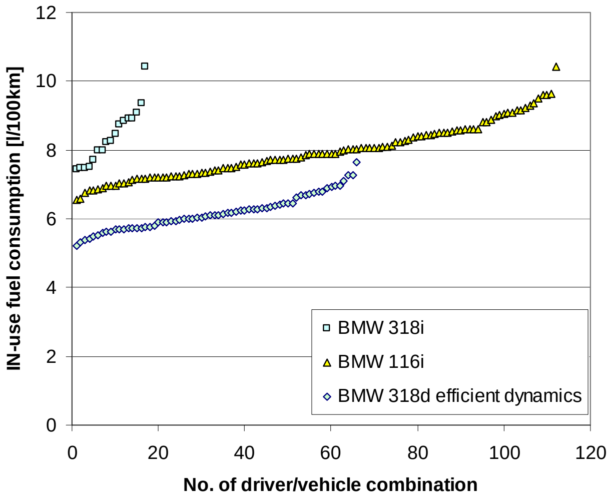


Figure 2-17: Distribution of the fuel consumption values reported in "spritmonitor.de" for three vehicle models.

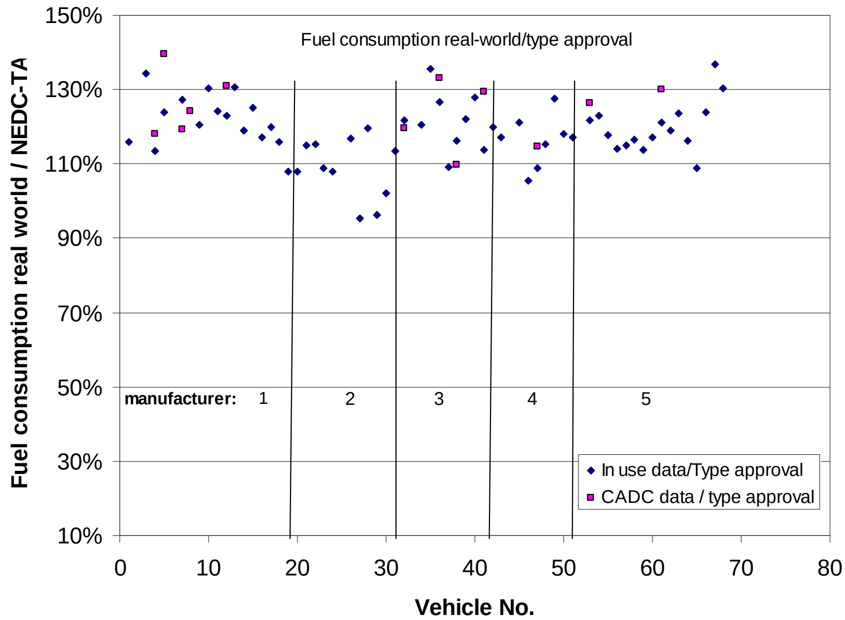


Figure 2-18: Ratio of fuel consumption from passenger cars reported from in use testing as well as from tests in the CADC test cycle compared to the type approval values.

Relevance of the Artemis driving cycles

For 11 of the models in sample "B", data from the CADC test cycle on the chassis dynamometer were also available. Here a mix of the three CADC parts Urban, Road and Motorway, each weighted by a 1/3 factor, was used for comparison. The CADC 1/3-Mix lead on average to 4% higher fuel consumption values than the FC InUse data for the particular vehicles. Compared to the FC TA the CADC leads to 25% higher fuel consumption values. However, it has to be considered, that the CADC does not include cold starts. Cold starts are responsible for approximately 10% extra fuel consumption in the NEDC (e.g. Zallinger, 2010). Unfortunately it is not clear for all vehicles tested over CADC in the ARTEMIS database whether real world or type approval resistance values have been used when executing the tests. We know that at least three of the vehicles were tested in the CADC with type approval driving resistance data. Thus the CADC cycle with "real world driving resistances" would have approximately 5% to 15% higher fuel consumption values than the CADC data in the actual data base (27% to

73% of the vehicles eventually tested with type approval driving resistance values). If a cold start would be added to the CADC we may have approximately 3% to 7% extra fuel consumption. In total this analysis suggests that the CADC, when equally weighing the three parts, might lead to fuel consumption which in cases may be up to 20% higher than the in-use one, under hot engine driving conditions. It will be later show though that CADC relevance for FC InUse depends on vehicle category.

Impact of vehicle specifications

Looking at the fuel used (Figure 2-19); no difference in the average ratio between FC InUse and type FC TA is found between petrol and diesel cars (+18% for both). In section 2.1.6, the ratio was +20% for diesel cars and +14.6% for gasoline cars. For gasoline driven cars a trend towards a smaller increase of in-use fuel consumption compared to type approval with increasing vehicle size is visible (Figure 2-19 and Table 2-4). This trend was found also in section 2.1. Reasonable technological explanations can not be found from the vehicle data for this trend (the power to mass ratios is rather increasing towards the larger vehicle categories). A different user profile and/or a different driving behaviour for the vehicle categories during in-use operation could be an explanation. Beside different gear shift behaviour also the shares of highway and rural driving can be substantially different for small cars and large cars. According to German investigations, larger cars typically have higher shares in highway driving than small cars. Especially for gasoline engines the efficiency is worse in urban driving (low engine loads) than in highway driving and we may assume that small gasoline cars are used especially for short distance trips. Certainly the observed trend can also be an artefact from the rather small vehicle sample too.

For the diesel driven categories the small cars and SUVs show lower ratios between in-use and type approval fuel consumption. Beside the shares in highway and urban driving also a different driving style between the different categories may be expected. Vehicles with higher power to mass ratio may have on average higher acceleration levels than vehicles with rather low engine power. However, such influences have not been investigated yet and are also not included in the actual study.

We would recommend recording in future driving behaviour studies also the vehicle specifications, to understand how the driving profile and conditions depend on vehicle category. Then a more systematic analysis of eventually important influences would be possible.

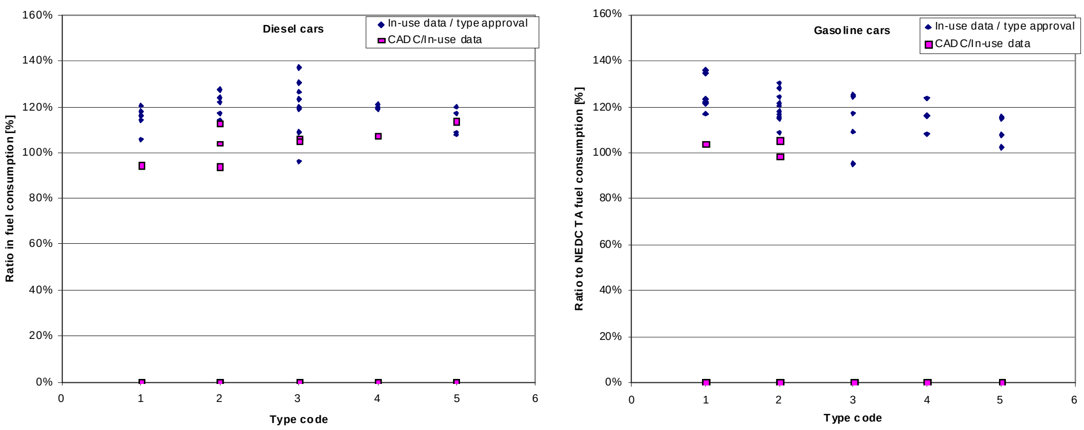


Figure 2-19: Ratio of fuel consumption reported from in use testing compared to the type approval values for diesel cars (left picture) and gasoline cars (right picture).

Table 2-4: Ratio of fuel consumption reported from in use testing compared to the type approval values for diesel and gasoline cars according to vehicle classes.

	Mass [kg]	Power [kW]	Capacity [cm^3]	TA FC [l/100km]	In-use/type approval*
			Gasoline		
Small car	1131	66	1289	5.5	125%
Limousine	1413	105	1732	6.6	120%
Estate	1454	105	1795	7.3	114%
Van	1530	92	1595	7.5	116%
SUV	1785	145	2242	9.8	110%
			Diesel		
Small car	1283	74	1469	4.6	115%
Limousine	1433	92	1809	4.6	120%
Estate	1546	102	1927	5.4	121%
Van	1634	98	1855	5.9	120%
SUV	1955	151	2525	8.0	114%

* Ratios of fuel consumption reported from in-use tests to type approval value of the model

The vehicle weight, number of gears, rated engine power, engine concept and swept volume of the engine show no clear influence on the excess in-use fuel consumption versus type approval values (e.g. Figure 2-20).

Figure 2-21 summarises the absolute fuel consumption values found for the vehicle sample analysed here in detail. It is obvious, that the vehicle categories with higher mass and larger dimensions, which also show on average a higher engine power, do have higher fuel consumption values than smaller cars in all tests. Furthermore it can be seen that the CADC 1/3 mix tends to overestimate the fuel consumption of large cars more significantly than that of smaller cars. Since the CADC is known to introduce dynamic driving conditions, the vehicle mass has a high impact in CADC FC, since the mass is a determinant for the power required in acceleration. We can assume that the real world conditions found from "spritmonitor.de" do have more cruising phases than the CADC. Since the different vehicle categories may have been driven in the spritmonitor.de In-Use sources with different average driving styles and different shares of urban, road and motorway driving the CADC 1/3 mix may not be similarly representative for all categories. Since no better information is available yet, the 1/3 mix is used here for all categories. Since the CADC 1/3 mix is not used for setting up the final equations for the real world fuel consumption but for calibration of the PHEM model only, this simplification is not relevant here.

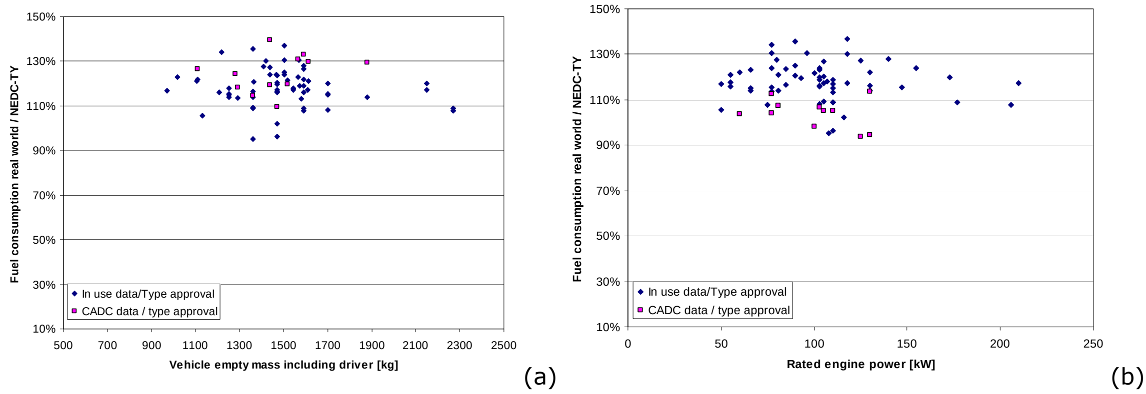


Figure 2-20: Ratio of fuel consumption reported from in use testing compared to the type approval values over the vehicle mass (a) and over the rated engine power (b)

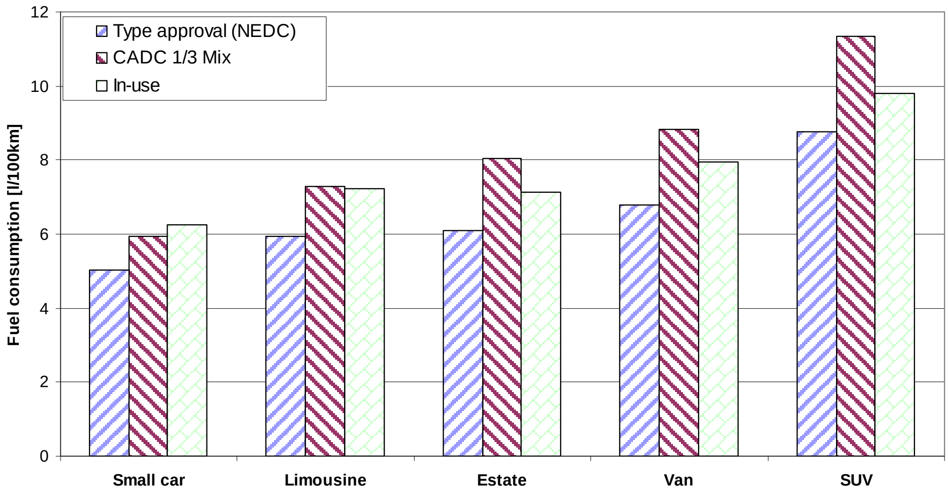


Figure 2-21: Fuel consumption values for different test cycles and from in-use tests from the vehicle sample.

The data analysed here already indicates, that the real world fuel consumption values for emission inventory models could be set up in two possible ways:

- as function of the vehicle characteristics
- as function of the type approval data reported

Several makes and models already optionally offer measures for improved fuel efficiency (engine start/stop e.g. in "Blue-Motion" and "Efficient Dynamics). For the models analysed here, the fuel efficient versions showed also in the in-use data a better fuel efficiency than the standard versions (e.g. Figure 2-22).

Thus it is the more accurate option for inventory models to consider also the data in the type approval (CO_2 or fuel consumption values recorded for the new registered fleet[8]). Alternatively also data on the share of the relevant technologies in the fleet can be collected (such as the share of engine start stop functions, of longer axis transmission ratio, of six gears instead of five, of brake energy regeneration etc.). However, it may be hard to gain such information for the national new vehicle fleet. This statement is also proved with the findings in the regression analysis (see chapter 4).

[8] Since for registrations before the year 2000 typically no data on the type approval fuel consumption in the NEDC is available, the final equations to estimate the fuel consumption should be applicable also without data on the fuel efficiency.

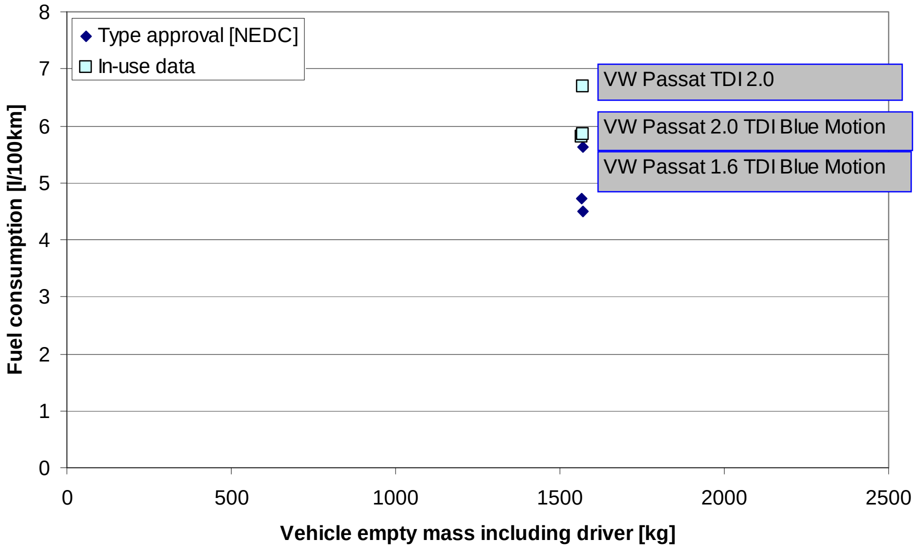


Figure 2-22: Fuel consumption values from type approval data and from in-use tests for three versions of a VW Passat estate with diesel engine.

2.2 Light commercial vehicles

The market of light-commercial vehicles (LCVs) in Europe (N1 according to UNECE classification) is very diverse as there are several vehicle types sold per manufacturer. These types are further distinguished into different vehicle configurations (transmission, chassis configuration, vehicle weight, etc). For example, Ford Transit is one of the most popular vehicles of this type available in Europe. This is offered in five versions as a van (short, medium, and long wheelbase, sport, and jumbo (double rear axles)), two versions as a minibus (M2 – 14 and 17 people), and as a chassis cab in four versions (short, medium and long wheelbase and long chassis). In addition this is offered with single or double-cabin front compartment and as a two-wheel or all-wheel drive. Finally, the chassis-cab has infinite configurations, depending on the rear compartment to be added. Therefore a model which is powered in total by only two engine types (a 2.2 gasoline and a 2.4 diesel – the latter one covering over 90% of the sales) has infinite configurations which make it extremely difficult to estimate the real-world vehicle emissions.

The Peugeot Boxer, being on the market since 1994, is another example. Engines offered in 1994 were a 1.9-litre diesel, a 2.5-litre diesel and a 2.5-litre turbo diesel. In 2002, all engines became HDi common rail versions – a 2.0-litre, a 2.2-litre and a 2.8-litre. In total, there are 140 variants, with three wheelbases (short, medium, long) and four gross vehicle weights of 2.5, 2.9, 3.3 and 3.5 tonnes[9].

The above clearly show that it is more difficult to obtain a representative picture for N1 vehicles compared to passenger cars and it is also difficult to provide handles for the inventory compiler to tune the fuel consumption factors.

For modelling LCVs with vehicle simulation tools in the subsequent tasks, it is necessary to model as much as possible representative vehicle types or, in other words, vehicle types that represent a good portion of the total market. Dealers of the main manufacturers dominating the market (e.g. VW, Ford, Fiat) were the main source of information, complemented with information contained in automotive magazines and websites. In general, most of the technical data required for the simulations were obtained from the above sources. In cases of missing data

[9] http://www.parkers.co.uk/vans/reviews/peugeot/boxer-1994.aspx?model=1105&page=4

(mainly for transmission ratios and aerodynamic drag), car manufacturers were contacted directly with the request to review the data and fill missing values. To this aim, a formal letter was sent out to individual ACEA members.

Classes of N1 vehicles (for the purpose of emission legislation) are defined on the basis of reference mass:

- Class I: reference mass ≤ 1305kg
- Class II: 1305 kg < reference mass ≤ 1760 kg
- Class III: reference mass > 1760 kg

Table 2-1 summarises the selected vehicles, grouped by manufacturer and N1 class. In total, detailed technical data for 19 individual models from 10 manufacturers were collected. When adding different variants of the same models, the number increases to 79. A list of the individual vehicles with key technical specifications is given in Annex 4.

Table 2-5: Summary of light commercial vehicles selected for the simulations (number of different types of each model in parentheses).

Manufacturer	**N1-I**	**N1-II**	**N1-III**
Peugeot	Partner (1)	–	Boxer (6)
Renault	Kangoo (4)	Traffic (4)	–
Fiat	Fiorino (2)	Doblo (3), Ducato (6), Scudo (4)	–
Citroen	–	Berlingo (4)	Jumpy (4)
Mercedes	–	–	Vito (3), Sprinter (2)
Iveco	–	–	Daily (3)
Opel	Combo (3)	Vivaro (6)	–
Nissan	NV200 (2)	–	–
Ford	–	–	Transit (10)
Volkswagen		Caddy (6)	Transporter (6)

The above vehicle selection makes up a representative sample, based on their sales at a European level as shown in (

Table **2-6**)

Although sales are presented by manufacturer (and not by vehicle model), it can be assumed that the above selected models are among the most popular, contributing thus significantly to the sales of each manufacturer.

Table 2-6: Total sales* per manufacturer in Europe and in selected countries in 2009.

Manufacturer	**Europe**	**France**	**Italy**	**Greece**
Peugeot	153 822	66 436	9 393	223
Renault	205 360	116 498	6 850	147
Fiat	167 592	32 373	51 740	1446
Citroen	165 091	66 833	9 718	499
Mercedes	116 030	16 929	4 989	611
Iveco	44 461	10 505	10 652	15
Opel	72 649	6 772	4 722	531
Nissan	44 764	6 498	4 926	2 883
Ford	157 908	20 197	9 204	1877
Volkswagen	148 510	11 506	5 614	710
Total sales	**1 408 540**	**373 986**	**125 399**	**14 549**
Total market share	**90.6 %**	**94.8 %**	**93.9 %**	**61.5 %**

* Sources: www.acea.be , www.ccfa.fr , www.anfia.it , www.seea.gr

3 Methodology and data analysis

3.1 Outline

In this task, the methodology and the tools to calculate fuel consumption and CO_2 emissions at a vehicle level are presented. Two tools are used in the following, PHEM for passenger cars and CRUISE for light commercial vehicles. The two tools have equivalent characteristics and approach. The models were fed with the characteristics of sample "B" presented in section 2.1.7 for PCs and 2.2 for LCVs. The model specifications are as follows:

- The PHEM model calculates the engine power demand based on the driving resistance values and losses in the drive train. Fuel consumption and emissions are then interpolated from engine maps as function of engine speed and torque. PHEM provides instantaneous results over the cycles as well as emission and fuel consumption factors.

- CRUISE is AVL's vehicle and powertrain level simulation tool and fulfils the same criteria as PHEM, i.e. it can simulate the vehicle operation over a driving pattern and can calculate emissions and fuel consumption, provided it can be fed with appropriate vehicle specifications and engine maps. Although use of the ADVISOR model was initially planned, CRUISE was eventually selected as it is more up-to-date compared to the free version of ADVISOR (2002). CRUISE instead of PHEM has been used for LCVs, purely on the basis of model availability.

The following elements may be obtained as a result of these simulations:

- Technological assessment of the influence of the parameters (mass, engine power, rolling resistance, aerodynamic drag, etc.) in terms of a regression equation similar to the approach in section 2.1.

- Influence of the parameters as function of the average cycle speed as input for the COPERT model and possibly also for HBEFA.

- A better understanding of the important factors leading to different results in type approval compared to real world driving.

The general concept of the parameterisation was the following:

1. The two models are fed with engine maps to represent an 'average' vehicle per category;
2. The models are fed with a range of alternative parameters, according to the market information collected in chapter 2;
3. Fuel consumption and CO_2 emissions are calculated for a range of driving cycles (real-world and NEDC);
4. FC and CO_2 functions for a range of limited parameters are developed, according to the simulations in the previous step.

This methodology is in detail elaborated in the following.

3.2 Comparison of PHEM and CRUISE for a test case

A test case is examined in order to compare the performance of the two models. Both models were fed with the same engine map and the same vehicle configuration. Calibrated maps for 'average' Euro 4 LCV for each class (N1-I, II and III, gasoline and diesel) were used. Then fuel consumption was calculated over the CADC and the NEDC cycles with both models. The same gearshift strategy has been used with both models. Table 3-1 summarises the results of this comparison.

Table 3-1: Fuel consumption (in g/km) simulated with PHEM and CRUISE for Euro 4 LCVs.

LCV category	Driving cycle	PHEM	CRUISE	Deviation
Gasoline Euro 4 N1-I	NEDC	53.3	52.4	1.6 %
Gasoline Euro 4 N1-II	NEDC	61.7	61.2	0.8 %
Gasoline Euro 4 N1-III	NEDC	91.0	90.3	0.8 %
Gasoline Euro 4 N1-I	Artemis	56.0	54.7	2.4 %
Gasoline Euro 4 N1-II	Artemis	63.5	62.5	1.7 %
Gasoline Euro 4 N1-III	Artemis	95.2	93.6	1.7 %
Diesel Euro 4 N1-I	NEDC	53.3	51.8	3.0 %
Diesel Euro 4 N1-II	NEDC	67.1	64.9	3.3 %
Diesel Euro 4 N1-III	NEDC	84.2	82.1	2.4 %
Diesel Euro 4 N1-I	Artemis	53.5	51.0	4.7 %
Diesel Euro 4 N1-II	Artemis	70.7	68.0	3.8 %
Diesel Euro 4 N1-III	Artemis	88.3	86.8	1.6 %
Diesel Euro 4 N1-I DPF	NEDC	54.0	52.6	2.6 %
Diesel Euro 4 N1-II DPF	NEDC	67.9	66.7	1.8 %
Diesel Euro 4 N1-III DPF	NEDC	87.8	86.2	1.8 %
Diesel Euro 4 N1-I DPF	Artemis	54.1	52.8	2.6 %
Diesel Euro 4 N1-II DPF	Artemis	71.5	70.4	1.6 %
Diesel Euro 4 N1-III DPF	Artemis	92.0	90.8	1.8 %

In general, there is a reasonably good agreement between the two models. The fuel consumption calculated with CRUISE is somewhat lower than PHEM predicts for all LCV categories. This deviation between the two models is on the order of 2.2 % on average, ranging from 0.8% to 4.7%. The above results suggest that there is no fundamental difference in the calculation approach of the two models and hence no further calibration is needed.

3.3 Passenger cars

The influence of detailed vehicle data, such as transmission ratios of the gear box, variations in the vehicle mass and rolling resistance coefficients can be simulated with vehicle longitudinal models such as the model PHEM (see Annex 5). The simulation will give more pronounced results than test data, since single parameters can be varied isolated while from the available vehicle tests typically all vehicle parameters are at least slightly different between different makes and models.

The average cars from the analysis in section 2.1.7 were used as a basis for the simulation. For the simulation runs the limousine and estate cars were pooled together since the differences between these vehicles concepts were quite small. The estate version of a vehicle typically has a slightly higher vehicle weight but the vehicle weight is varied later in the simulation over a broad range. Thus the influence of a different weight is considered in the analysis. For vans the detailed data base was rather small and the technological dependencies between weight, power, size etc. were quite similar to the "medium cars". Furthermore it may be hard to classify several models to estate or van when applying the resulting dependencies to assess the fuel consumption value of an entire vehicle fleet. Thus Vans were not used as a separate category here.

The vehicle types listed in Table 3-2 remained for the simulation. The detailed data necessary for the simulation with the model PHEM which is not shown in the table, such as transmission ratios, moments of inertia for different parts of the drive train etc., were applied according to the formulas described in Hausberger (2010).

Table 3-2: Basic passenger car data used in the simulations

	Diesel cars			Gasoline cars		
	small	**Medium***	**SUV**	**small**	**Medium***	**SUV**
Mass [kg]	1200	1450	1900	1150	1400	1700
P [kW]	70	100	140	65	90	125
C_d x A [m²]	0.601	0.585	0.892	0.588	0.569	0.830
r_0 [-]	0.011	0.009	0.011	0.010	0.0082	0.0095
r_1 [s/m]	5.17E-05	4.13E-05	5.166E-05	5.166E-05	4.133E-05	4.753E-05
No. of gears	5	6	6	5	6	6

* Average of the limousine and estate in section 0

In the simulation runs single parameters were varied systematically for each vehicle category:

- Mass (up to +/-300 kg)
- Rated engine power (+/- 30 kW)
- Air resistance, $C_d \times A$ (+/-30%)
- Rolling resistance, R_0 and R_1 (+/-30%)
- No. of gears (5 or 6)

Transmission ratios (adapted to a v-max in the highest gear at rated engine speed between 140 km/h and 220 km/h)

The engine maps for the specific fuel consumption were obtained from the data in Hausberger (2010) with additional three EURO 5 vehicles measured in Zallinger (2010). The fuel consumption measured in the transient test cycle (CADC) was used to set up transient engine maps according to the standardised PHEM procedure as specified e.g. in Hausberger (2010).

This results in a fuel consumption map for the average engine of the tested vehicles. In PHEM the specific fuel consumption is specified in the maps as [g/h]/$kW_{\text{rated engine power}}$. This value allows an easy scaling of the average emission map by the rated power of the engine. Basically this approach assumes constant fuel consumption in [g/h]/$Litre_{\text{swept volume}}$ at same effective mean pressure and engine speed and that higher rated engine power values are gained by higher swept volumes. The interpretation of this assumption simply is, that an engine with similar technology but 50% higher swept volume will have a 50% higher rated engine power and also 50% higher fuel consumption in [g/h] when running at the same effective mean pressure. This approach was tested by recalculating the data from section 0 (for the makes and models where all necessary technological information was available) and proved to be quite accurate. Differences between measurement and simulation were below 10%, which is within the expected range as result of differences in the engine technologies and in the engine parameterisation[10]. Using the same engine fuel consumption map for all vehicle categories leads to a better comparability of results. However, with this approach either the rated engine power or the swept volume of the engine can be used as parameter for the regression analysis in chapter 4 since both parameters are linear connected with the approach followed here. Figure 3-1 shows the fuel efficiency map used in the simulation for diesel engines.

[10] The same engine can have different fuel consumption maps if it is used e.g. one time in a limousine and the other time in a SUV since the vehicles have to meet the type approval limits for pollutant emissions in the particular vehicle in [g/km]. Together with drivability issues this can lead to different applications of the engine settings.

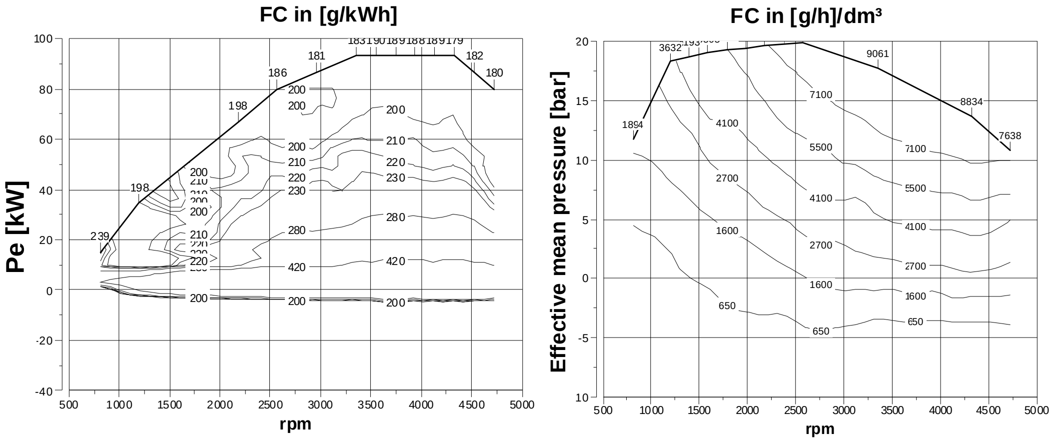


Figure 3-1: Fuel consumption map of the average Euro 5 diesel engine used in the simulation (left picture in PHEM standard, right picture in swept volume specific values).

3.3.1 Calibration of the PHEM simulation

With the vehicle data and the engine emission maps different driving cycles were simulated with the base settings of the vehicles. The results were compared with the available measured data described in section 2.1 for the validation of the vehicle parameters extracted from the data base on the selected vehicle sample.

The main findings were:

- Compared to the fuel consumption reported by in-use tests, the CADC with 1/3 mix led to higher values for some vehicle categories/fuels, the IATS is slightly higher than the in-use data while HBEFA3.1 led to lower values[11]. By simply taking the average from the HBEFA cycles and the IATS cycles and adding 5% for cold start extra fuel consumption the reported in-use fuel consumption was met quite well for all vehicle categories (e.g. Figure 3-2). This cycle mix from IATS and HBEFA 3.1 is referred to here as "Real World Mix".

- While the in-use fuel consumption data and the "Real World Mix" are approximately 20% higher than the type approval fuel consumption, the data from NEDC with cold start when using the "real world driving resistance values" is on a similar level than the in-use data (-7% to +6%).

- The type approval values of the vehicle sample were overestimated by the model PHEM for all diesel cars by 5% to 11% although the driving resistance values were lowered in the "type approval simulation" for all vehicle categories by 18% against the real world settings, to take the optimum conditions at type approval coast down tests into consideration (see section 2.1). There may be some additional optimisations which are not reflected by the model input data which was gained mainly from real world test cycles or the type approval driving resistances are on average by more than 20% lower than the "real world driving resistances" used here. Since only for a few vehicles the type approval resistance function and measured real world resistance values are available no reliable statement on this ratio can be made.

- The model input data not defined from the data collection had to be tuned to lowest reasonable settings to meet the in-use fuel consumption recordings (e.g. consumption of auxiliaries like air conditioning, rotational inertia of the tires, transmission and engine, losses in the transmission system etc. This my indicate that the available in-use data either consists of rather fuel efficient drivers or that the "Real World Mix" tends to overestimate the real world fuel consumption (due to the related gear shift model and/or

[11] CADC, IATS and HBEFA 3.1 cycles are tested in hot running conditions. To compare the results with in use data approximately 5% cold start extra fuel consumption has to be added.

due to the vehicle speed trajectories of the cycles and/or due to the weighting of urban, road and motorway driving).

- Although it is not clear that the average from HBEFA and IATS cycles is representative for European driving, in further analysis this "Real World Mix" was used to depict real world fuel consumption values. The 5% cold start extra fuel consumption was applied to make the "real world test cycles" comparable to the in-use data which always includes cold starts. In the further analysis on the influence of vehicle parameters only hot starts are integrated since inventory models do have separate cold start models.

Diesel small cars

The simulated NEDC with real world driving resistance values and with type approval resistance values meets the measured fuel consumption with +/- 5% accuracy. The CADC as well as the fuel consumption from "Real World Mix" meets the measurements exactly. An exact match of measured real world data and simulation however can not be expected in general, since only for a small share of the vehicles measured real world cycles are available (CADC, IATS, HBEFA) while for each model the type approval data and in-use data is known. Thus the sample on measurements for type approval fuel consumption is much larger than for "real world mix" fuel consumption and the average values cannot be directly compared.

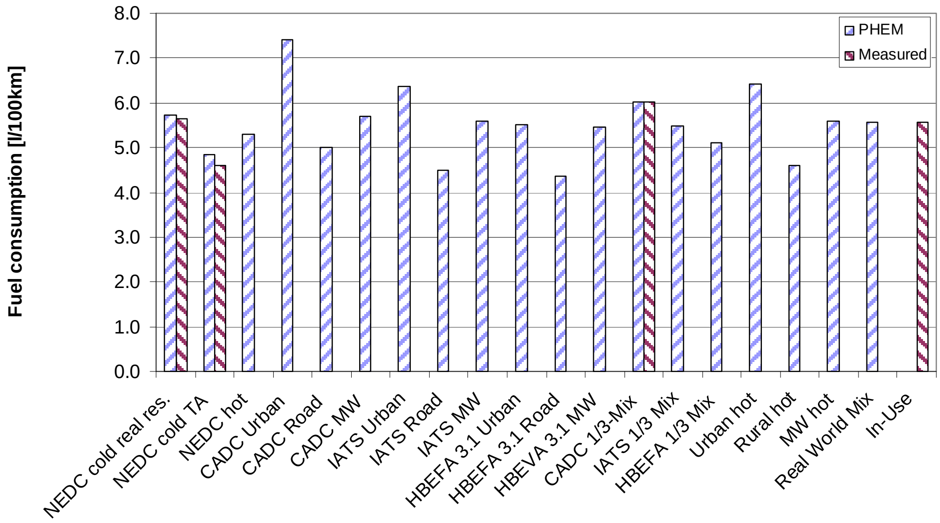


Figure 3-2: Fuel consumption simulated with PHEM for "Diesel small cars" compared to measured results from section 2.1.

Diesel medium cars

Figure 3-3 shows the results for medium cars. The test results in the type approval are overestimated by PHEM by 11%. This may be partly due to the share of cars already equipped with engine start/stop systems and brake energy recuperation. These systems save approximately 5% higher fuel efficiency in the NEDC but are not simulated with PHEM in the "basis medium car" since engine start/stop systems are not applied in vehicles with construction years before 2008. The remaining overestimation may be due to the driving resistance values used for the type approval simulation where no reliable data for the majority of vehicles were available. The fuel consumption from the in-use tests is met by the PHEM simulation quite well (-1% from the "Real World Mix" against the In-use average). This difference is within the accuracy of the simulations. Especially the assumptions on the "average traffic situations" influence the results by much more then the 1% difference.

Diesel SUVs

Figure 3-4 shows the results for SUV's with diesel engine. The test results in the type approval are overestimated by PHEM by 6%. The fuel consumption from the In-use tests is met by the PHEM simulation quite well (-2% from the "Real World Mix" against the In-use average). This difference is within the accuracy of the simulations.

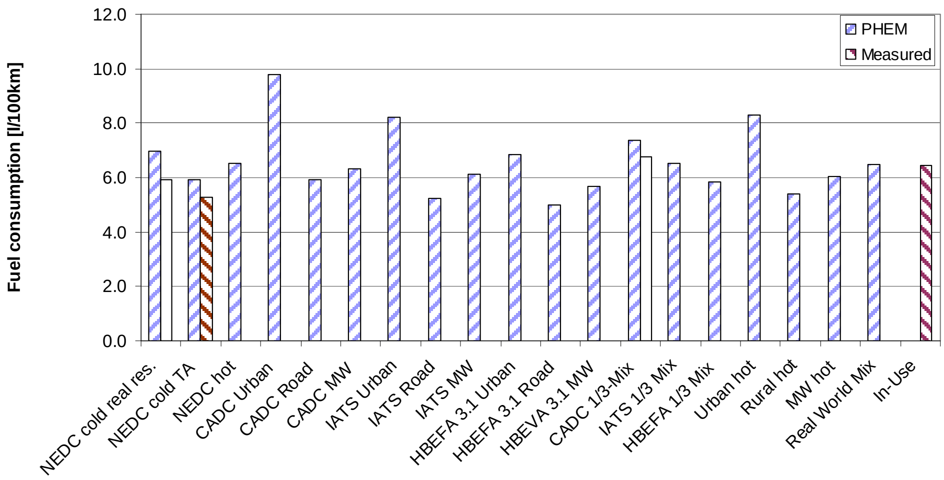


Figure 3-3: Fuel consumption simulated with PHEM for "Diesel medium cars" compared to measured results from section 2.1 (note: samples indicated by the white bars cover only a few vehicles and are not representative).

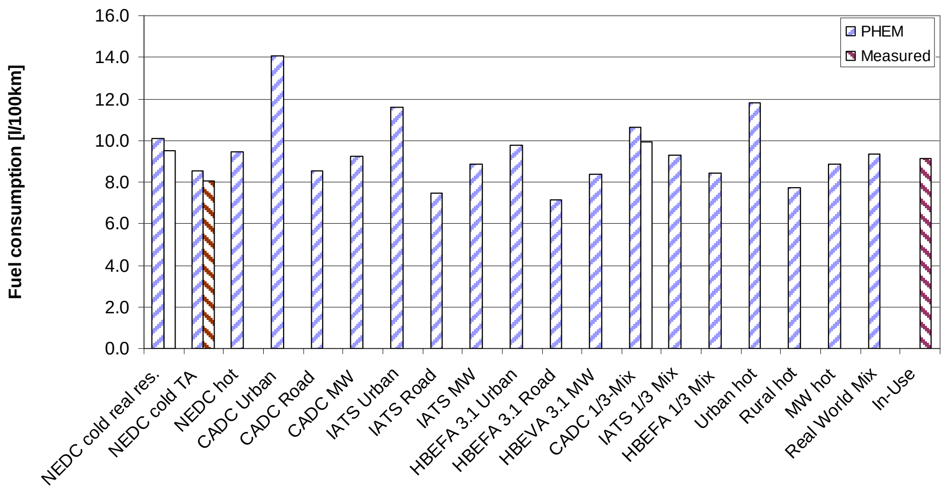


Figure 3-4: Fuel consumption simulated with PHEM for "SUV Diesel" compared to measured results from section 2.1 (note: samples indicated by the white bars cover only a few vehicles and are not representative).

Gasoline small cars

The simulation results for the base case "Gasoline small car" are shown in Figure 3-5. As for diesel cars the simulation gives a good agreement between the in-use data from the spritmonitor.de and the "Real World Mix" consisting of the average from HBEFA 3.1 cycles and IATS with 5% extra cold start fuel consumption added. Similar to the diesel cars the type approval values are overestimated by PHEM although the air and rolling resistances are set 18% lower for the type approval simulation compared to the "real world simulation".

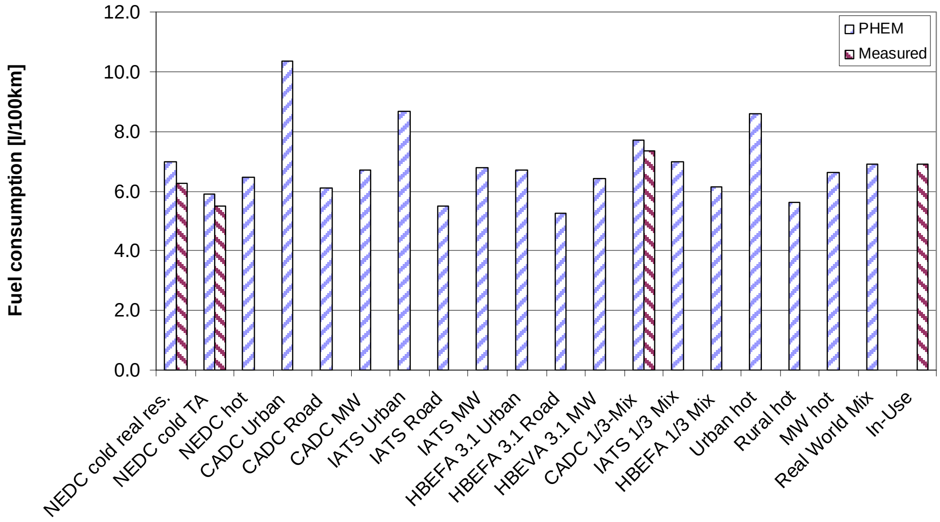


Figure 3-5: Fuel consumption simulated with PHEM for "Gasoline small cars" compared to measured results from section 2.1.

Gasoline medium cars

Figure 3-6 shows the results for the basic "Gasoline Medium Car". The simulation overestimates the type approval value by 8% for this vehicle category while the in-use data is met with +1% from the "Real World Mix".

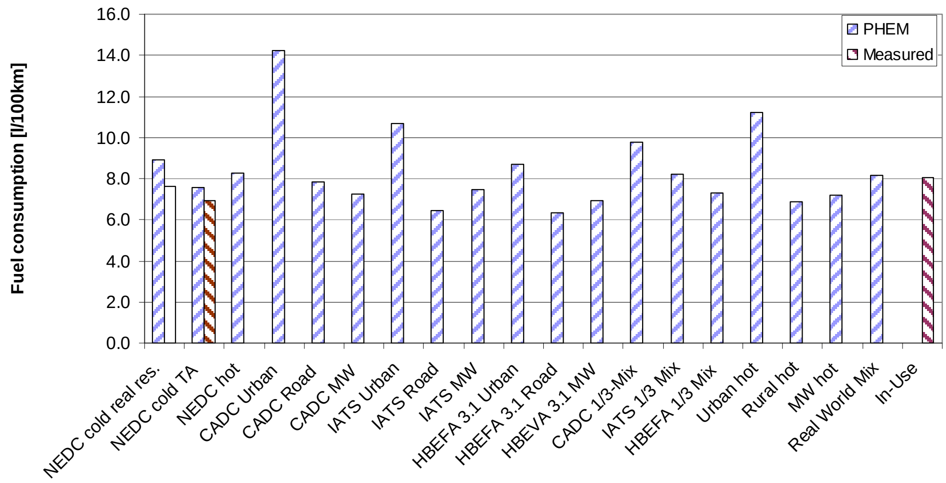


Figure 3-6: Fuel consumption simulated with PHEM for "Gasoline medium cars" compared to measured results from section 2.1 (note: samples indicated by the white bars cover only a few vehicles and are not representative).

Gasoline SUVs

For the Gasoline SUV's both, type approval and in-use data are overestimated by PHEM (+6% and +4% respectively, Figure 3-7). In general the model input data not specified in the data collection, such as inertia of rotating masses, power consumption from auxiliaries etc. were set already to lowest reasonable values. A tuning of the model towards lower fuel consumption values would thus have improved the conformity of the results but not the reliability of the later variation of vehicle parameters.

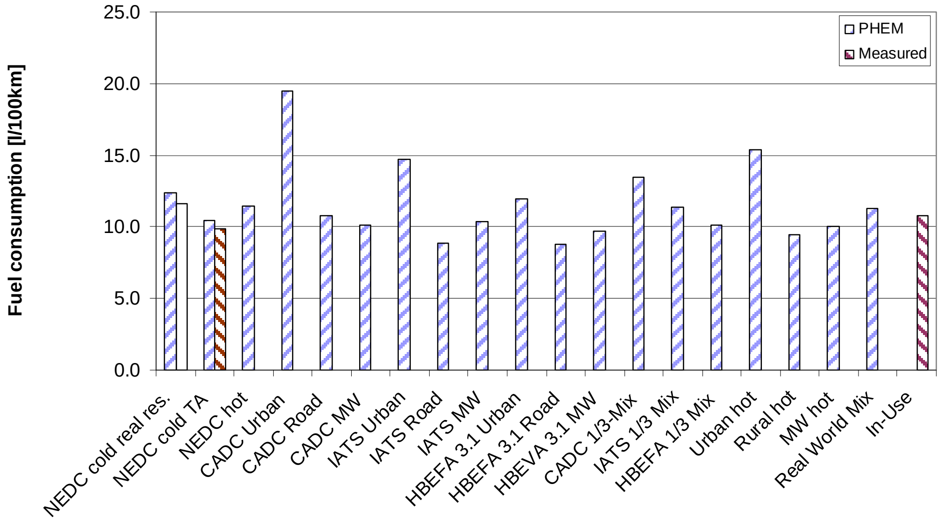


Figure 3-7: Fuel consumption simulated with PHEM for "SUV Gasoline" compared to measured results from section 2.1 (note: samples indicated by the white bars cover only a few vehicles and are not representative).

3.3.2 Sensitivity studies

After the parameterisation of the model PHEM for the six vehicle categories, the single vehicle parameters have been varied as described in section 2.2:

- Mass (+/-300 kg)
- Rated engine power (+/- 30 kW)
- Air resistance, Cd × A (+/-30%)
- Rolling resistance, R_0 and R_1 (+/-30%)
- No. of gears (5 or 6)
- Transmission ratios (adapted to a v-max in the highest gear at rated engine speed between 140 km/h and 220 km/h)

Actual engine developments tend towards a downsizing of the engines resulting in a reduced swept volume but unchanged or even increased rated engine power. At the moment there is not sufficient data available to take this trend into consideration in the analysis.

In these variations one parameter was varied while all other vehicle parameters remained unchanged against the basis value. It has to be noted, that in reality typically several parameters are changed together (e.g. engine power with vehicle weight or transmission ratios with engine rated power). Thus the results of the variation of one single parameter do not lead necessarily to representative fuel consumption behaviour for the entire vehicle fleet for all settings of the parameters.

For all parameter variations all test cycles have been simulated for the categories small cars, medium cars and SUV's, with gasoline engines and also with diesel engines. The resulting fuel consumption values are been analysed in chapter 4 with multiple regression for the most important influencing factors on the fuel consumption of the cars.

The effects of variations of single parameters are shown in the following to interpret the data which is introduced in the multiple regression formulas.

Figure 3-8 shows the results for the variation of the vehicle mass for diesel cars. As expected, the simulated real world fuel consumption ("Mix" of HBEFA 3.1 and IATS, including cold starts) is higher than the NEDC values for all variations and an increasing weight increases the fuel consumption. Obviously the different fuel consumption of the three vehicle classes simulated is not explained by the weight only. This also meets the expectations since at least the air resistance and the rolling resistance are different for a very heavy small car with the original size and tires of the small cars and for a very light weight constructed SUV with the size and tires of the basis SUV.

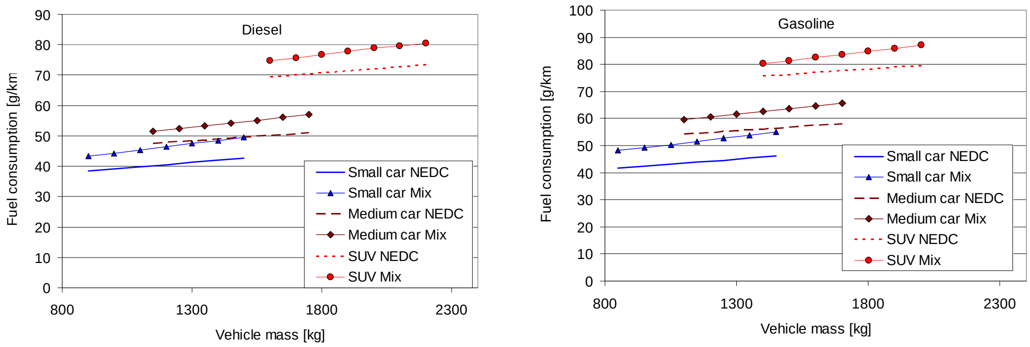


Figure 3-8: Fuel consumption simulated with PHEM for Diesel cars (left) and gasoline cars (right) with variation of the vehicle mass.

Figure 3-9 shows the relative changes of the fuel consumption due to the relative change of the vehicle mass against the basis vehicle mass of each diesel category simulated with PHEM. It can be seen, that the effect of 20% change in the vehicle mass is approx. 5% change in the fuel consumption for all three vehicle categories in the real world mix. The effect of the vehicle mass is lowest in the NEDC cycle while the mass shows the highest influence in the urban cycles (right picture). Beside the influence on the rolling resistance the mass influences also the power to overcome the inertia of the vehicle during phases of acceleration. Thus cycles with many acceleration and braking manoeuvres are more sensitive to the mass than cycles with high shares of cruising and idling (like the NEDC).

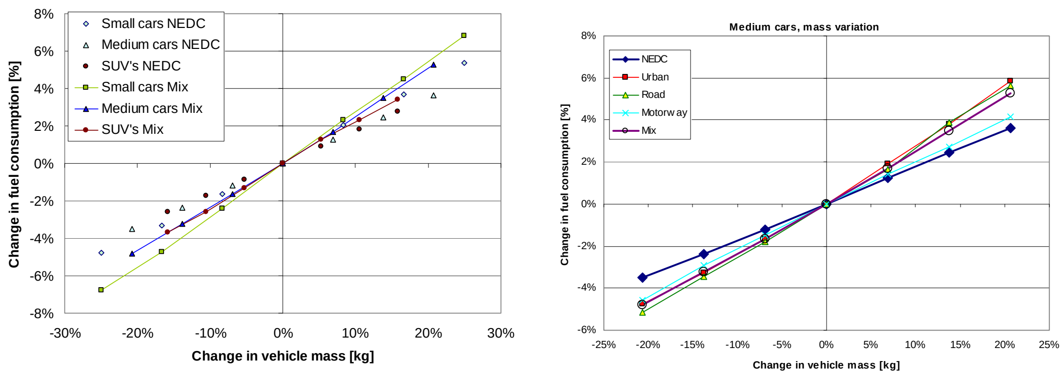


Figure 3-9: change of the fuel consumption simulated with PHEM for Diesel cars over the change of the vehicle mass (left picture: comparison of the vehicle categories, right picture influence of the driving cycle).

Figure 3-10 shows similar results for gasoline vehicles. As expected the influence of the vehicle mass is in a similar range than for the diesel cars.

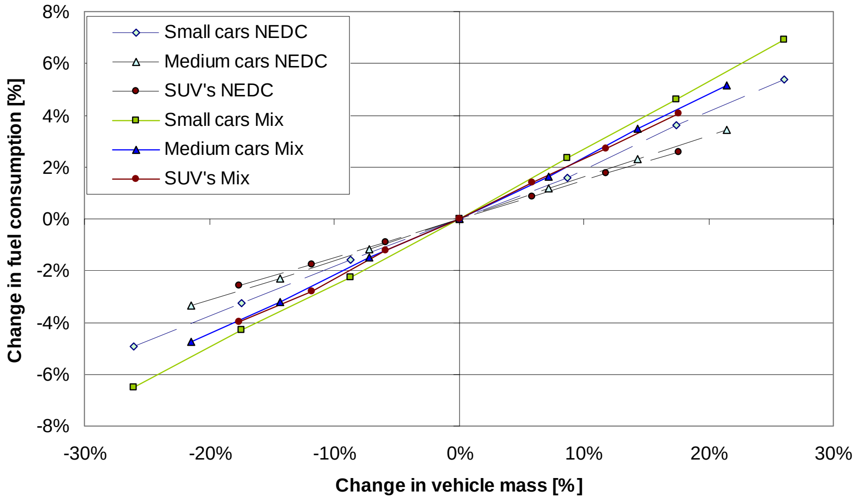


Figure 3-10: Change of the fuel consumption simulated with PHEM for Gasoline cars over the change of the vehicle mass.

Figure 3-11 shows the influence of the rated engine power. The relative effect is similar for all simulated vehicle categories in the real world mix (i.e. +10% fuel consumption with +20% change in the rated power). The absolute values however, differ between the "medium car" and the SUV's and the small cars with the same engine power. Obviously the rated engine power [kW] per driving resistance [kW] is on average higher for the "medium cars" compared to small cars and SUV's. With other words, the same engine will result in lower fuel consumption if it is used in an estate car than in a SUV. The higher fuel consumption for small cars with a similar engine power than the medium cars in this variation results from an "over-motorisation" of such a small car which lead to driving in engine loads with worse fuel efficiency, especially since the transmission ratios are not changed against the basis values here. The influence of the engine power is smaller in highway driving than in urban driving and NEDC since the gradient of the fuel efficiency in the engine map is steeper in the areas of low engine power compared to cycles which need higher engine power output.

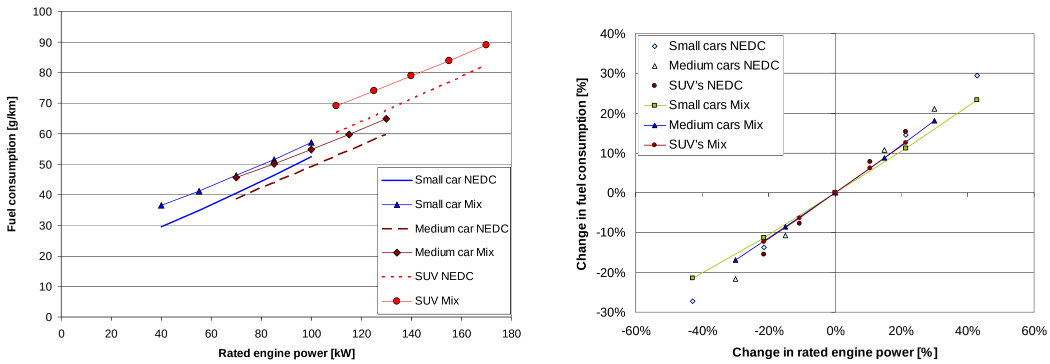


Figure 3-11: Fuel consumption simulated with PHEM for Diesel cars with variation of the rated engine power (left: absolute changes, right relative changes).

Figure 3-12 shows the influence of the rated engine power on the fuel consumption for gasoline cars. For gasoline cars a higher influence exists since the Otto engine has a more pronounced gradient in the fuel efficiency over the actual engine load due to the throttling of the intake air at lower loads. Thus an increase engine power shifts the engine load points in the simulation towards points with lower fuel efficiency if the other parameters remain unchanged. It has to be pointed out, that this simulation assumes a power increase due to an increasing swept volume. Modern turbocharged gasoline engines can have higher rated power values at lower swept volumes and higher fuel efficiency than former natural aspirated engines. Thus the trend shall not be seen as a general valid tendency.

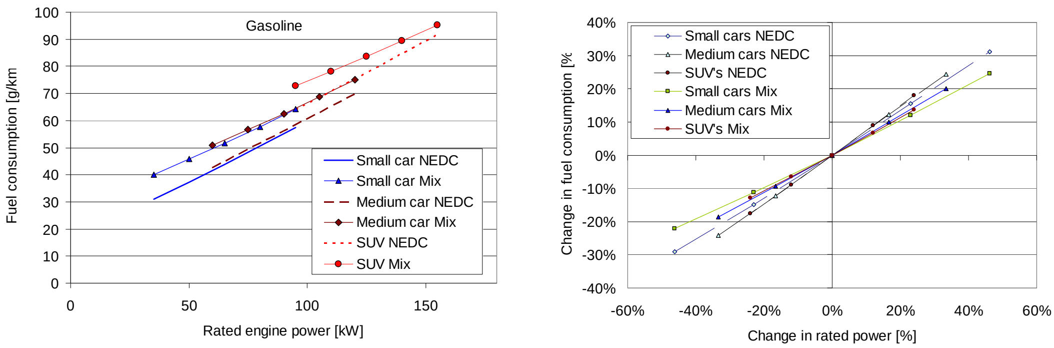


Figure 3-12: Fuel consumption simulated with PHEM for Gasoline cars with variation of the rated engine power (left: absolute changes, right relative changes).

Figure 3-13 and Figure 3-14 show the influence of the air resistance (% change in C_d x frontal area) for diesel and gasoline cars. Again we find similar relative effects for all vehicle categories although the absolute values of the fuel consumption are different. The relative effect for the "medium cars" is lower than calculated for SUV's and small cars. According to the data available the aerodynamic drag coefficient seems to be lowest for the estate and limousine shaped cars. Thus the share of the air resistance on the total engine power demand is lower for these cars than for SUV's and small cars (if we use the same driving cycles and the same shares of urban, road and motorway driving for all categories).

Certainly the effect of the air resistance is highest in fast cycles (approx. -3% to -4% fuel consumption in the highway mix for -10% air resistance) than in slow cycles (-0.2% to -0.7% fuel consumption in the urban mix for -10% air resistances).

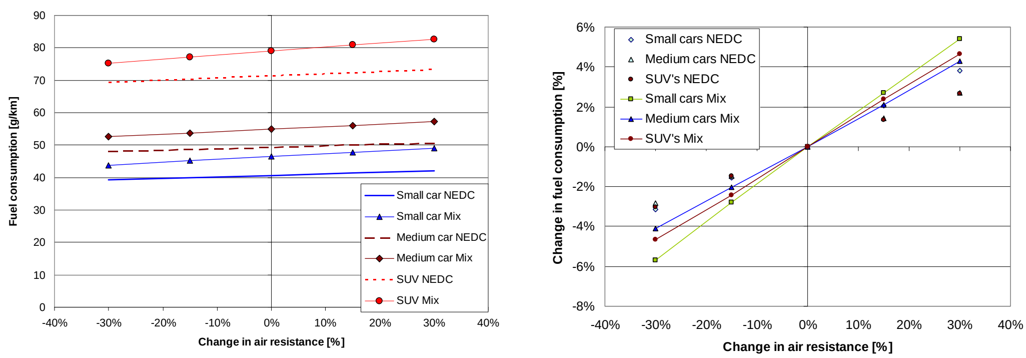


Figure 3-13: Fuel consumption simulated with PHEM for Diesel cars with variation of the air resistance (left: absolute change, right relative change).

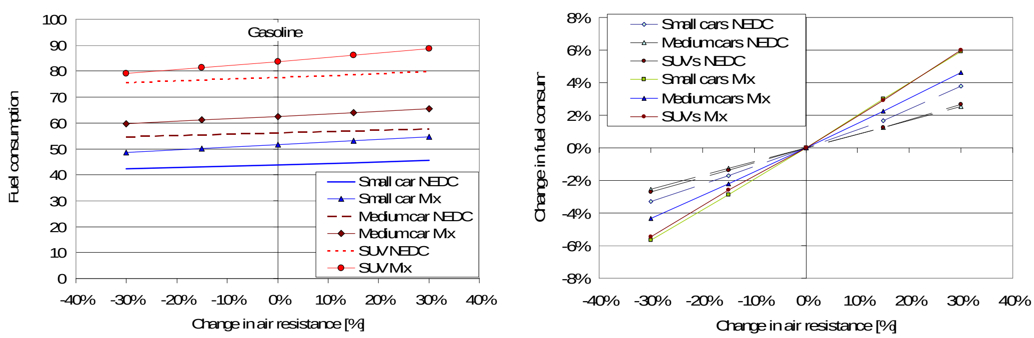


Figure 3-14: Fuel consumption simulated with PHEM for Gasoline cars with variation of the air resistance (left: absolute change, right relative change).

The influence of changes in the rolling resistance is a bit lower than from changes in the air resistance (Figure 3-15 and Figure 3-16). According to the data available, the share of rolling resistance in the entire power demand from the engine is higher for small cars than for medium cars and SUV's. Thus changes of the rolling resistance have the largest effect in the segment of small cars. For 10% reduction in the rolling resistance 1% to 2% reduction in fuel consumption was simulated. For gasoline cars a smaller effect was computed than for diesel cars. This is rather an artefact since the rolling resistance coefficients were slightly lower for gasoline cars than for diesel cars. This could be an effect of the small vehicle sample with mostly unknown tires rather than a significant difference.

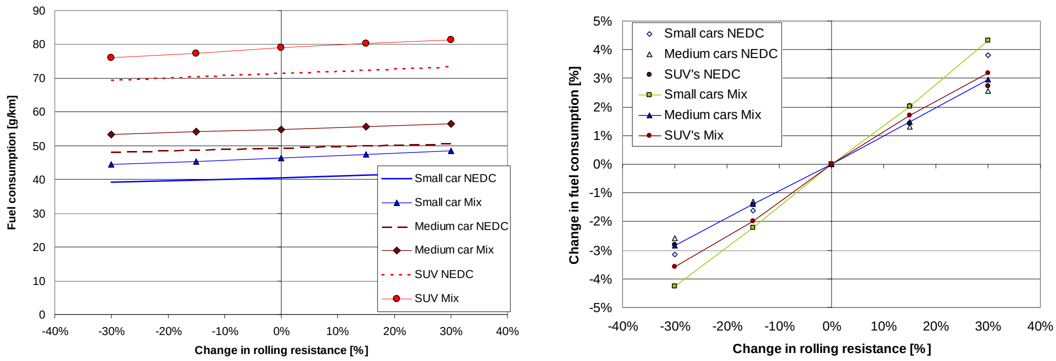


Figure 3-15: Fuel consumption simulated with PHEM for Diesel cars with variation of the rolling resistance (left: absolute change, right: relative change).

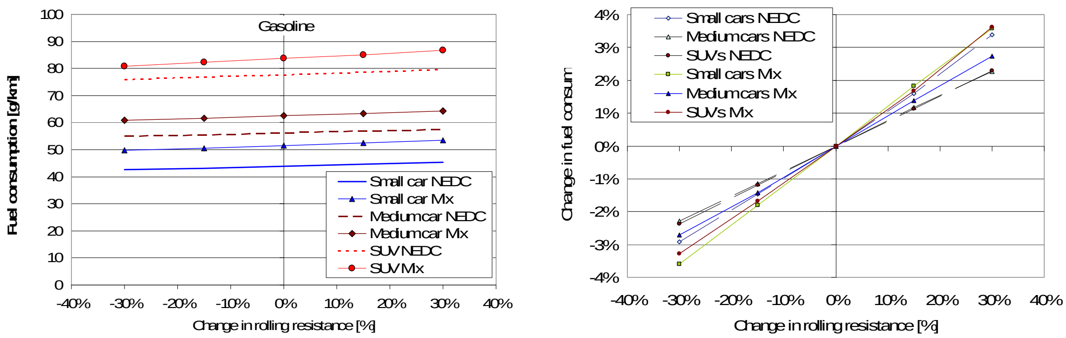


Figure 3-16: Fuel consumption simulated with PHEM for Gasoline cars with variation of the rolling resistance (left: absolute change, right: relative change).

Figure 3-17 shows the influence simulated for the transmission ratio of the axis. A lower transmission ratio decreases the engine speed at a given vehicle speed if the gear shift manoeuvres remain unchanged. A lower engine speed results typically in a better engine efficiency. The effect is limited due to the drivability of the vehicle since a small transmission ratio reduces also the available torque and thus the potential for acceleration. In real world driving the driver can compensate the fuel efficiency benefits of a lower transmission ratio if he simply changes later to the next higher gear. This effect occurs also in the driver model in PHEM. For the NEDC, where the gear shift points are fixed, higher benefits are found than for the real world mix, where only in the CADC the gear shift points have been fixed in PHEM while for the HBEFA 3.1 cycles and for the IATS the driver model in PHEM selects the appropriate gear.

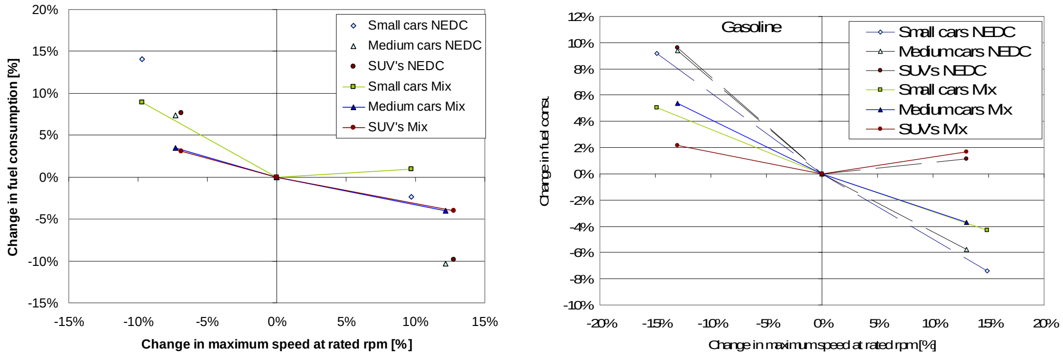


Figure 3-17: Fuel consumption simulated with PHEM for cars with variation of the transmission ratio of the axis (left: Diesel, right: Gasoline).

3.4 Light-commercial vehicles

As input to the CRUISE software, a number of key vehicle characteristics such as mass, drag coefficient, frontal area, engine map and other technical data are required. These are used by the model to calculate the engine operating points over a specified driving cycle and therefore efficiency and fuel consumption. For this study, the main parameters which were used as input for the model were fuel consumption maps, engine power, frontal area and aerodynamic drag, vehicle mass, rolling resistance coefficient(s), gear and final drive ratios, wheel diameter and dimensions and weight of various components.

Calibrated engine maps per vehicle category were used for the simulations. These have been developed in the framework of the HBEFA 3.1 project. The engine maps have been mainly derived from passenger cars and correspond to the three weight categories (N1-I, N1-II, N1-III) of light duty vehicles, further distinguished into fuel used (diesel-gasoline) and emission standard (Euro 0 to Euro 6).

In addition to the definition and simulation of an 'average' vehicle, as in the case of passenger cars, a number of individual light commercial vehicles were simulated, instead of using an average car for each category. There are two main reasons for this decision:

- The diversity of the LCVs market in Europe, with too many different configurations, resulting in large uncertainties associated with producing an 'average' vehicle per category.
- The fact that there are currently only two LCV classes in COPERT, namely gasoline and diesel. Simulation of as many as possible individual vehicles would make possible to develop consumption factors for all three weight classes (N1-I, II and III).

Key technical specifications for the selected vehicles are presented in Table 3-3. The type approval fuel consumption (TA FC) reported by each manufacturer is also included in the same table.

However, 'average' vehicles for each class, similar to passenger cars, were also considered in this case. Values for each parameter were averaged over all vehicles in each LCV class (see Annex 4 for detailed technical data for all individual LCVs) and are presented in Table 3-4. The engine maps used for the 'average' vehicles were calibrated to match average TA values of all LCVs of the same class.

Table 3-3: Technical data of light commercial vehicles selected for the simulations

LCV category	Engine Capacity [cm^3]	Max Power [kW]	Max Torque [Nm/rpm]	Fuel Type	Emission Standard [Euro]	Frontal Area [m^2]	Drag coefficient	Weight [kg]	TA FC [l/100km]
N1-I									
Opel Combo 1.6 Cargo	1597	64	138/ 3000	G	4	2.58	0.35	1210	7.8
Opel Combo 1.7 Cargo	1686	55	165/ 1800	D	3	2.58	0.35	1285	5.4
Nissan NV200 Van	1461	63	200/ 2000	D	4	3.74	0.35	1250	5.2
Fiat Fiorino 1.4 8v	1360	54	118/ 2600	G	4	2.65	0.32	1070	6.9
Fiat Fiorino 1.3 16v Multijet	1248	55	190/ 1750	D	4	2.65	0.32	1090	4.5
N1-II									
Fiat Doblo 1.4 95hp	1368	70	127/ 4500	G	5	3.38	0.32	1340	7.2
Fiat Doblo 1.6 Multijet 105hp	1598	77	290/ 1500	D	5	3.38	0.32	1410	5.2
Opel Vivaro 2.0CDTI 16v 115hp	1995	84	290/ 1600	D	4	4.3	0.35	1700	8.2
Fiat Ducato X250 Medium WB 100 Multijet Cab 30	2198	74	250/ 1500	D	4	4.9	0.31	1620	8.1
Fiat Scudo Van 90 Multijet SW	1560	66	180/ 1750	D	4	3.35	0.325	1661	7.2
Fiat Scudo Van 120 Multijet LW	1997	88	300/ 2000	D	4	3.35	0.325	1732	7.4
N1-III									
Ford Transit SWB Low Roof	2399	76	285/ 1600	D	4	4.6	0.4	1849	9.5
Mercedes Sprinter 210CDI	2143	70	250/ 1400	D	5	4.8	0.4	2060	8.9-9.4
Peugeot Boxer L1H1 120hp	2198	88	320/ 2000	D	4	4.6	0.4	1860	7.6
Iveco Daily S18	3000	130	400/ 1250	D	4	4.7	-	2190	8.98

Table 3-4: Technical data of the 'average' light commercial vehicles

LCV class	Engine Capacity [cm^3]	Max Power [kW]	Max Torque [Nm]	Fuel Type	Emission Standard [Euro]	Frontal Area [m^2]	Drag coefficient	Weight [kg]	FC [l/100km]
N1-I Gasoline	1479	62	128	G	4	3.36	0.35	1163	7.56
N1-I Diesel	1467	59	185	D	4	3.34	0.35	1221	5.42
N1-II Gasoline	1648	75	154	G	4	3.90	0.34	1479	8.48
N1-II Diesel	2026	82	269	D	4	4.11	0.34	1624	7.89
N1-III Diesel	2216	95	319	D	4	4.81	0.4	1996	9.25

From the above table it is evident that no N1-III Gasoline LCVs were selected for the present analysis. This is due to the very low share (approx. 0.2 %) of this LCV class in the European fleet, based on data from a previous study (AEA, 2009). In general, only a small number of gasoline vehicles (3 out of the 15) were selected, which is consistent with their low market share.

3.4.1 CRUISE Parameterisation

As a first step, the above vehicles were set-up within the CRUISE model to calculate their type approval fuel consumption. To this aim, all input parameters collected above related to vehicle, engine, transmission and wheel were entered into the software. Once the vehicles were set-up, the legislated driving cycle (NEDC) was simulated. The NEDC consists of an urban sub-cycle (UDC) and an extra urban sub-cycle (EUDC). Where necessary, the engine maps were calibrated to match the fuel consumption reported by each manufacturer.

In order to determine fuel consumption of the above selected vehicles under real-world driving conditions, and not only under type approval, the Artemis (CADC) driving cycles were introduced in CRUISE. The Artemis cycles are distinguished into three driving cycles that simulate different road operating conditions: An urban cycle (Artemis Urban) resembling urban driving conditions, a semi-urban cycle (Artemis Road) simulating the operation of the vehicle in a regular medium-speed road, and an extra urban cycle (Artemis Motorway) simulating the operation in a high-speed road (André, 2004). The three Artemis cycles can be further split into sub-cycles, i.e. Artemis Urban (1-5), Artemis Road (1-5) and Artemis Motorway (1-4).

In the case of passenger cars it was shown that CADC cycles at a 1/3 mix each overestimate fuel consumption and that the IATS and HBEFA driving cycles were a better mix. There is no such evidence for light commercial vehicles and information on typical driving patterns and real-world fuel consumption is missing. One may expect that LCVs may have completely different driving patterns than PCs and, in addition, typical driving patterns may be difficult to define within each LCV category. For example, one may consider a diesel N1-II vehicle used for the delivery of soda refreshments in restaurants and cafes with many 10 min stops during the day. However, the same vehicle type may be used for delivery of press between cities, hence conducting an entirely different driving pattern. We therefore believe that there is a need for better information of LCVs driving patterns. As a result, it is expected that the exact selection of a driving cycle (CADC or IATS or HBEFA) to simulate 'real-world' driving in this case is within the uncertainty range of the actual driving patterns used by such vehicles.

The simulated fuel consumption of the above vehicles over the NEDC and CADC are presented in Table 3-5, Table 3-6 and

Table **3-7** for the N1-I, N1-II and N1-III vehicles respectively. Results for both individual and 'average' vehicles per LCV class are shown in the tables. Emissions over the CADC are higher by 16% on average compared to type approval for the N1-I category. This, however, decreases for larger vehicles, being 10% for the N1-II and 5% for the N1-III vehicles. The deviation for urban cycles (UDC vs Artemis urban) is more uniform for the three categories, ranging from 14 % for the N1-III to 18% for the N1-I vehicles. For extra-urban conditions the deviation decreases from 23 % for the N1-I to 13% for the N1-III on average.

Table 3-5: Simulated fuel consumption (in l/100 km) for N1-I vehicles; Fuel type in parentheses (G for gasoline and D for diesel)

Driving cycle	Opel Combo 1.6 Cargo (G)	Opel Combo 1.7 Cargo (D)	Nissan NV200 (D)	Fiat Fiorino 1.4 8v (G)	Fiat Fiorino 1.3 16v (D)	Average N1-I (G)	Average N1-I (D)
Type approval FC	7.80	5.40	5.20	6.90	4.50	–	–
UDC	10.23	7.09	6.68	8.82	5.86	9.59	6.78
EUDC	6.17	4.41	4.48	5.68	3.57	6.39	4.57
NEDC	7.73	5.43	5.34	6.83	4.41	7.56	5.42
Artemis urban	12.12	8.17	7.98	10.55	6.93	11.36	7.99
Artemis road	7.32	5.00	5.78	6.62	4.95	7.22	5.72
Artemis motorway	8.92	5.78	6.49	8.19	5.34	9.58	6.29
Artemis (all)	8.87	5.77	6.39	8.00	5.34	9.05	6.17

Table 3-6: Simulated fuel consumption (in l/100 km) for N1-II vehicles; Fuel type in parentheses (G for gasoline and D for diesel)

Driving cycle	Fiat Doblo 1.6 MTJ 105 hp (D)	Opel Vivaro 2.0CDTI 16v (115hp) (D)	Fiat Ducato X250 MWB 100MJT Cab 30 (D)	Fiat Doblo 1.4 95hp (G)	Fiat Scudo Van 90 MTJ SW (D)	Fiat Scudo Van 120 MTJ LW (D)	Average N1-II (G)	Average N1-II (D)
Type approval FC	5.20	8.20	8.10	7.20	7.20	7.40	–	–
UDC	6.64	10.63	10.79	9.09	9.32	10.14	10.98	10.12
EUDC	4.44	6.93	6.36	6.21	5.80	5.98	7.04	6.42
NEDC	5.25	8.20	8.05	7.26	7.14	7.44	8.48	7.89
Artemis urban	7.69	12.55	13.13	11.04	10.77	11.55	13.12	11.15
Artemis road	5.34	7.67	7.69	6.93	7.06	7.66	8.56	6.88
Artemis motorway	5.35	9.50	9.37	9.25	7.01	7.60	10.34	7.31
Artemis (all)	5.31	9.48	9.34	8.79	7.18	7.69	10.10	7.14

Table 3-7: Simulated fuel consumption (in l/100 km) for N1-III vehicles

Driving cycle	Ford Transit SWB Low Roof (D)	Mercedes Sprinter 210CDI (D)	Peugeot Boxer L1H1 120hp (D)	Average N1-III (D)
Type approval FC	9.50	8.9-9.4	7.61	–
UDC	11.84	11.93	9.27	12.69
EUDC	7.92	7.83	6.44	7.34
NEDC	9.41	9.36	7.64	9.25
Artemis urban	13.62	13.43	10.51	14.34
Artemis road	9.27	8.40	7.38	8.58
Artemis motorway	10.65	9.19	8.37	8.95
Artemis (all)	10.22	9.51	8.20	9.16

The above baseline simulation results are graphically illustrated in Figure 3-18, Figure 3-19 and Figure 3-20 for the N1-I, N1-II and N1-III vehicles respectively. A best fit curve is presented separately for the 'individual vehicles' sample and the 'average' vehicle per LCV class, as well as for diesel and gasoline vehicles. Type approval values of the individual vehicles simulated are also shown in each graph.

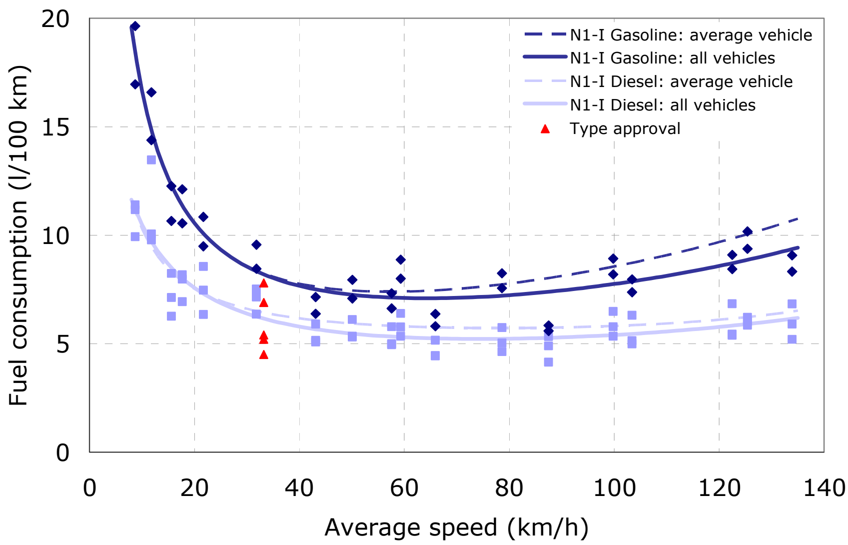


Figure 3-18: Simulation results for N1-I vehicles

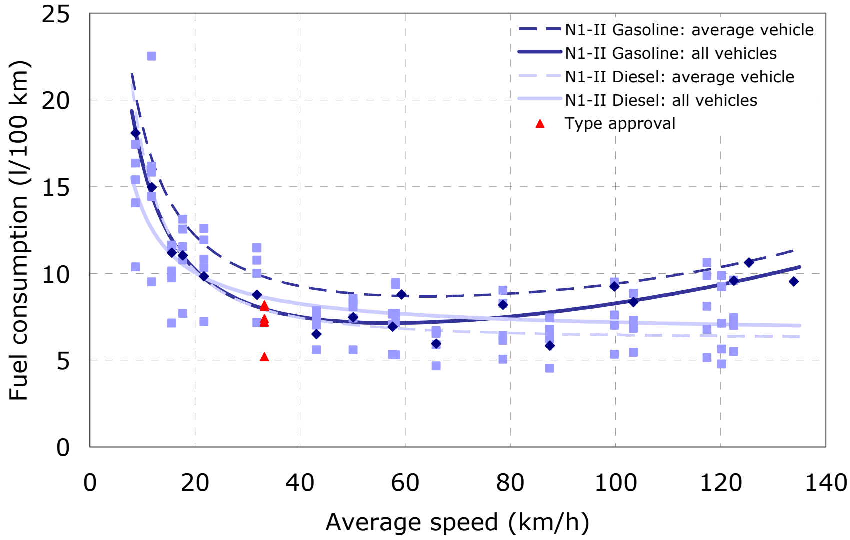


Figure 3-19: Simulation results for N1-II vehicles

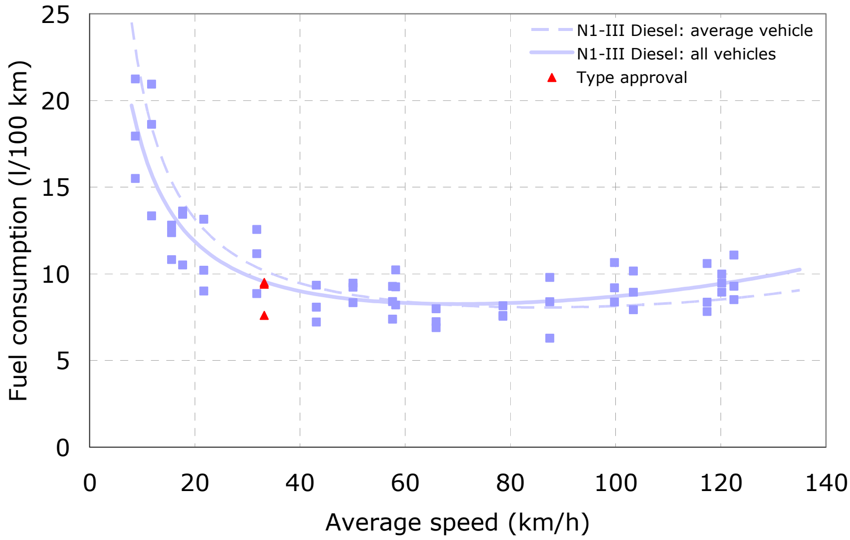


Figure 3-20: Simulation results for N1-III vehicles

From the above graphs it is evident that the 'average' vehicle is very close to the best fit of all individual vehicles for the N1-I and the N1-III classes, whereas larger deviations may be observed for N1-II vehicles. For the N1-II gasoline, this is due to the fact that only one vehicle was simulated, which is the lightest from all N1-II vehicles selected for the analysis and hence the very low fuel consumption observed (dark blue straight line in Figure 3-19). The effect of the number of gears is also evident for the N1-II class. Gasoline vehicles have a five-speed gearbox, which results in an increase in fuel consumption with increasing average speed above 70 km/h. On the other hand, fuel consumption of diesel vehicles, which are equipped with a six-speed gearbox, is kept at a constant level for the same speed range.

3.4.2 Validation

From the A300 database three vehicles were selected, for which detailed technical data exist. These vehicles were simulated with CRUISE and the resulting fuel consumption was compared to the respective measured values. Two of the selected vehicles were Euro 4 and one was Euro 2. Other key technical data are shown in Table 3-8.

Table 3-8: Technical data of the selected LCVs from the A300 database

LCV class	LCV class	Engine Capacity [cm^3]	Max Power [kW]	Fuel Type	Emission Standard [Euro]	Weight [kg]	Number of gears	TA FC [l/100km]
Opel Combo B 17D	N1-I	1686	44	D	2	1860	5	5.4
Fiat Ducato	N1-III	2287	88	D	4	1925	5	8.2
Mercedes Vito	N1-III	2148	80	D	4	1885	6	8.1

The results of this comparison for the selected vehicles are presented in Figure 3-21. Best fits of the tested and the simulated fuel consumption over all Artemis cycles (and sub cycles) are shown in each graph, as well as the individual values from which the best fits were estimated. In general, there seems to be a reasonably good agreement between measured and simulated fuel consumption values for all vehicles, particularly for the low-medium speed range (up to average speeds of about 80 km/h).

Above that speed, the two lines generally tend to diverge slightly with increasing speed for all vehicles. These differences are likely due to an underestimation of the vehicles' air resistances in the simulations with CRUISE. The exact values for both the frontal area and the aerodynamic coefficient (see also section 2.2) of the tested vehicles are unknown and hence the assumed values might be slightly underestimated.

In order to demonstrate this effect, a second simulation for each of the three vehicles was performed, increasing the aerodynamic coefficients by 0.03, i.e. for the Opel from 0.35 to 0.38 and for the Fiat and the Mercedes from 0.4 to 0.43. The results of these additional simulations, included in the same graphs, clearly show that the initial differences for high average speeds may be attributed to the vehicles' aerodynamic characteristics.

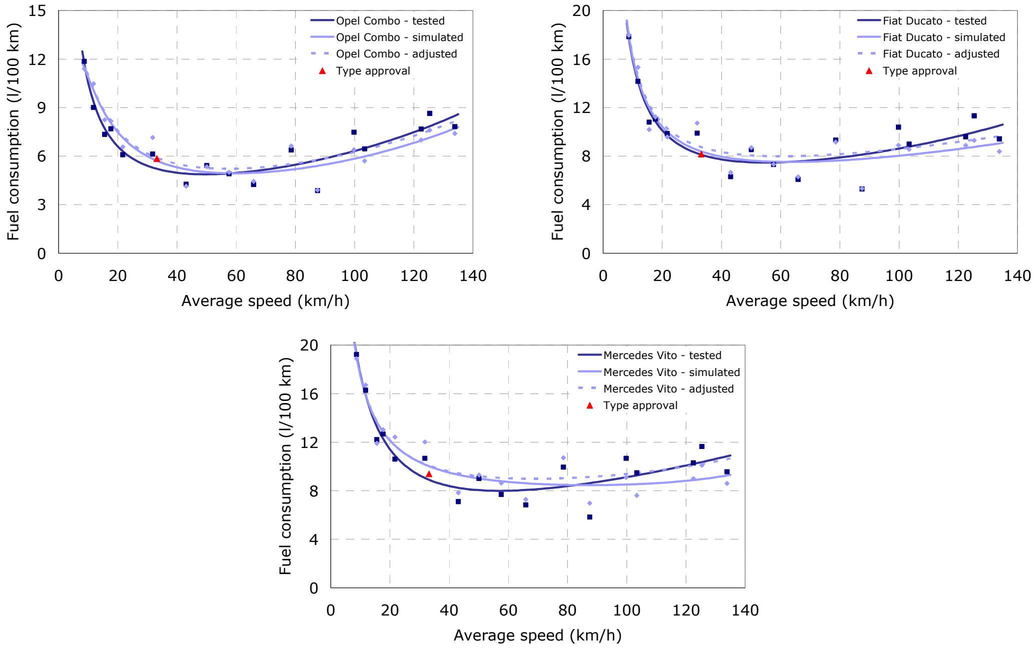


Figure 3-21: Comparison of tested and simulated fuel consumption for the selected LCVs from the A300 database.

3.4.3 Baseline fuel consumption functions

In COPERT 4 and HBEFA 3.1 LCVs are only distinguished into gasoline and diesel, i.e. there is no split in weight classes. Therefore, new baseline functions are introduced in the following, further distinguishing gasoline vehicles in two classes, i.e. N1-I and N1-II, and diesel vehicles in three classes, i.e. N1-I, N1-II and N1-III.

The 'average' vehicles introduced in section 3.4 (technical characteristics shown in Table 3-4) were used to produce the new baseline fuel consumption functions for COPERT. The equation used is of the following general form, similarly to passenger cars:

$$f(\text{baseline}) = \frac{a + c \cdot v + e \cdot v^2}{1 + b \cdot v + d \cdot v^2} + \frac{f}{v} \qquad (1)$$

The coefficients included in Table 3-9 for each LCV class offer the best fit to the simulated fuel consumption of the 'average' vehicles, shown in Table 3-5 to

Table **3-7**.

Table 3-9: Coefficients for the suggested baseline fuel consumption factors for all LCV classes

LCV class	R^2	a	b	c	d	e	f
N1-I Gasoline		7083.234	7.262	-1.818	-0.02196	0.1625	-823.913
N1-II Gasoline		10578.471	11.234	12.690	-0.04445	-0.0023	-798.230
N1-I Diesel		9493.609	19.193	36.588	-0.10109	-0.3914	-434.114
N1-II Diesel		1614.110	6.049	62.335	0.33465	2.1082	-86.614
N1-III Diesel		11638.117	15.904	28.212	-0.07151	-0.2320	-570.534

The proposed baseline fuel consumption of gasoline LCVs as function of the average speed is graphically represented in Figure 3-22. It is evident that the current COPERT function, also shown in the same graph, is not representative of Euro 4 gasoline LCVs, as it largely overestimates fuel consumption in the medium (20 to 50 km/h) and the high (over 100 km/h) speed range.

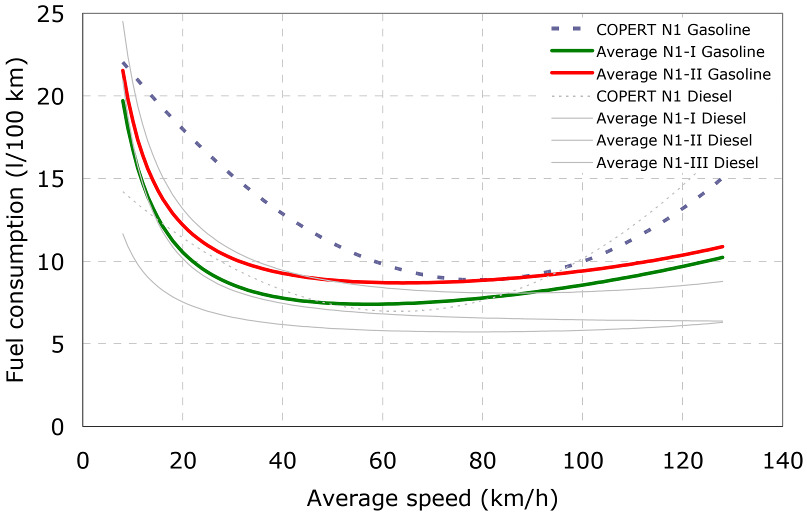


Figure 3-22: Proposed baseline fuel consumption functions for gasoline LCVs.

Similarly, Figure 3-23 shows the proposed fuel consumption functions of diesel LCVs and the current COPERT function.

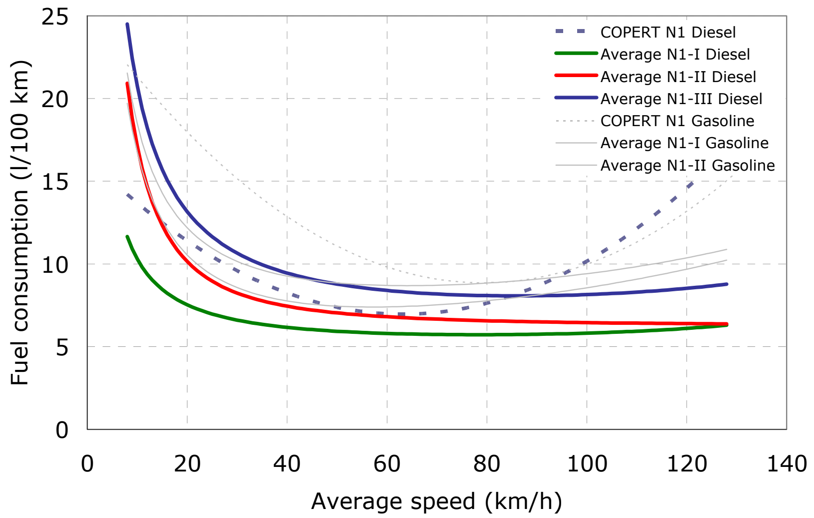


Figure 3-23: Proposed baseline fuel consumption functions for diesel LCVs.

3.4.4 Sensitivity studies

After this baseline calculation, a range of vehicle parameters obtained from section 2.2 were varied. From the various parameters examined, those with the greater influence on fuel consumption were selected. These include vehicle weight, power, aerodynamics, transmission and rolling resistance. The range by which these parameters were varied was determined by the market information received.

More specifically, from the technical data collected for the various models and types of Table 2-5, a range for the vehicle weight, power and frontal area was determined for each N1 class. For the aerodynamic coefficient and rolling resistance, for which data were difficult to collect for all models a variation of +/- 20% was applied.

For the transmission, although detailed gearbox ratios were available for the selected vehicles, having a range of values for each gear would lead to unrealistic gearbox configurations, affecting thus vehicle driveability. Therefore, a uniform variation of +/-10 % was selected. Table 3-10 summarises the variation ranges for the above parameters for each vehicle class.

Table 3-10: Variation range for individual parameters

	N1-I		**N1-II**		**N1-III**	
Fuel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
Weight (kg)	1070-1248	1090-1287	1340-1660	1333-1760	1875-1932	1772-2306
Power (kW)	55-77	51-77	58-88	55-120	85-105	62-136
Frontal area (m^2)	2.58-3.89	2.58-3.89	3.38-4.9	3.38-4.9	3.61-6.19	3.61-6.19
CD	+/- 20%	+/- 20%	+/- 20%	+/- 20%	+/- 20%	+/- 20%
Transm. ratios	+/- 10%	+/- 10%	+/- 10%	+/- 10%	+/- 10%	+/- 10%
Rolling resistance	+/- 20%	+/- 20%	+/- 20%	+/- 20%	+/- 20%	+/- 20%
TA FC (l/100 km)	6.6-8.2	4.5-5.4	7.2-10.3	4.9-9.3	10.1-10.45	7.2-10.4

For the subsequent simulations each of the above selected parameters was varied independently. The effect of each parameter on fuel consumption is presented separately for each N1 class. In the following figures the variation of each parameter is presented in percentage change over baseline configuration for each vehicle simulated. The same applies also for the fuel consumption. In general, gasoline and diesel vehicles exhibit a similar behaviour in terms of their response to variation of the above parameters and thus are presented together in the following graphs.

Figure 3-24 shows the effect of vehicle mass variation. As expected, fuel consumption increases with vehicle mass for all classes. On average, a 20% increase in mass results in about 5% increase in fuel consumption, which is consistent with what was found previously for passenger cars. This increase (or decrease in case of mass reduction) is lowest for heavier vehicles (N1-III) and highest for lighter vehicles (N1-I), whereas N1-II are in between. The effect on fuel consumption seems to be somewhat higher over the type approval, although differences in absolute terms are rather negligible. The reason that FC increase with mass is more prominent for relatively smaller vehicles is not straightforward to explain. One reason could be engine efficiency variations as a function of size. Larger engines operate at relatively lower RPM and have a higher efficiency over the complete engine map. Thus operating a large engine at a different region would have a relatively smaller effect than for a small engine.

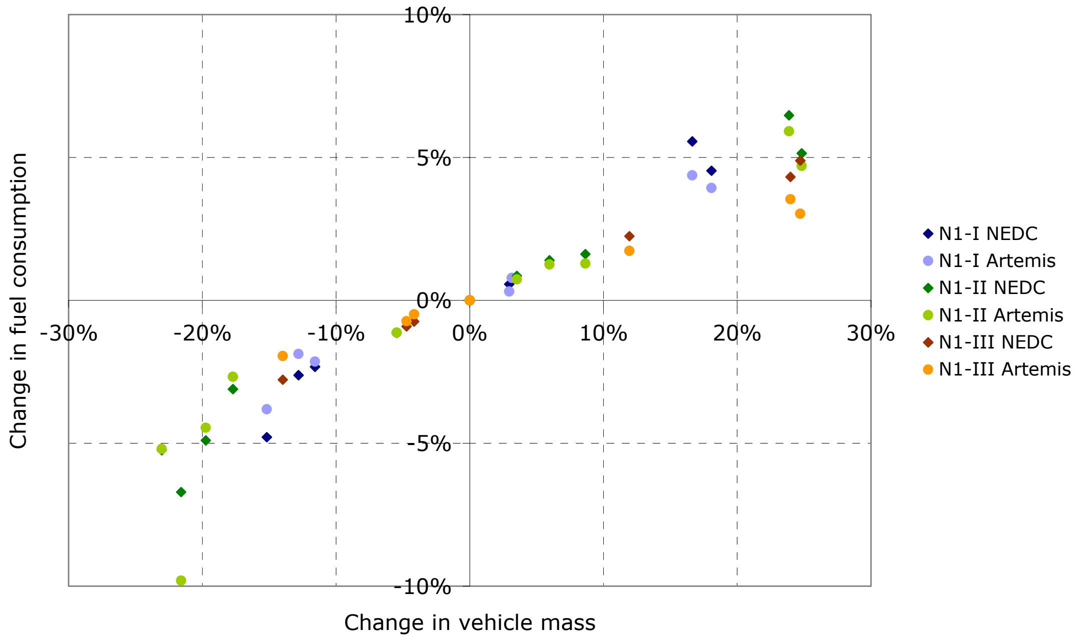


Figure 3-24: Parameterisation results – Effect of vehicle mass

Figure 3-25 shows the effect of air resistance (aerodynamic coefficient and/or frontal area) variation. As expected, fuel consumption increases with air resistance for all classes. This increase (or decrease in case of air resistance reduction) is lower for N1-II and N1-III vehicles (about 4 to 4.5% for a 20% increase in air resistance) compared to N1-I (increase of about 5.5%). The effect on fuel consumption is considerably higher over real-world conditions, due to the higher speeds compared to the NEDC. The reasons for the higher sensitivity of the N1-I category to air resistance changes are the same explained for the effect of mass.

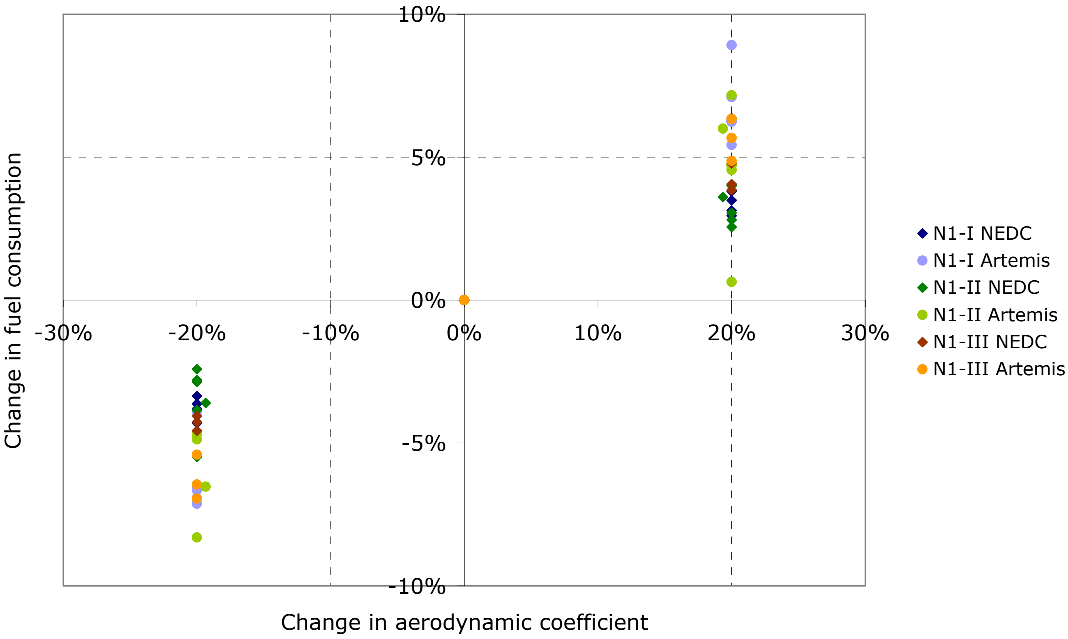


Figure 3-25: Parameterisation results – Effect of air resistance

Figure 3-26 shows the effect of rated engine power variation. Fuel consumption increases with engine power for all classes. This is because when power increases, the engine is forced to operate at lower efficiency to overcome the same resistance. On average, a 40% increase in engine power results in about 20% increase in fuel consumption, which is consistent with what was found previously for passenger cars. These variations are on the same order of magnitude for all three classes, without any clear trend. An interesting observation is that the effect on fuel consumption seems to be somewhat higher over the type approval, which is mainly due to moving outside the area of optimum efficiency of the engine map. This is also consistent with what was found previously for passenger cars.

Figure 3-27 shows the effect of transmission ratios variation. Fuel consumption increases with higher transmission ratios for all classes. These variations are on the same order of magnitude for all three classes, without any clear trend due to the high variability in results. It should be noted that there is a fixed gearshift strategy for both the NEDC and CADC.

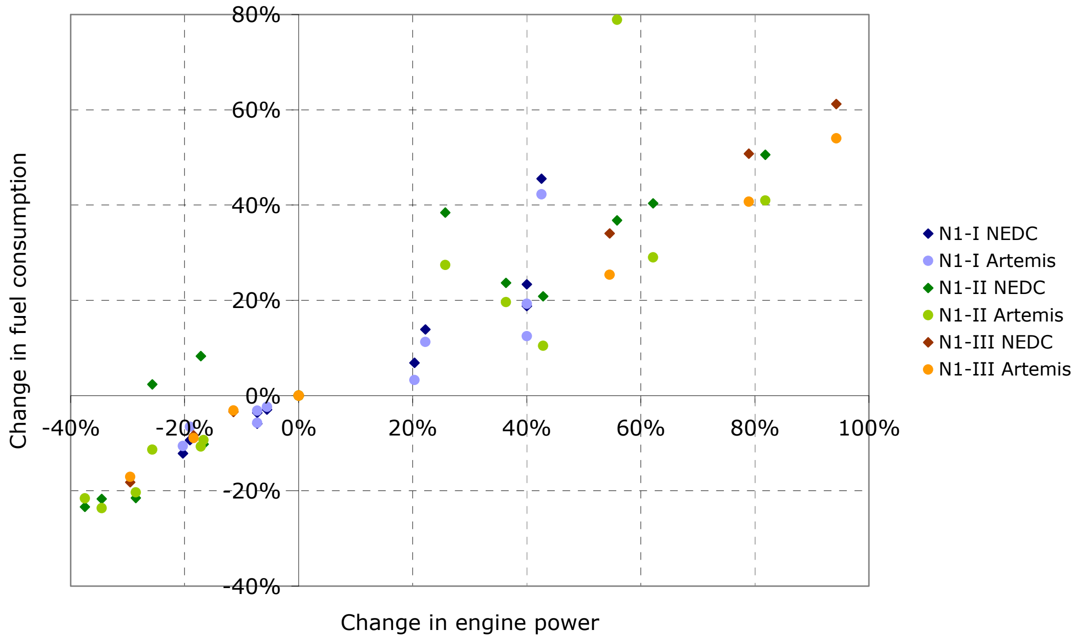


Figure 3-26: Parameterisation results – Effect of engine power

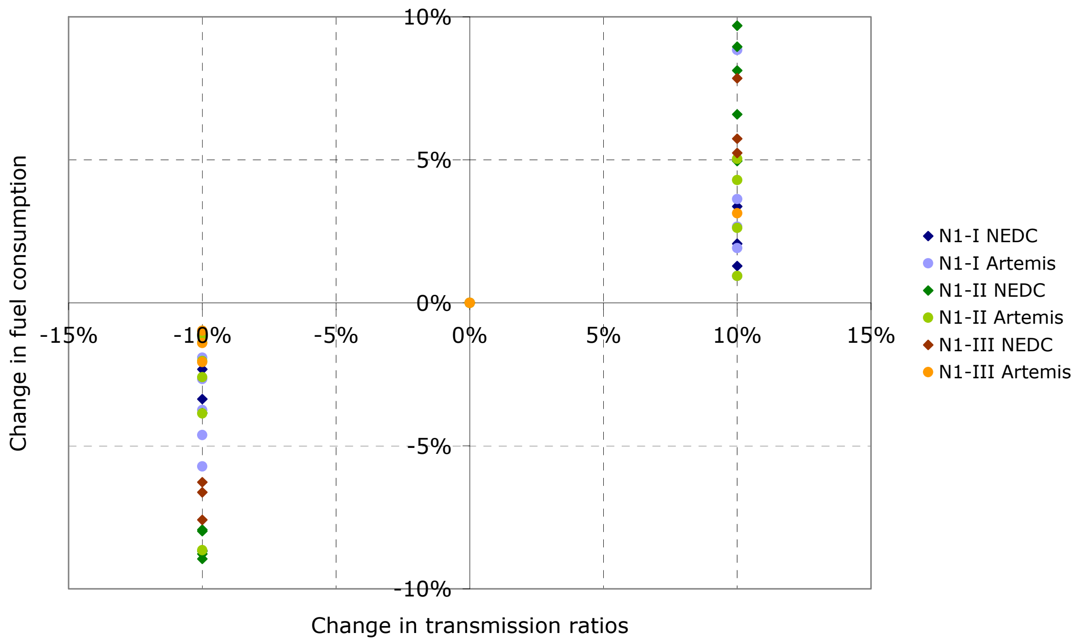


Figure 3-27: Parameterisation results – Effect of transmission ratios

Figure 3-28 shows the effect of rolling resistance variation. Fuel consumption increases with rolling resistance for all classes. This increase (or decrease in case of rolling resistance reduction) is lower for N1-III vehicles (about 1% for a 10% increase in rolling resistance) compared to N1-I and N1-II (increase of about 2%), which is consistent with what was found previously for passenger cars (Figure 3-15 and Figure 3-16). The effect on fuel consumption seems to be somewhat higher over the type approval, although differences in absolute terms are rather negligible.

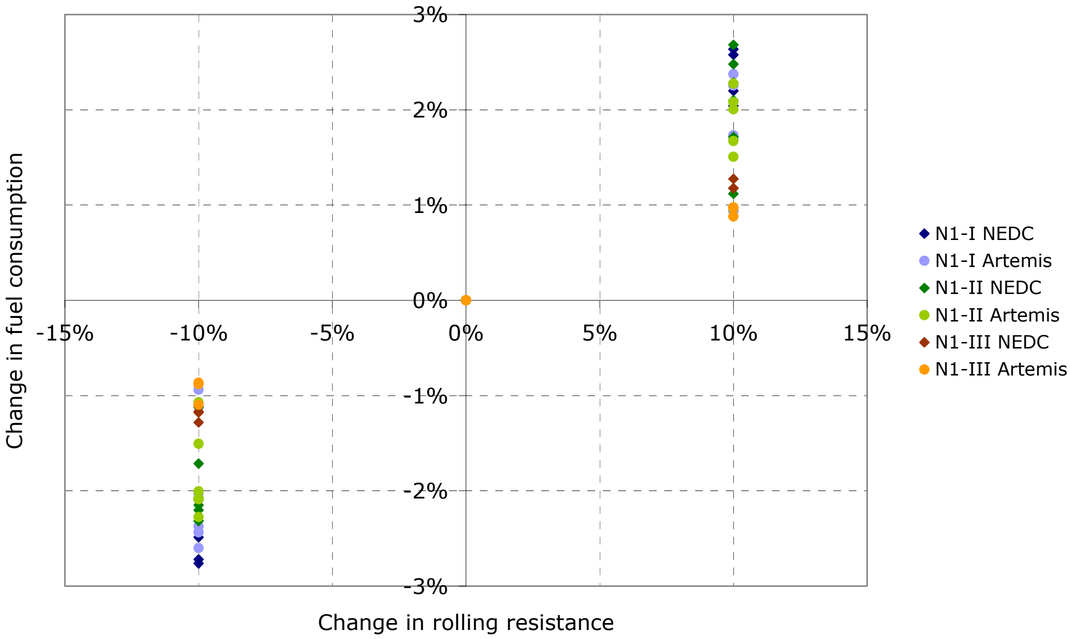


Figure 3-28: Parameterisation results – Effect of rolling resistance

3.4.5 Statistical analysis

A meta-analysis of the data developed in section 3.4 was conducted for the light commercial vehicles, with the aim to develop models for LCVs to predict fuel consumption on the basis of vehicle specifications. In this case, no independent data on FC InUse could be located. Therefore, the whole analysis should be based on simulated data. The models developed were of the general formula:

FC [g/km]= f(baseline) * g(mass) * h(aero) * i(power) * j(gear) * k(roll) (2)

In these functions, f(baseline) is the baseline function of FC for the 'average' LCV per category. The functions g, h, i, j and k are correction functions which differentiate this baseline emission according to the different vehicle parameters, i.e. vehicle mass, aerodynamic coefficient, engine power, transmission ratios and rolling resistance respectively.

The above equation can be directly used to calculate the fuel consumption of a particular vehicle type of particular specifications. For example, if the Euro 4 diesel N1-I vehicles in Italy have a smaller weight than in Germany, then by adjusting the mean weight in the relevant function (g), the corrected fuel consumption for the same vehicle type in the two countries will be calculated.

3.4.6 Regression analysis

The fuel consumption simulated with CRUISE in section 3.4 was used as dependent variable for the regression analysis. Each of the vehicle parameters identified above, i.e. vehicle mass, aerodynamic coefficient, engine power, transmission ratios and rolling resistance is the independent variable.

A simple linear model was selected for the functions g, h, i, j, k:

g(mass), h(aero), i(power), j(gear), k(roll) = 1 + a * p (3)

Where a is the regression coefficient and p is the independent variable, given as percentage variation over baseline. As an example, to calculate the fuel consumption correction factor when reducing vehicle mass by 20%, p=-20 should be introduced in the above function.

Results of the regression analysis are summarised in Table 3-11, Table 3-12, Table 3-13, Table 3-14 and Table 3-15 for the N1-I diesel, N1-I gasoline, N1-II diesel, N1-II gasoline and N1-III diesel classes respectively. Indicators for the quality of fit, such as the standard error of the estimate and the coefficient of multiple determination (R^2) are also provided in the tables.

Table 3-11: Regression analysis results for diesel N1-I

Variable	Vehicle mass	Aerodynamic drag	Rated engine power	Transmission ratios	Rolling resistance
a	2.33E-03	2.36E-03	4.81E-03	5.15E-03	7.69E-04
Standard error	0.0148	0.0408	0.0446	0.0745	0.0342
R^2	0.7165	0.4726	0.8311	0.2178	0.1161

Table 3-12: Regression analysis results for gasoline N1-I

Variable	Vehicle mass	Aerodynamic drag	Rated engine power	Transmission ratios	Rolling resistance
a	2.57E-03	2.42E-03	8.33E-03	3.57E-03	1.24E-03
Standard error	0.0108	0.0363	0.0682	0.0183	0.0146
R^2	0.8142	0.5443	0.8561	0.7187	0.6613

Table 3-13: Regression analysis results for diesel N1-II

Variable	Vehicle mass	Aerodynamic drag	Rated engine power	Transmission ratios	Rolling resistance
a	2.34E-03	2.06E-03	5.51E-03	5.50E-03	8.95E-04
Standard error	0.0129	0.0322	0.0619	0.0422	0.0142
R^2	0.8445	0.5196	0.9159	0.5298	0.5151

Table 3-14: Regression analysis results for gasoline N1-II

Variable	Vehicle mass	Aerodynamic drag	Rated engine power	Transmission ratios	Rolling resistance
a	2.71E-03	2.69E-03	6.58E-03	3.93E-03	1.02E-03
Standard error	0.0157	0.0400	0.0614	0.0151	0.0069
R^2	0.8139	0.5505	0.9125	0.8215	0.8564

Table 3-15: Regression analysis results for diesel N1-III

Variable	Vehicle mass	Aerodynamic drag	Rated engine power	Transmission ratios	Rolling resistance
a	1.82E-03	2.13E-03	5.47E-03	4.48E-03	4.88E-04
B					
Standard error	0.0143	0.0304	0.0660	0.0349	0.0071
R^2	0.7212	0.5675	0.9263	0.5127	0.5594

Generally, the quality of fit is high taking into account the number of individual vehicles included in the analyses. It is somewhat lower for the transmission ratios and rolling resistance functions compared to the mass, aerodynamics and engine power functions. The parametric functions resulting from the regression analysis are illustrated in the following figures (Figure 3-29 to Figure 3-33).

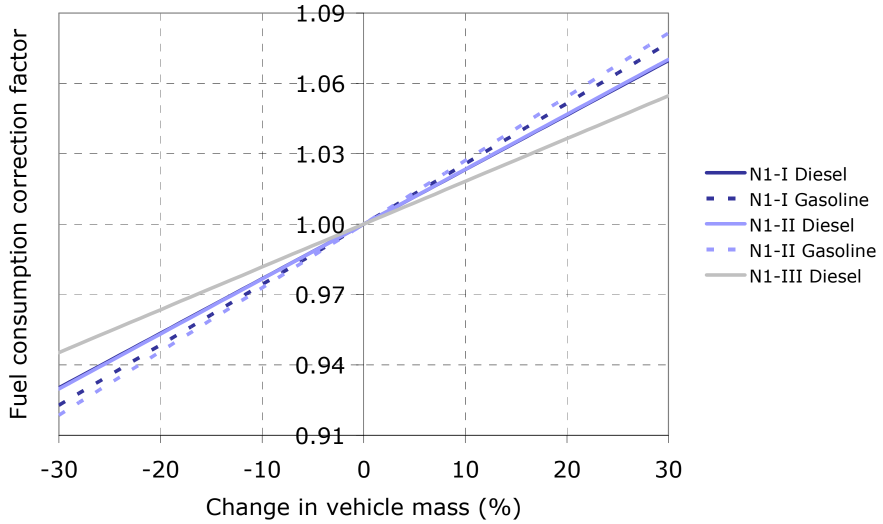


Figure 3-29: Effect of vehicle mass

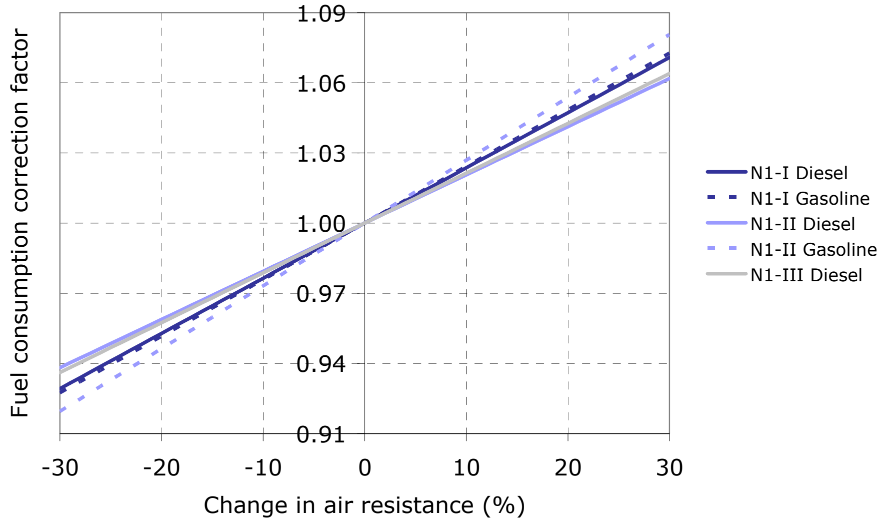


Figure 3-30: Effect of air resistance

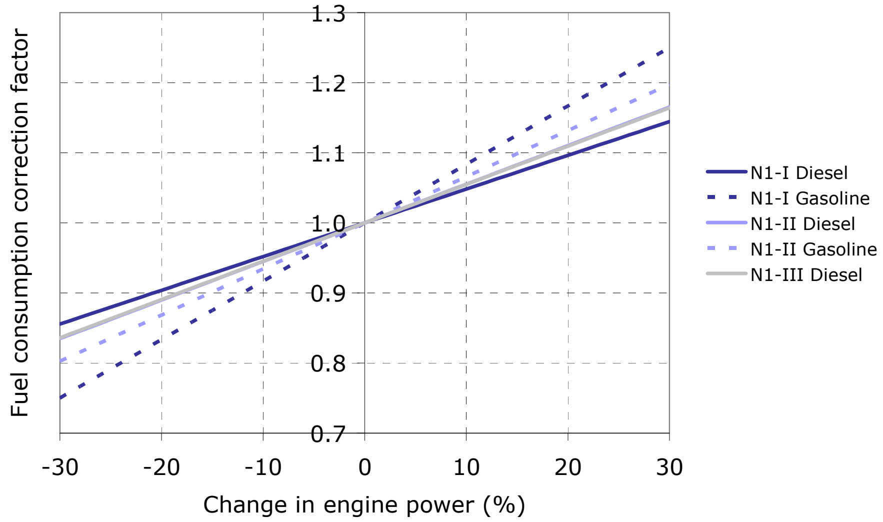


Figure 3-31: Effect of engine power

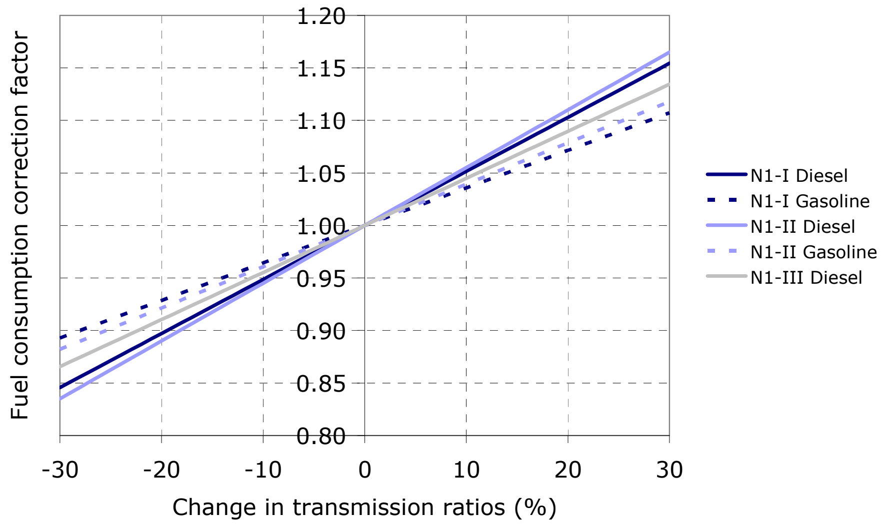


Figure 3-32: Effect of transmission ratios

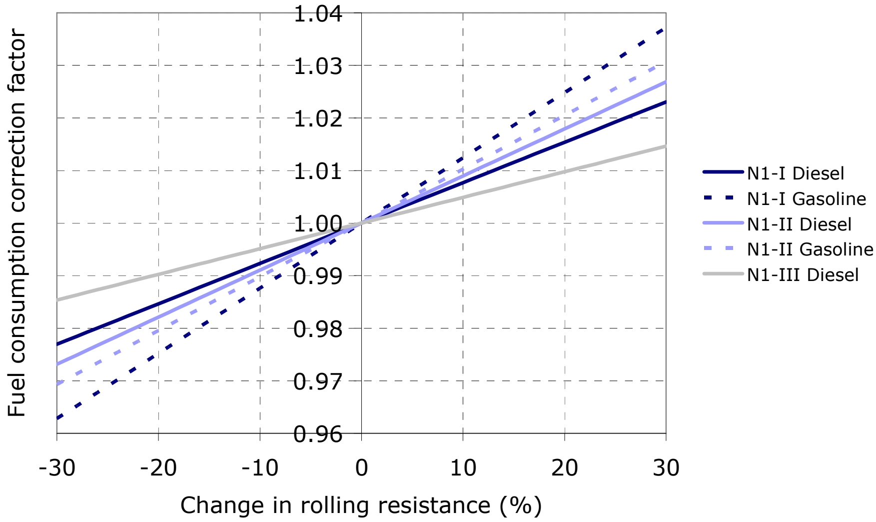


Figure 3-33: Effect of rolling resistance

4 Models to predict In-Use fuel consumption

4.1 Simplified models of in-use passenger car fuel consumption

In the context of emission inventory development and road transport emission models, the basic objective is to derive a function for calculating the real world fuel consumption based on either vehicle characteristics (only) or to include the type-approval fuel consumption as well, since one can assume that the latter information will be available at national level based on the CO_2 monitoring database. The data presented in section 2.1.1 from all sources (sample "All") and in section 2.1.6 (sample "A") can therefore be used to develop such multiple regression functions between FC InUse, vehicle specifications and FC TA values.

Several models have been tested using the available empirical data of sample "All" and sample "A". The set of vehicle specifications that can be used as possible independent variables (mass, power, capacity) was rather crude. Many additional specifications, such as emission concept, year of manufacture, or gearbox configuration, were not at all available or only available in a very limited extent[12]. Therefore the focus had to be put on the broadly available characteristics. Even more refined technical specifications like aerodynamics, transmission ratios, rolling resistance etc. were not at all or hardly available. Considering the application of such functions, it would be unlikely to have those characteristics available for the entire vehicle fleet. However, the additional influence of those variable types could be nevertheless of interest (e.g. for assessing the overall effect of the improvement of particular characteristics). The effect of these variables on fuel consumption is therefore analyzed in section 4.3.

Four simplified model families were tested in total. Three model families produce FC InUse as the dependent variable, using different linear combinations of independent variables (vehicle specifications), i.e.

$$FC_{In\text{-}Use}[g/km] = \left(b + m_1\,var_1 + m_2\,var_2 + m_3\,var_3 + m_4\,var_4\right) \qquad (4)$$

These three model families were the following:

- Model family V1X, which uses mass and power as the only independent variables (hence the family only consists of one member).
- Models family V2X, which use FC TA as an independent variable, and
  V21 adds mass
  V22 adds mass and power,
  V23 adds power/mass ratio
- Models family V4X, which use FC TA as an independent variable similar to model family V2X, and
  V41 adds mass, power, and cc
  V42 adds mass and cc
  V43 adds mass and power/cc

An additional model family (V3X) used the ratio FC InUse over FC TA as the dependent variable. Hence, the formulation in this case was:

[12] In principle such data could be collected (e.g. from registration authorities). However, the allocation of such data to the vehicles in the samples would have been often ambiguous and time consuming since the vehicles were not always described very precisely enough to allow a precise assignment of attributes.

$$\frac{FC_{In\text{-}Use}}{FC_{TA}}[g/km] = \left(b + m_1\ var_1 + m_2\ var_2 + m_3\ var_3\right) \qquad (5)$$

This, leads to:

$$FC_{In\text{-}Use}[g/km] = FC_{TA} \times \left(b + m_1\ var_1 + m_2\ var_2 + m_3\ var_3\right) \qquad (6)$$

In models family V3X, model

V31 adds mass

V32 adds mass and power

V33 adds power/mass

In addition, the models V21-G and V21-E have extended the model V21 by the variable "gear shift" (automatic resp. manual) and "emission concept" (in fact Euro-3, Euro-4 or Euro-5), using the data where this parameter was available (approximately 1/3 of the sample).

Table 4-1 gives an overview of the empirical models analysed to examine how well they can predict in-use fuel consumption. The R^2 values of the regression functions are also shown. The table shows the specification of the model, i.e. the independent variables used and as a result the R^2 values as an indicator for the quality of the fit. If appropriate, the models were fitted to the whole data set as well as to different subsamples (i.e. different data sources). All models are applied separately for petrol and diesel cars.

Table 4-1 shows that all models have comparatively high R^2 values. Adding variables (e.g. power or cc in addition to mass) increases the R^2 value only marginally (due to multi-correlation). Depending on the samples the statistical fits change in a limited range (e.g. for petrol cars from 0.87 to 0.93 for model V21). Nevertheless, depending on the case of application or assuming developments where mass, power and/or cc do not follow the same trends, a model with more variables could provide more adequate results.

Comparing the models which calculate FC TA in absolute terms (e.g. V22 or V42) resp. the ratio-model (V32), it turns out that V22 or V42 models perform better than V32 for petrol cars; while the difference is even more pronounced for diesel cars (example for sample "A" in Figure 4-1). Hence the models calculating FC TA in absolute terms are to be preferred. The models V22 or V42 perform well providing R^2 values of about 0.9 (petrol) and 0.85 (diesel).

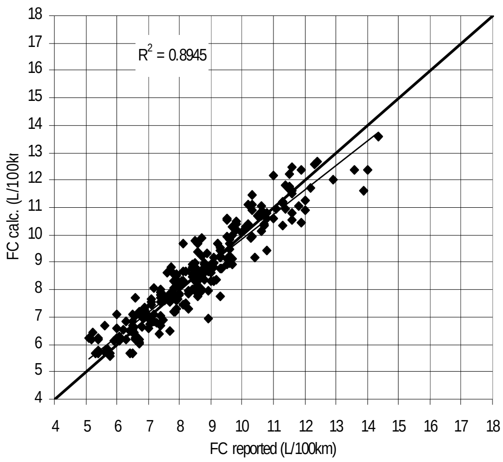
Table 4-1: Coefficients of determination R^2 of the different models (specified by different independent variables resp. different samples) for petrol resp. diesel cars

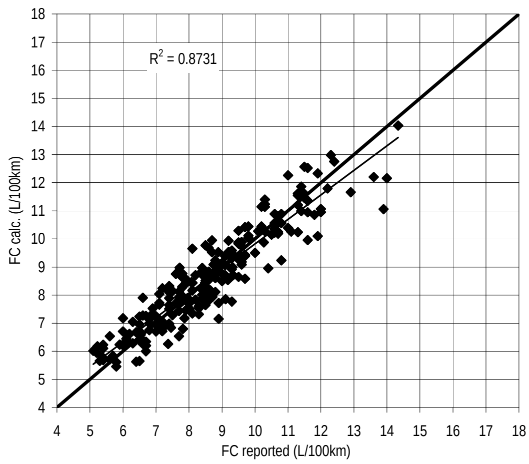
Petrol

Model	Nr of Veh	V11 (FC)	V21 (FC)	V22 (FC)	V23 (FC)	V31 (ratio)	V32 (ratio)	V33 (ratio)	V41(FC)	V42(FC)	V43(FC)	V21-G	V21-E
Var. 1		mass	FC TA	FC TA	FC TA	mass	mass	power/mass	FC TA	FC TA	FC TA	FC TA	FC TA
Var. 2		power	mass	mass	power/mass		power		mass	mass	mass	mass	mass
Var. 3				power					power	cc	power/cc		
Var. 4									cc			Gearshift	Em-Concept
Samples:													
all	611	0.805	0.892	0.906	0.890	0.861	0.861	0.871	0.907	0.898	0.901		
Sample A	238	0.797	0.871	0.895	0.876	0.843	0.843	0.848	0.896	0.873	0.887		
TCS, AR only	384		0.899	0.922	0.899								-
SMon only	29		0.916	0.921	0.905								-
A300DB only	140		0.928		0.922								
Sample with E-Conc	227		0.879										0.880
all excl TCS	259		0.893									0.894	

Diesel

Model		V11 (FC)	V21 (FC)	V22 (FC)	V23 (FC)	V31 (ratio)	V32 (ratio)	V33 (ratio)	V41(FC)	V42(FC)	V43(FC)	V21-G	V21-E
Var. 1		mass	FC TA	FC TA	FC TA	mass	mass	power/mass	FC TA	FC TA	FC TA	FC TA	FC TA
Var. 2		power	mass	mass	power/mass		power		mass	mass	mass	mass	mass
Var. 3				power					power	cc	power/cc		
Var. 4									cc			Gearshift	Em-Concept
Samples:													
all	317	0.727	0.852	0.854	0.826	0.802	0.802	0.822	0.857	0.857	0.852		
Sample A	172	0.823	0.876	0.880	0.840	0.803	0.803	0.830	0.882	0.881	0.876		
TCS, AR only	131		0.882	0.884	0.855								
SMon only	32		0.961	0.969	0.924								
A300DB only	81		0.874		0.862								
Sample with E-Conc	186		0.815										0.817
all excl TCS	195		0.845									0.849	





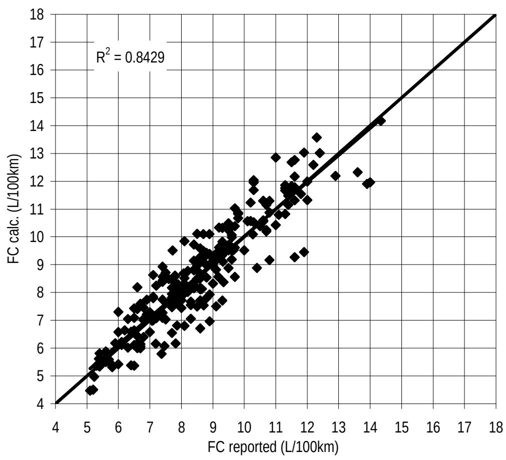


Figure 4-1: Comparison of the models V22 (upper left), V42 (upper right) and V32 (low) for petrol cars, using sample "A"

Adding gear shift or emission concept does not really improve the model (if added as a variable). Alternatively, application of the models to distinct samples could be considered (with automatic resp. manual gearshift-types). However, the sample size would then decrease considerably and would not allow robust results to be obtained.

Annex 6 lists all relevant statistical parameters of the different models for sample "All" as well as for sample "A". Considering also the contribution of the different variables used in the function (and assuming that a common model structure for petrol and diesel is more appropriate) then model V42 is preferred since all variables are significant (in both samples "All" and "sample A") while in model V22 (diesel, both samples) the variable power is not significant. Hence model V42 is proposed to be used as correction functions.

The correction functions then are as Table 4-2 shows:

Table 4-2: Parameters of the function (model V42) for petrol resp. diesel cars (specified by for different samples)

Sample:	Variables and values				
		CC	mass	FC TA	b
Sample all	Petrol	0.000392	0.00119468	0.64317739	1.14973753
Sample all	Diesel	0.000253	0.00145365	0.65413719	0.13381787

Where: FC TA (type approval) in L/100 km
mass = empty weight + 75 kg
CC=capacity (displacement in cubic centimetre)
b = constant

Considering the statistical significance of the functions and parameters as well as the homogeneity of the model parameters it is proposed to use model V42 based on Sample "All". The application of the exact correction function (sample "A" or sample "All") influences the result by only about 2% (sample "A" leading to slightly higher correction factors).

4.2 Detailed models of in-use passenger car fuel consumption

The simplified models in section 4.1 were derived without having information on detailed vehicle characteristics. Therefore, these models are ideal to apply for large vehicle fleets, for which obtaining detailed information is not possible. However, if detailed information is available, for example for a smaller vehicle fleet, then models where more information can be provided may probably achieve a better FC InUse prediction. This section provides such model options, using regression analysis on the more detailed vehicle sample "B".

Similar to the simple models, FC InUse was used as the dependent variable, however this time expressed in g/km, because InUse FC in this case is determined by tests conducted on the chassis dynamometer and are not measured on the road. Independent variables tested were the vehicle category, mass (kg), power (kW), Cd × A, rolling resistance coefficient as [$r_0+18\times r_1$], the transmission ratio "i_{tot}" as [i_{axis} x $i_{highest\ gear}$] and the fuel consumption in the type approval in [g/km] as "FC TA".

All parameters with exception of the vehicle category were statistically significant and can be integrated into the regression model.

The following three families of regression models were established:

- Model FC-1 without FC TA included but taking into account detailed vehicle specifications (i.e. resistances also included). The model is applicable to EURO 5 cars; correction factors for EURO 0 to EURO 4 have to be applied separately.

- Model FC-2 without FC TA included and restricted to variables which can most likely be made available for a national fleet of new vehicle registrations. Similar to FC-1, this model is applicable to EURO 5 cars, while correction factors for EURO 0 to EURO 4 have to be applied separately).
- Model FC-3 including the FC TA value and vehicle mass.

Each model is separately parameterised for diesel cars and for gasoline cars. The model FC-3 is recommended for new passenger car fleets, where the FC TA is known typically from the CO_2 Monitoring Database. The effect of advanced drivetrain technology (such as start-stop) on fuel consumption seems to be reflected by the type approval data quite well. Other parameters which could define the specific fuel efficiency of an engine and energy losses in the propulsion system in a similar way are not available on a fleet statistics level.

4.2.1 Diesel car regression models

Model FCD-1

The detailed model without the type approval fuel consumption value from the vehicle fleet reaches a high quality (Table 4-3) but several parameters are necessary, which may be quite hard to be found for national vehicle fleets (Table 4-4). From the simulation runs also the total transmission ratio had a significant influence on the real world fuel consumption. Since the effect of a variation in the transmission ratios on the gear shift behaviour of the drivers includes a rather high uncertainty, the transmission ratio was excluded from model FCD-1.

Table 4-3: Quality of the regression model FCD-1 for the fuel consumption of diesel passenger cars

Model	R	R^2	corrected R^2	Standard error
FCD-1	0.999[e]	0.998	0.998	0.577

The parameters listed in Table 4-4 lead to the following equation for the assessment of the real world fuel consumption of Euro 5 diesel cars:

$$FC[g/km] = -6.17 + 0.3 \times P_{rated}[kW] + 16.5 \times (c_d \times A)[m^2] + 939.4 \times (r_0 + 18 \times r_1) + 0.0085 \times m\,[kg] \quad (7)$$

With P_{rated}: average engine rated power of the fleet [kW]

m: vehicle mass (empty weight + 75kg for driver and 20 kg for fuel), corresponding to the mass in the license

$r_0+18\,r_1$: value for the rolling resistance coefficient at 18 m/s[13] [-]

Table 4-4: Coefficients of the regression model FCD-1 for the fuel consumption of diesel passenger cars

Model		Non standardised coefficient		Standardised coefficient		
		Coefficient B	Standard error	Beta	T	Sig.
FCD-1	(Constant)	-6.166	0.703		-8.770	0.000
	Power (kW)	0.298	0.006	0.658	48.532	0.000
	C_d x A	16.494	0.957	0.188	17.239	0.000
	r_0+18*r_1	939.431	57.239	0.110	16.412	0.000
	Mass (kg)	0.0085	0.001	0.191	13.924	0.000

13 The average speed of the real world cycle mix from section 0 is 67 km/h, thus 18 m/s were used to depict “average rolling resistance” for the speed dependent part of the rolling resistance coefficient.

Model FCD-2

The simplified model, also without the type approval fuel consumption value from the vehicle fleet, reaches also an astonishing high quality (Table 4-5). The parameters necessary to calculate the diesel car fleet fuel consumption should be available (Table 4-6).

Table 4-5: Quality of the regression model FCD-2 for the fuel consumption of diesel passenger cars

Model	R	R^2	corrected R^2	Standard error
FC-2	0.982[c]	0.964	0.963	2.66

Table 4-6: Coefficients of the regression model FCD-2 for the fuel consumption of diesel passenger cars

		Non standardised coefficient		Standardised coefficient		
		Coefficient B	Standard error	Beta	T	Sig.
FCD-2	(Constant)	1.045	2.465		0.424	0.673
	Power (kW)	0.374	0.032	0.825	11.824	0.000
	Mass (kg)	0.0182	0.003	0.411	6.834	0.000
	Category	-3.907	1.427	-0.233	-2.737	0.008

The parameters listed in Table 4-6 lead to the following equation for the assessment of the real world fuel consumption of Euro 5 diesel cars:

$$FC[g/km] = 1.045 + 0.374 \times P_{rated}[kW] + 0.018 \times m\,[kg] - 3.91 \times category \qquad (8)$$

With category: small cars = 1. medium cars = 2. SUVs = 3

m: vehicle mass (empty weight + 75kg for driver and 20 kg for fuel), corresponding to the mass in the licence

Model FCD-3

The model with the type approval fuel consumption value from the vehicle fleet reaches also a high quality (Table 4-7). Besides the TA FC value which should be available from approx. year 2000 on (KBA data even since 1997) from the CO_2 monitoring database, only the average mass of the vehicles in the fleet has to be known (Table 4-8).

Table 4-7: Quality of the regression model FCD-3 for the fuel consumption of diesel passenger cars

Model	R	R^2	corrected R^2	Standard error
FCD-3	0.995[b]	0.989	0.989	1.44

Table 4-8: Coefficients of the regression model FCD-3 for the fuel consumption of diesel passenger cars

Model		Non standardised coefficient		Standardised coefficient	T	Sig.
		Coefficient B	Standard error	Beta		
FCD-3	(Constant)	2.981	0.861		3.462	0.001
	FC NEDC TA	0.895	0.030	0.879	29.455	0.000
	Mass (kg)	0.0056	0.001	0.125	4.192	0.000

The parameters listed in Table 4-8 lead to the following equation for the assessment of the real world fuel consumption of Euro 5 diesel cars:

$$FC[g/km] = 2.981 + 0.895 \times TA\_FC[g/km] + 0.0056 \times m[kg] \quad (9)$$

With TA_FC: Fuel consumption value of the fleet in the type approval test (from CO_2 Monitoring Database) in [g/km]

m: vehicle mass (empty weight + 75kg for driver and 20 kg for fuel), corresponding to the mass in the licence

Model FCD-3 is comparable to model V22 from section 4.1, which also has the fuel consumption in type approval and the vehicle mass but also the engine power as variables. Figure 4-2 compares the results from model V22 with the regression models FCD-1 to FCD-3 for the diesel cars with the input data on the fuel consumption of the diesel car fleet. The regression models FCD-1 and FCD-3 meet the input data with a maximum deviation of 7% and 10% respectively. Model FCD-3 has a maximum deviation of 8% but needs less input data. Model V22 which was elaborated from the large data based on in-use tests from different sources has a maximum deviation of 9% with an average of +/-3% against the values defined as "real world" fuel consumption in this section.

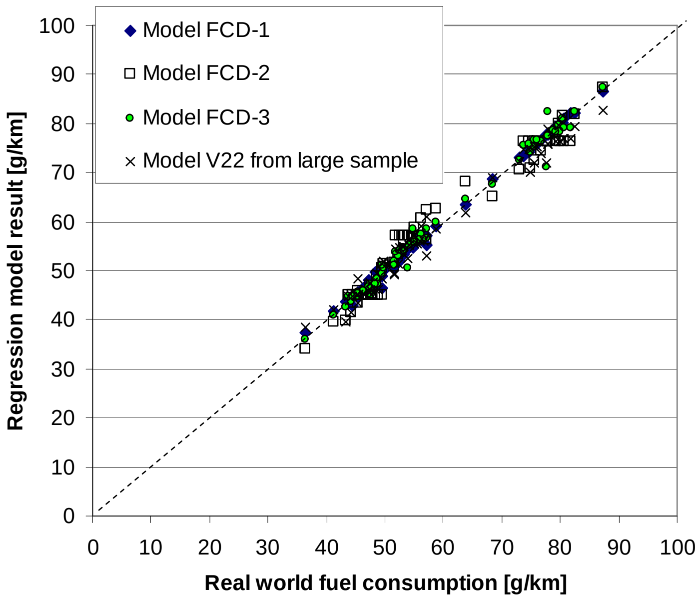


Figure 4-2: Fuel consumption simulated with the regression models for diesel cars EURO 5. The real world fuel consumption represents the simulated real world mix for the selected makes and models of diesel cars from section 2.1.7 (sample "B").

It has to be pointed out that the "real world" mix was defined in this section as average of the IATS and the HBEFA V3.1 cycles with 5% additional cold start fuel consumption while in the analysis in section 4.1 the real world fuel consumption was obtained from the in-use data recorded from different drivers in the real world operation. Therefore, the consistency between the predicted real world fuel consumption from model FCD-3 and V22 is astonishingly good. However, the influence of the single variables is different. In model FCD-3 the engine rated power is not significant while in V22 the rated power is included. Furthermore, model FCD-3 predicts a more significant increase of FC over FC TA than model V22 does. The differences in the models FCD and V22 may be explained by the different average driving styles for different vehicle categories and power to weight ratios in an in-use sample while the models FCD were build up with the same test cycles for all variations in the vehicle parameters. Uncertainties in both the PHEM model and in-use data set can influence the results too.

4.2.2 Gasoline car regression models

The set up of the regression models for gasoline cars followed the same methods as already described for diesel cars.

Model FCG-1

The detailed model for gasoline cars without the type approval fuel consumption value from the vehicle fleet reaches a similar high quality than the model for diesel (Table 4-9). Some of the parameters may hardly be available for national vehicle fleets (Table 4-10). Compared to the model FCD-1 for diesel cars the engine power has a higher influence, while the rolling resistance coefficients show slightly less effect. These results are in line with the analysis on the effect of single parameters shown in section 2.1.3.

Table 4-9: Quality of the regression model FCG-1 for the fuel consumption of gasoline passenger cars

Model	R	R^2	corrected R^2	Standard error
FCG-1	0.992[e]	0.985	0.984	1.78

Table 4-10: Coefficients of the regression model FCG-1 for the fuel consumption of gasoline passenger cars

Model		Non standardised coefficient		Standardised coefficient		
		Coefficient B	Standard error	Beta	T	Sig.
FCG-1	(Constant)	2.490	2.067		1.205	0.232
	Power (kW)	0.327	0.014	0.697	23.319	0.000
	C_d x A	14.985	2.520	0.144	5.947	0.000
	r_0+18*r_1	532.638	173.843	0.050	3.064	0.003
	Mass (kg)	0.010	0.001	0.214	7.286	0.000

The parameters listed in Table 4-10 lead to the following equation for the assessment of the real world fuel consumption of Euro 5 gasoline cars:

$$FC[g/km] = 2.49 + 0.327 \times P_{rated}[kW] + 14.99 \times (c_d \times A)\,[m^2] + 532.64 \times (r_0 + 18 \times r_1) + 0.01 \times m\,[kg] \qquad (10)$$

With P_{rated}: average engine rated power of the fleet [kW]

m: vehicle mass (empty weight + 75kg for driver and 20 kg for fuel), corresponding to the mass in the licence

$r_0+18\ r_1$: value for the rolling resistance coefficient at 18 m/s [-]

Model FCG-2

The simplified model for gasoline cars was set up similarly to the diesel car model without the type approval fuel consumption value from the vehicle fleet. The gasoline model reaches also an astonishing high quality (Table 4-11). The parameters necessary to calculate the gasoline car fleet fuel consumption should be available (Table 4-12). In contrary to diesel cars the "Category" of the car has no significant influence on the fuel consumption value and should not be included into the regression model from a statistical point of view. Since the parameters are more in line with the diesel parameters when the "Category" is included and since also the parameter for "Category" is reasonable we suggest to use the equation as given below or to exclude the Category for diesel cars too.

Table 4-11: Quality of the regression model FCG-2 for the fuel consumption of gasoline passenger cars

Model	R	R²	corrected R^2	Standard error
FCG-2	0.985[c]	0.97	0.968	2.5

Table 4-12: Coefficients of the regression model FCG-2 for the fuel consumption of gasoline passenger cars

Model		Non standardised coefficient		Standardised coefficient	T	Sig.
		Coefficient B	Standard error	Beta		
FCG-2	(Constant)	11.011	2.241		4.913	0.000
	Power (kW)	0.354	0.027	0.755	13.131	0.000
	Mass (kg)	0.013	0.002	0.283	5.780	0.000
	Category	-0.390	1.235	-0.023	-0.316	0.753

The parameters listed in Table 4-12 lead to the following equation for the assessment of the real world fuel consumption of Euro 5 gasoline cars:

$$FC[g/km] = 11.01 + 0.354 \times P_{rated}[kW] + 0.013 \times m\,[kg] - 0.39 \times category \qquad (11)$$

With category: small cars = 1. medium cars = 2. SUV's = 3

m: vehicle mass (empty weight + 75kg for driver and 20 kg for fuel), corresponding to the mass in the licence

Model FCG-3

The model with the type approval fuel consumption value from the vehicle fleet reaches also for gasoline cars a high quality (Table 4-13). Beside the type approval fuel consumption value which should be available from approx. the year 2000 on (KBA data even since 1997) from the CO_2 monitoring only the average mass of the vehicles in the fleet has to be known (

Table 4-14).

Table 4-13: Quality of the regression model FCG-3 for the fuel consumption of gasoline passenger cars

Model	R	R²	corrected R^2	Standard error
FCG-3	0.997	0.994	0.994	1.12

Table 4-14: Coefficients of the regression model FCG-3 for the fuel consumption of gasoline passenger cars

Model		Non standardised coefficient		Standardised coefficient	T	Sig.
		Coefficient B	Standard error	Beta		
FCG-3	(Constant)	8.112	0.676		11.999	0.000
	FC NEDC TA	0.869	0.019	0.916	45.418	0.000
	Mass (kg)	0.0043	0.001	0.091	4.493	0.000

The parameters listed in

Table 4-14 lead to the following equation for the assessment of the real world fuel consumption of Euro 5 gasoline cars:

$$\text{FC [g/km]} = 8.11 + 0.869 \times \text{TA\_FC [g/km]} + 0.0043 \times \text{m [kg]} \qquad (12)$$

With TA_FC: Fuel consumption value of the fleet in the type approval test (from CO_2 Monitoring Database) in [g/km]

m: vehicle mass (empty weight + 75kg for driver and 20 kg for fuel), corresponding to the mass in the licence

Model FCG-3 is comparable to model V22 from section 4.1, which also has the same variables with the addition of engine power. Figure 4-3 compares the results from model V22 with the regression models FCG-1 to FCG-3. The regression models FCG-1 and FCG-2 meet the input data with a maximum deviation of 7% and 8% respectively. Model FCG-3 has a maximum deviation of 6% and needs less input data (as long as CO_2 fleet monitoring data is available). Model V22 which was elaborated from the large data base on in-use tests from different sources has a maximum deviation of 8% with an average of +/-2% against the values defined as “real world” fuel consumption in this section. All remarks made in the section for diesel cars before are valid also for the gasoline models.

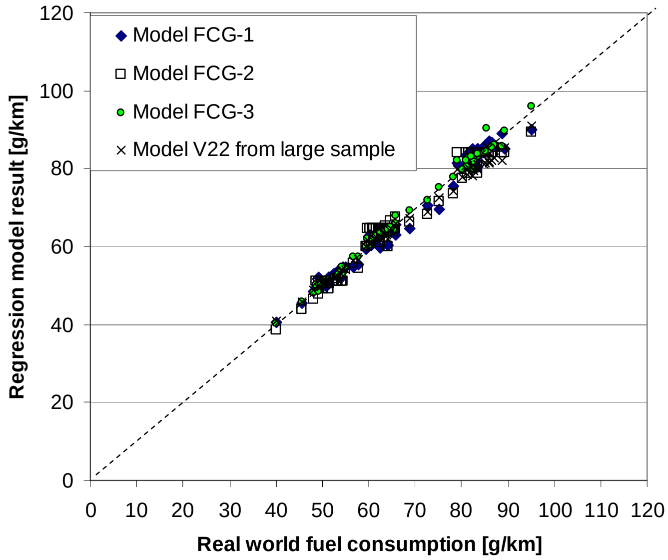


Figure 4-3: Fuel consumption simulated with the regression models for gasoline cars EURO 5. The real world fuel consumption represents the simulated real world mix for the selected makes and models of gasoline cars from section 2.1.7 (sample "B").

4.2.3 Summary for the regression models on average fuel consumption

The results from the large sample of vehicles from various in-use data sources (samples "A"/"All") and the results from the limited vehicle sample (sample "B") combined with the vehicle simulation match very well. The resulting regression models FC-3 and V22 which include the information on the average fuel consumption in type approval of a large vehicle sample give nearly the same results for the vehicle types selected. Thus the approach of simulating fuel consumption factors with the model PHEM based on a smaller sample of vehicles which then can be calibrated for the variability in local car fleets seems to be a reasonable approach.

For older vehicles where typically no information on the type approval fuel consumption is available, the model FC-1 or FC-2 for gasoline and diesel cars could basically be applied. Since these models have been elaborated with Euro 5 engine maps they do not consider the degradation of engine efficiency as we go back in time. Therefore, the application of the model FC-1 to older vehicles requires correction factors for to account for reduced efficiency. To obtain such engine efficiency corrections the engine maps included in the model PHEM were analysed. These maps have been used to calculate the emission factors in HBEFA v3.1 (Hausberger et. al., 2009) and have been produced on the basis of actual measurements of vehicles. To get a reasonable average fuel consumption value from the engine maps, the engine efficiency was weighted according to frequency of operation over the IATS cycle. Figure 4-4 shows the load points of the complete IATS cycle in the normalised engine map together with the standardised map points from the model PHEM.

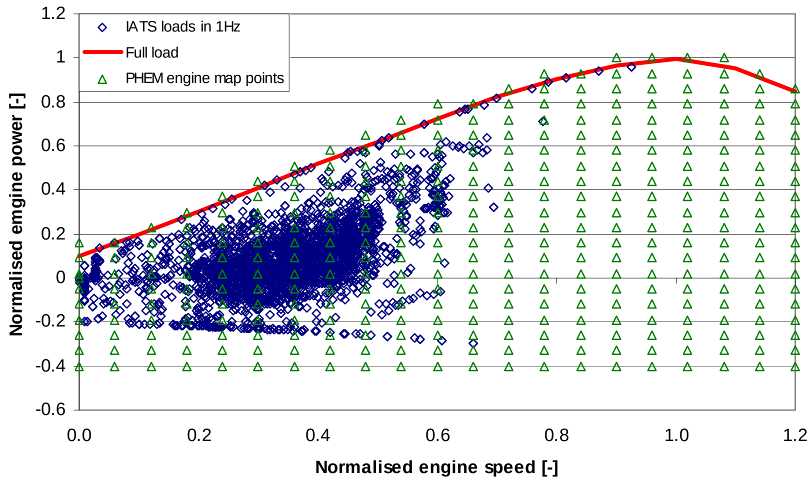


Figure 4-4: Load points of the EURO 5 gasoline car in the IATS cycle in the normalised engine map

Table 4-15 shows the resulting correction factors for Euro categories. For Euro 5 no correction is necessary, since the EURO 5 engine maps were used to establish the fuel consumption functions.

Eqs. (13) and (14) show the models FCD-1 and FCG-1 extended with the engine efficiency factor F_{ei}. (i describing Gasoline or Diesel and the Euro class). If instead of the FC-1 models the models FCD-2 and FCG-2 are applied for older technologies it has to be considered that these models do not take improvements in air resistance and in rolling resistance into consideration. Thus the older technologies would be underestimated with model set FC-2 even when the engine efficiency factors are applied.

Table 4-15: Suggested ratio "Fe_i" for the influence of the engine efficiencies and transmission ratios on the fuel consumption

	EU 0	EU 1	EU 2	EU 3	EU 4	EU 5	EU 6
	Ratio of engine fuel efficiency compared to EURO 5, Fe [-]						
Gasoline	1.40	1.12	1.09	1.10	1.02	1.00	0.98
Diesel	1.49	1.42	1.33	1.18	1.02	1.00	0.95

Diesel:

$$FC = Fe_{Diesel,i} \times (-6.17 + 0.3 \times P_{rated}[kW] + 16.5 \times (c_d \times A) + 939.4 \times (r_0 + 18 \times r_1) + 0.0085 \times m\,[kg]) \tag{13}$$

Gasoline:

$$FC = Fe_{Gasoline,i} \times (2.49 + 0.327 \times P_{rated}[kW] + 14.99 \times (c_d \times A) + 532.64 \times (r_0 + 18 \times r_1) + 0.01 \times m\,[kg]) \tag{14}$$

4.3 Model including average speed

To elaborate a speed dependent function for the real world fuel consumption of the passenger car and the light commercial vehicle fleets, basic physics have been considered, since the important vehicle parameters have different effects over the vehicle speed and acceleration ranges. If effects of road gradient, tyre slip, losses in the transmission system and power demand of auxiliaries (such as air conditioning systems) are neglected, only the rolling, the air, and the inertial resistances account for the actual engine power demand.

The following is a simplified formula for calculating the necessary driving power over the cycle:

$$P = P_{\text{rolling resistance}} + P_{\text{air resistance}} + P_{\text{inertial}} \tag{15}$$

This leads to a simplified equation to calculate the actual engine power demand of a vehicle in a test cycle as a function of some vehicle parameters (eq. (16)). From Eq. (16) it can be seen that the rolling resistance has typically a linear and second order influence with speed, while air resistance has a third order impact on engine demand. The vehicle mass also influences the power required to overcome inertial forces. This is zero for a cycle that starts and ends at the same speed. For the fuel consumption mainly the positive part of acceleration is relevant. Other acceleration events influence the engine load distribution and thus the average engine efficiency over a cycle but not the average engine power demand (only indirectly due to different speed levels and thus different air resistances etc.). Therefore a speed dependent function for engine power demand is basically of 3rd order as shown in Eq. (17).

$$P_e = \underbrace{m \times g \times v \times (r_0 + r_1 \times v)}_{\text{Rolling resistance}} + \underbrace{\frac{\rho_{air}}{2} C_d \times A \times v^3}_{\text{air resistance}} + \underbrace{(m + m_{Rot}) \times a \times v}_{\text{inertial}} \tag{16}$$

$$P_e = 0.001 \times [v \times (m \times g \times r_0 + 1.05 \times m \times a) + v^2 \times m \times g \times r_1 + v^3 \times \frac{\rho_{air}}{2} C_d \times A] \tag{17}$$

With P_e: engine power [kW]

m: vehicle mass (empty weight + 75kg for driver and 20 kg for fuel), corresponding to the mass in the license

m_{Rot}: equivalent mass of rotational inertia, here set to 5% of the vehicle mass [kg]

g: gravitational acceleration [9.81 m/s²]

(r_0, r_1): rolling resistance coefficients

v: velocity [m/s]

ρ: density of the air [kg/m^3]

A: frontal area of the vehicle [m^2]

a: acceleration of the vehicle [m/s²]

4.3.1 Default approach

For a given engine power demand the actual fuel consumption is defined by the engine efficiency or, in engineering terms, by the brake-specific fuel consumption, Eq. (18).

$$b_e = \frac{Fc}{P_e} \text{ in [g/kWh]} \tag{18}$$

With P_e: engine power [kW]

Fc: Fuel consumption in [g/h]

The fuel consumption in [g/km] is simply derived by division with the vehicle velocity. To be compatible to the kW unit the vehicle speed was applied in SI units before [m/s]. This unit is kept during the derivation of the final equation for the fuel consumption factors.

$$Fc\,[g/km] = \frac{b_e \times P_e}{3.6 \times v} \qquad \text{with v in [m/s]}$$

Together with Eq. (17) we get a straightforward formula for the fuel consumption value as function of speed and some main vehicle parameters.

$$Fc\,[g/km] = b_e \times 0{,}000278 \times [m \times (g \times r_0 + 1.05 \times a) + v \times m \times g \times r_1 + v^2 \times \frac{\rho_{air}}{2} \times c_d \times A] \qquad (19)$$

The application of this equation as a function of the mean speed of a driving situation requires the definition of a "brake equivalent acceleration level" to replace the acceleration (a) in Eq. (19). The "brake-equivalent acceleration level" has to consider this part of acceleration work which is annihilated in friction by mechanical brakes during the cycle. This "brake-equivalent acceleration level" certainly depends on the speed profile[14]. Obtaining an average b_e for a traffic situation requires the definition of the driving cycle(s) corresponding to this situation since b_e depends on the engine power and engine speed.

Thus the following approach could be directly derived from the detailed vehicle models PHEM and CRUISE to feed HBEFA and COPERT. With this approach consistent data sets would be used also for passenger cars and LCV as it is the situation for HDV already.

PHEM is applied to simulate emission and fuel consumption factors for the HBEFA traffic situations (already done for HBEFA 3.1).

The resulting basic hot emission factors could be used to calculate "default" average fuel consumption and emission functions for flat road for COPERT. Correction functions can also be gained by the basic PHEM emission factors which are available from -6% to +6% road gradients.

For fuel consumption functions adapted to local fleet data, following steps are added systematically (the user only needs to apply the resulting set of equations according to Eq. (21).

From the model results of PHEM and CRUISE the average positive engine power and the fuel consumption are available for each cycle. From the fuel consumption in [g/km], the cycle speed in [km/h] and the average engine power [kW] the specific fuel consumption can be easily computed in [g/kWh]. The specific fuel consumption for the single traffic situations is then plotted over average cycle speed to obtain a best fit function (Figure 4-5).

[14] If a vehicle just accelerates to a velocity and then coasts down with the engine shut off no additional fuel consumption originates from acceleration since all acceleration work is "paid back" during the deceleration. In typical traffic situations motoring phases and mechanical braking annihilate parts of the acceleration work as soon as higher decelerations occur.

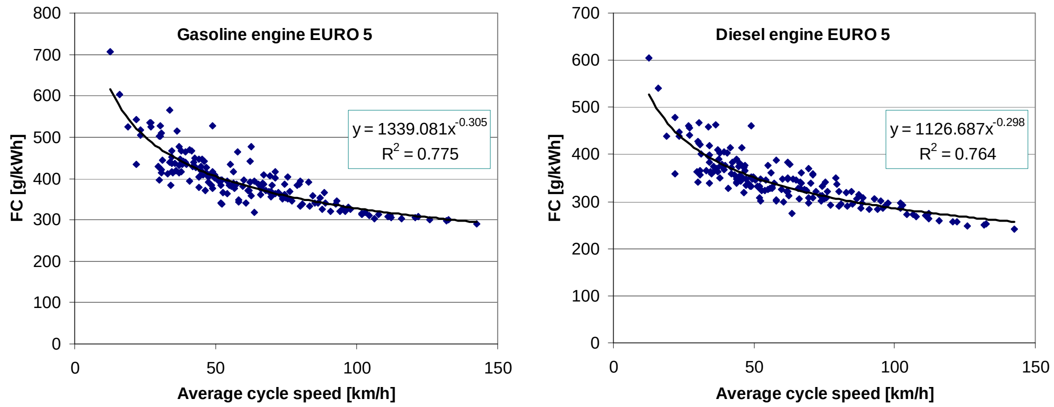


Figure 4-5: Brake specific fuel consumption b_e from the average EURO 5 HBEFA 3.1 passenger car engines as function of the average cycle speed

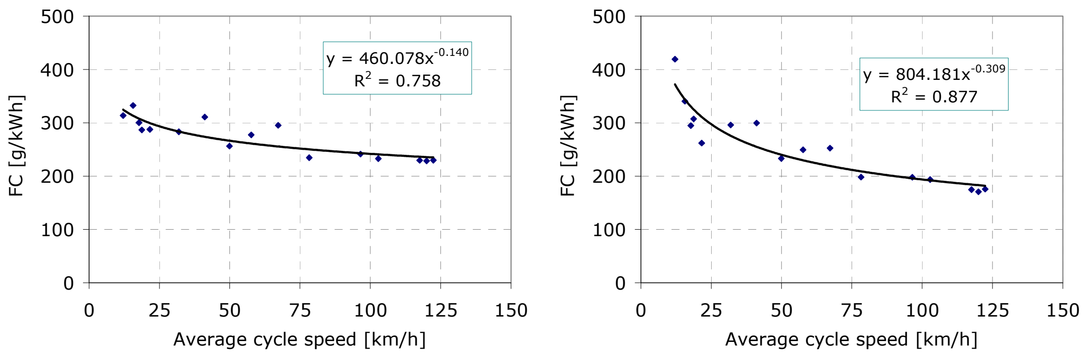


Figure 4-6: Brake specific fuel consumption (b_e) as function of the average cycle speed for gasoline N1-II (left) and diesel N1-III (right) Euro 5 LCVs.

From the average positive engine power simulated with PHEM and CRUISE for each traffic situation, the power for overcoming the rolling resistance and air resistance are subtracted. The remaining engine power demand is due to acceleration power from the "brake equivalent acceleration level (b_{ea})" and from losses in the transmission system. From this remaining power demand and the given vehicle mass (as defined in HBEFA) the "brake equivalent acceleration" can be calculated.

$$bea = \frac{P_e - P_{air\ resistance} - P_{rolling\ resistance}}{v \times m} \qquad (20)$$

With P in [W], v in [m/s] and m in [kg]

The results for the single traffic situations are then plotted over average cycle speed to obtain a best fit function as shown in Figure 4-7 for Euro 5 gasoline cars and in Figure 4-8 for gasoline and diesel LCVs.

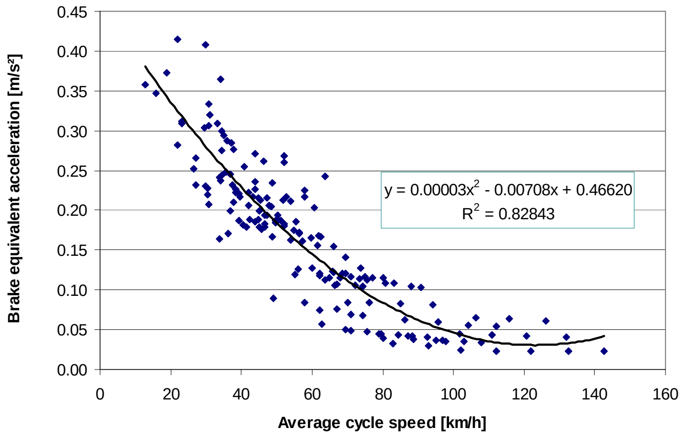


Figure 4-7: "Brake equivalent acceleration (bea)" from the traffic situations with flat road in the HBEFA 3.1 as function of the average cycle speed for gasoline EURO 5 cars

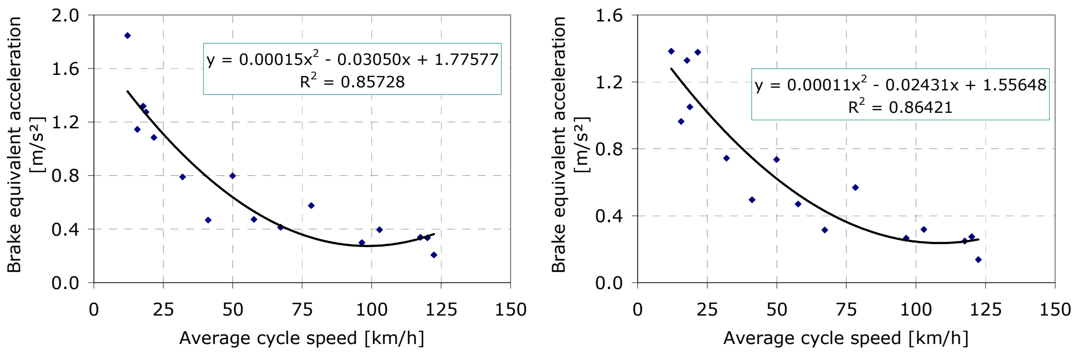


Figure 4-8: "Brake equivalent acceleration (bea)" as function of the average cycle speed for gasoline N1-II (left) and diesel Ni-III (right) Euro 5 LCVs. Similar correlations have been produced for all LCV categories.

The brake equivalent acceleration depends on the vehicle parameters and thus is different for each vehicle class (gasoline, diesel, Euro 0 to Euro 6) in the same traffic situations. To simplify the approach an average brake equivalent acceleration is defined subdivided only into gasoline and diesel (due to their typical different vehicle masses and engine efficiencies).

Eq. (19) is applied with b_e and bea as functions of the average cycle speed. The brake specific fuel consumption shall be subdivided according to gasoline and diesel as shown in Figure 4-5 for Euro 5 passenger cars and in Figure 4-6 for LCVs. Other Euro classes can be computed similarly from the PHEM results for the HBEFA 3.1 or from the "Fe_i" ratios in Table 4-15 to consider the influence of the engine efficiencies and transmission ratios globally. Since engine improvements from Euro 0 to Euro 5 do not necessarily have similar effects in the entire engine map, the global "Fe_i" ratios are a simplification.

This approach has been set up from the HBEFA and tested. This leads to the following sets of equations:

$$FC\,[g/km] = Fe_i \times b_e \times 0.000278 \times [m \times (9.81 \times r_0 + 1.05 \times bea) + (v / 3.6) \times m \times g \times r_1 + (v/3.6)^2 \times 0.6 \times c_d \times A] \quad (21)$$

with: Gasoline PC: $bea = 0.45 - 0.007 \times v + 0.000028 \times v^2$ (bea in [m/s²]; v in [km/h])

$b_e = 1339 \times v^{-0.305}$ (b_e in [g/kWh]; v in [km/h])

Diesel PC: $bea = 0.4 - 0.006 \times v + 0.000023 \times v^2$

$b_e = 1125 \times v^{-0.300}$

Gasoline LCV:

N1-I: $bea = 1.80 - 0.031 \times v + 0.00016 \times v^2$

$b_e = 1475.7 \times v^{-0.310}$

N1-II: $bea = 1.78 - 0.031 \times v + 0.00015 \times v^2$

$b_e = 460.1 \times v^{-0.140}$

Diesel LCV:

N1-I: $bea = 1.88 - 0.032 \times v + 0.00016 \times v^2$

$b_e = 481.7 \times v^{-0.202}$

N1-II: $bea = 1.73 - 0.030 \times v + 0.00015 \times v^2$

$b_e = 840.5 \times v^{-0.347}$

N1-III: $bea = 1.56 - 0.024 \times v + 0.00011 \times v^2$

$b_e = 804.2 \times v^{-0.309}$

The Fe values as a function of fuel and emission standard can be obtained from Table 4-15. As an approximation, it is expected that LCV fuel consumption will change with emission standard the same way as passenger cars.

The results from the equations are shown in Figure 4-9 and Figure 4-10 for diesel and gasoline Euro 5 vehicles respectively, as an internal validation check of the method applied. The regression coefficients of 0.93 and 0.94 show a very good agreement. The method can be thus seen as useful for both COPERT and HBEFA to correct for different PC and LCV fleet compositions around Europe. In COPERT simply the results of the equations can be applied to predict fuel consumption. "Default values" from the EU average for Cd×A, r_0, r_1 and m are documented in the HBEFA report (Hausberger, 2009). For the HBEFA the equation needs to be applied one time for the "default" EU average vehicle data from the HBEFA emission factors and one time for country specific data. By dividing the speed dependent best fit functions for both vehicle sets gives a speed dependent, country specific correction function for the HBEFA traffic situations.

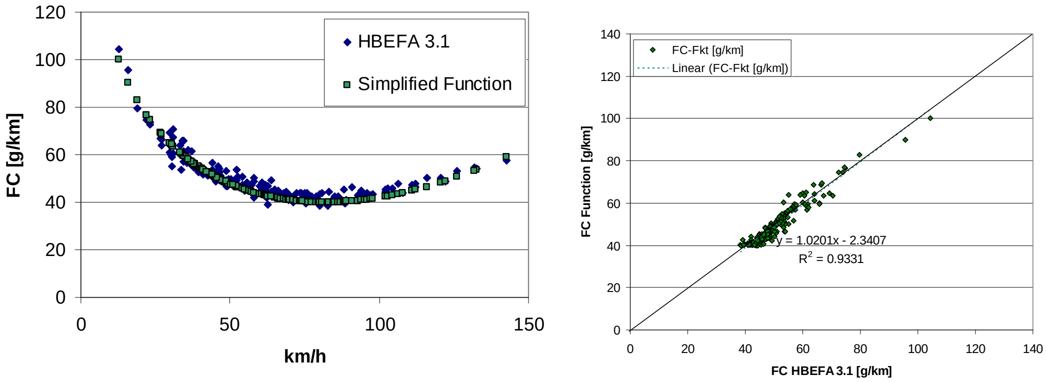


Figure 4-9: Comparison of the fuel consumption factors from the EURO 5 diesel vehicle in the flat HBEFA V3.1 traffic situations compared to the results of the simplified function.

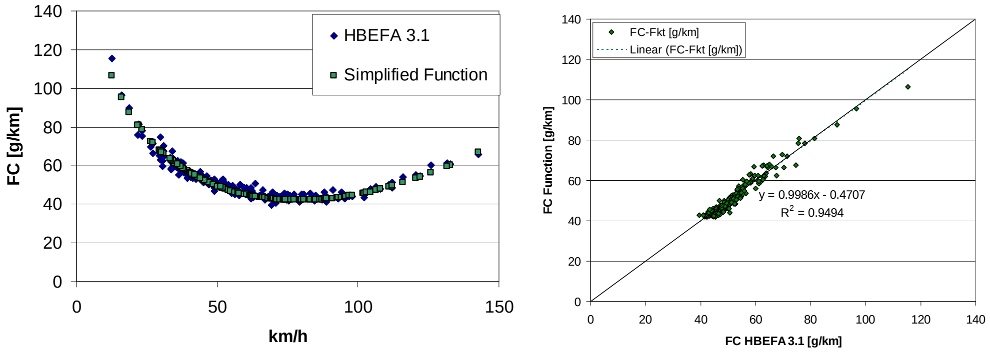


Figure 4-10: Comparison of the fuel consumption factors from the EURO 5 gasoline vehicle in the flat HBEFA V3.1 traffic situations compared to the results of the simplified function.

4.3.2 Comparison to COPERT fuel consumption functions

The function for calculating the speed dependent fuel consumption for cars (equation (21)) was also tested against the fuel consumption functions defined in the actual version of COPERT for the EURO 5 vehicles. COPERT uses the approach given in Eq. (22) with the corresponding parameters shown in Table 4-16.

$$FC = \frac{a + c \cdot v + e \cdot v^2}{1 + b \cdot v + d \cdot v^2} \qquad (22)$$

Table 4-16: Parameters for the fuel consumption functions of Euro 5 cars in COPERT

	a	b	c	d	e
Diesel PC <2.0 l Euro 5	161.9413	0.122982	2.183648	-0.00078	-0.0128
Diesel PC >2.0 l Euro 5	194.8899	0.0719	0.187226	-0.00033	0.00999
Petrol PC <1.4 l Euro 5	136.2596	0.026	-1.64754	0.000228	0.0312
Petrol PC 1.4-2.0 l Euro 5	173.7871	0.0685	0.364001	-0.00025	0.00874
Petrol PC >2.0 l Euro 5	285.031	0.0728	-0.13718	-0.00042	0

Figure 4-11 shows the results from the COPERT functions compared to the actual equation for gasoline cars. Since the average values for vehicle mass, rolling resistance coefficients and $C_d \times A$ necessary to apply Eq. (21) are not available for the three cylinder capacity classes from COPERT only a qualitative assessment of the differences is possible.

The results from Eq. (21) and HBEFA V3.1 basically fit very well with COPERT in a speed range up to 40 km/h. For higher speeds Eq. (21) and HBEFA V3.1 lead to lower fuel consumption values than COPERT. The reasons for these different trends can not be identified without a definition of the technical data of the vehicles in the COPERT data base. The most likely differences are:

a) COPERT is based on the results from the CADC sub-cycles while the actual function is based on the HBEFA traffic situations. This may already lead to different trends over the average speed.

b) The technical data for the average gasoline and diesel car may be quite different in the COPERT functions and in the HBEFA V3.1 data. The results suggest that in the actual function the frontal area and/or the C_d value of the vehicles is lower than in the COPERT data[15].

If COPERT or the actual function and HBEFA reflect the real world trends more representative can not be answered at the moment since neither a validated set of "representative European driving cycles" nor average technical data for the European fleet is available. In Benz (2009) the model PHEM with the HBEFA V3.1 data was used to study effects of reducing traffic jams in Germany. The results were completed with data from the automotive industry (fuel consumption values and measured speed curves). The different data sets showed a very good agreement in the trends. Additionally a lot of effort was put into the development of representative driving cycles for the HBEFA V3.1 while the CADC covers several relevant traffic situations but was not designed to be representative without further weighting of the single sub-cycles. This may indicate that the actual function presented in this report may be more representative.

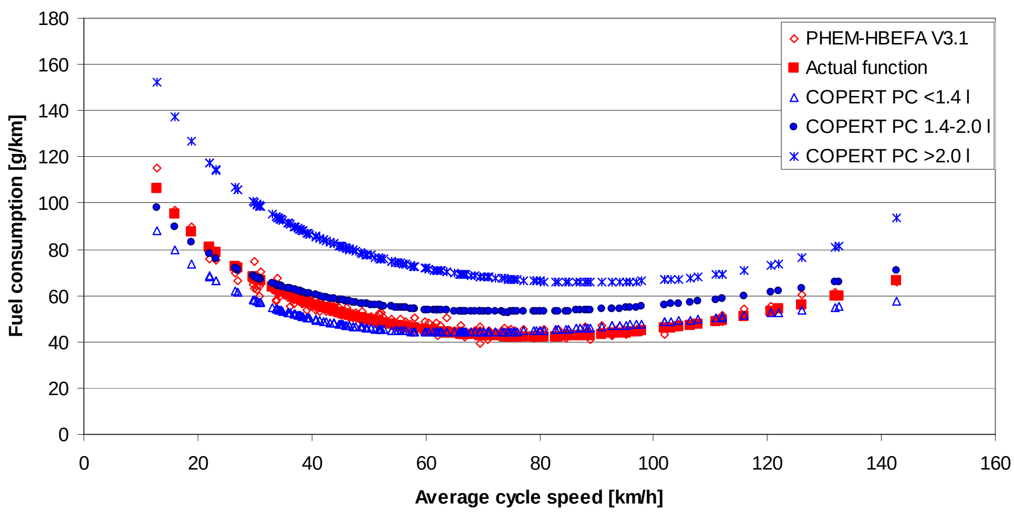


Figure 4-11: Comparison of the fuel consumption factors from the Euro 5 gasoline cars from the basic function elaborated here with the COPERT functions and with the HBEFA V3.1 traffic situations.

[15] In HBEFA V3.1 the vehicle mass and engine power was adapted to EU average values while COPERT used the (unknown) average of the corresponding vehicles in the ARTEMIS300 data base. The detailed technical data (rolling resistance coefficients and C_dxA) is not available for fleet averages at all. In HBEFA and thus in the actual function these values where assessed for the EU fleet average from a limited number of vehicle data. The ARTEMIS 300 data base does not contain these values for most of the tested vehicles. Since COPERT is based on the tests in the ARTEMIS 300 db the detailed technical data of the vehicle fleet in COPERT is unknown.

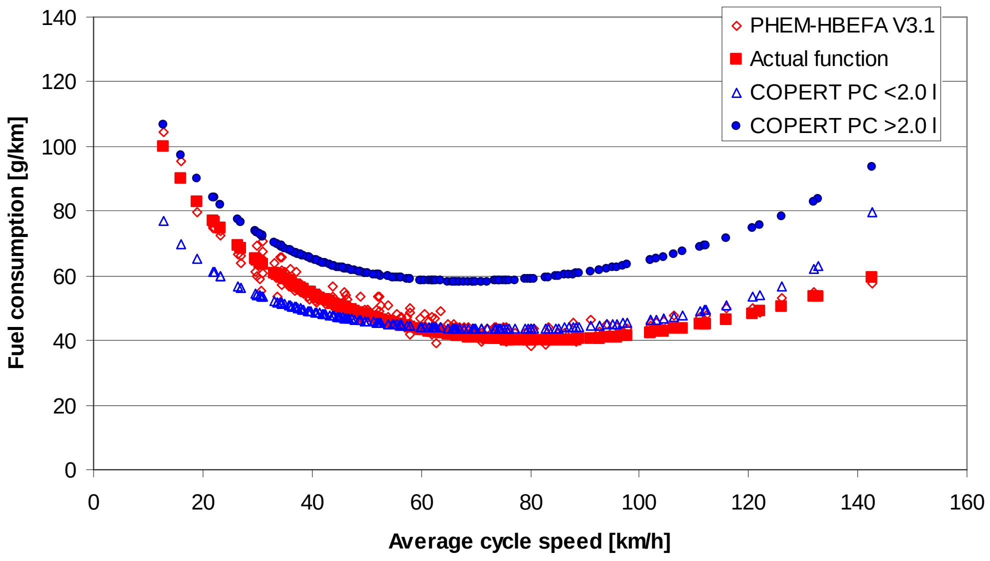


Figure 4-12: Comparison of the fuel consumption factors from the Euro 5 diesel cars from the basic function elaborated here with the COPERT functions and with the HBEFA V3.1 traffic situations.

What shall be learned from the comparison is:

1) The technical data of each tested vehicle shall be collected in future. This would allow adaptations to regional differences in emission models and is a basic requirement for a scientific comparison of model results

2) Actual methods to gain emission factors from average bag results of different cycles and test vehicles do not allow the analysis of influences of driving behaviour and vehicle characteristics. Instantaneous models can take such effects into consideration but the data base for vehicle characteristics (as suggested in 1)) and on the driving behaviour needs to be improved to get a more reliable trend from the instantaneous models.

4.3.3 Alternative option with explicit idling fuel consumption

The specific fuel consumption in [g/kWh] is not defined at idling conditions since there the effective power output of the engine is zero kW. An option is to depicture idling consumption separately as a constant basic fuel consumption of the engine to overcome internal friction losses.

$$be_{V2} = \frac{FC_{cycle} - FC_{idling}}{P_{Pos_{cycle}}} \quad \text{in [g/kWh] with FC in [g/h] and } P_{Pos} \text{ in kW} \qquad (23)$$

This approach was tested with the data from the HBEFA V3.1 also. The fuel consumption in idling (FC_{idling}) is gained from the basic engine emission maps in PHEM. For the Euro 5 diesel cars the idling fuel consumption value in the PHEM map is 563 g/h. This results in the brake specific fuel consumption formula shown in Figure 4-13. The linear approach for the regression equation was used to allow a calculation also for zero vehicle speed.

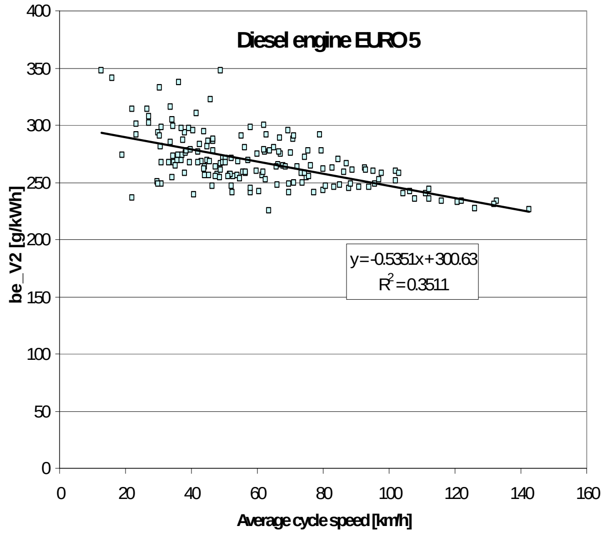


Figure 4-13: Brake specific fuel consumption b_{eV2} with subtracted idling fuel consumption for the average EURO 5 HBEFA 3.1 diesel engine

In the total formula for the fuel consumption the idling fuel consumption again has to be converted here into g/km as the target unit for HBEFA and COPERT. This demand leads to a division by the vehicle speed. The remaining equation for the fuel consumption in [g/km] is equal to equation (21) but with b_{e_V2} instead of b_e:

$$Fc_{V2} = \frac{FC_{idling}}{v} + b_{e-V2} \times 0.000278 \times [m \times (9.81 \times r_0 + 1.05 \times bea) + (v/3.6) \times m \times g \times r_1 + (v/3.6)^2 \times 0.6 \times c_d \times A] \qquad (24)$$

Figure 4-14 compares the results of the two sets of equations (21) and (24). The quality of both equations is nearly similar (the regression coefficient of FC_{V2} is slightly higher but the inclination of the linear equation in the right picture of Figure 4-14 has a slightly higher difference to the ideal value 1.0 than the basic equation).

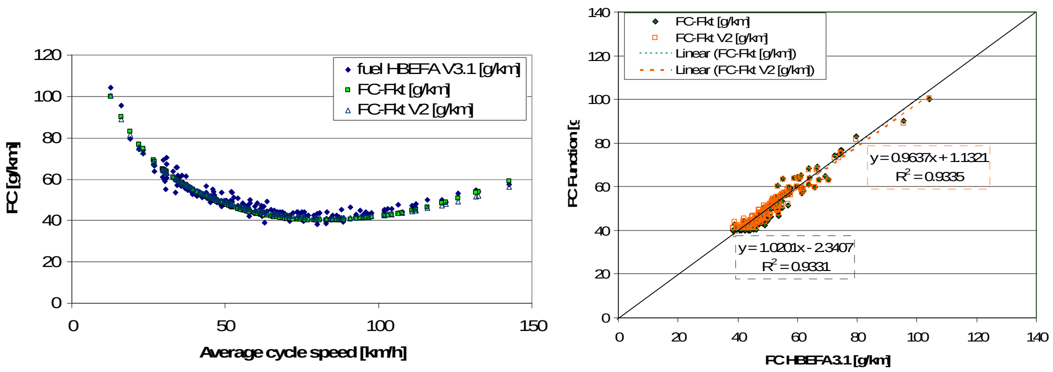


Figure 4-14: Comparison of the fuel consumption factors from the Euro 5 diesel vehicle in the flat HBEFA V3.1 traffic situations compared to the results of the simplified function (basic function and option with explicit idling consumption (V2))

In total we can conclude that the alternative option with explicit idling fuel consumption is closer to the physical basics but does not give advantages in the accuracy when simply average fuel consumption values in g/km shall be computed. A disadvantage is the slightly longer equation and especially the demand for separate idling fuel consumption values for all simulated categories of passenger cars and people not familiar with this approach may misinterpret the terminus "idling fuel consumption" which occurs here from friction losses of the engine even if the cycle does not have any idling phases. Thus we suggest using the basic equation without separate idling fuel consumption for the set up of the speed dependent correction functions.

Basically it would be advantageous to include also type approval data into such an approach. The type approval fuel consumption is a result of the vehicle parameters and the engine efficiency. The single parameters can not be extracted without the driving resistance values used in type approval. This information is at the moment not available.

5 Conclusions and Impacts

5.1 Models for In-Use fuel consumption prediction

Three different models can be proposed to calculate in-use fuel consumption data of light duty vehicles, depending on the available data.

Type-approval data available

If only the CO_2 monitoring database data are available (type-approval CO_2, vehicle mass and cylinder capacity) and the effect of travelling speed is not of importance, then the following model may be used for gasoline and diesel vehicles respectively.

$$FC_{InUse,\,Gasoline}[l/100\,km] = 1.15 + 0.000392 \times CC + 0.00119 \times m + 0.643 \times FC_{TA}$$

$$FC_{InUse,\,Diesel}[l/100\,km] = 0.133 + 0.000253 \times CC + 0.00145 \times m + 0.654 \times FC_{TA}$$

Where: FC_{TA} (type approval) in l/100 km
m = empty weight + 75 kg
CC=capacity (displacement in cubic centimetre)
b = constant [l/100 km]

Type-approval data not available

For older vehicle technologies, type approval fuel consumption data may not be available. In this case a correction function has been developed which only uses vehicle specifications to predict in-use fuel consumption. The use of this model may be demonstrated, for example, for vehicle technologies/types not included in the CO_2 monitoring database, but which in-use fuel consumption has to be predicted. In this case, the following model may be used:

$$FC_{Diesel}[g/km] = Fe_{Diesel,i} \times (-6.17 + 0.3 \times P_{rated}[kW] + 16.5 \times (c_d \times A) + 939.4 \times (r_0 + 18 \times r_1) + 0.0085 \times m\,[kg])$$

$$FC_{Gasoline}[g/km] = Fe_{Gasoline,i} \times (2.49 + 0.327 \times P_{rated}[kW] + 14.99 \times (c_d \times A) + 532.64 \times (r_0 + 18 \times r_1) + 0.01 \times m\,[kg])$$

Where:

P_{rated}:	average engine rated power of the fleet [kW]
m:	reference mass (empty weight + 75kg for driver and 20 kg for fuel)
$r_0+18\times r_1$:	value for the rolling resistance coefficient at 18 m/s [-]
$c_d\times A$:	aerodynamic resistance [m^2]

Speed dependent model

If detailed vehicle data are available, and the effect of speed needs to be taken into account, then in-use fuel consumption can be directly simulated using the following model:

$$FC\,[g/km] = Fe_i \times b_e \times 0.000278 \times [m \times (9.81 \times r_0 + 1.05 \times bea) + (v/3.6) \times m \times g \times r_1 + (v/3.6)^2 \times 0.6 \times c_d \times A] \quad (25)$$

with: Gasoline PC: $bea = 0.45 - 0.007 \times v + 0.000028 \times v^2$ (bea in [m/s²]; v in [km/h])

$b_e = 1339 \times v^{-0.305}$ (b_e in [g/kWh]; v in [km/h])

Diesel PC: $bea = 0.4 - 0.006 \times v + 0.000023 \times v^2$

$b_e = 1125 \times v^{-0.300}$

Gasoline LCV:

N1-I: $bea = 1.80 - 0.031 \times v + 0.00016 \times v^2$

$b_e = 1475.7 \times v^{-0.310}$

N1-II: $bea = 1.78 - 0.031 \times v + 0.00015 \times v^2$

$b_e = 460.1 \times v^{-0.140}$

Diesel LCV:

N1-I: $bea = 1.88 - 0.032 \times v + 0.00016 \times v^2$

$b_e = 481.7 \times v^{-0.202}$

N1-II: $bea = 1.73 - 0.030 \times v + 0.00015 \times v^2$

$b_e = 840.5 \times v^{-0.347}$

N1-III: $bea = 1.56 - 0.024 \times v + 0.00011 \times v^2$

$b_e = 804.2 \times v^{-0.309}$

For the two last models, the fuel efficiency correction "Fe", takes into account the engine efficiency degradation for older vehicle technologies. These can be obtained from the following table:

	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
	Ratio of engine fuel efficiency compared to Euro 5, Fe [-]						
Gasoline	1.40	1.12	1.09	1.10	1.02	1.00	0.98
Diesel	1.49	1.42	1.33	1.18	1.02	1.00	0.95

5.2 Impact and application to HBEFA

In HBEFA the fuel consumption already depends on national stock data and it is calculated as follows.

As a primary source, the PHEM model provides fuel consumption for a "norm vehicle" (more precisely: a Euro-3 vehicle petrol resp. diesel, model year 2002, which was calibrated to CADC values of the A300DB). For this "norm vehicle" the fuel consumption was calculated by PHEM for all available driving cycles and hence for all HBEFA traffic situations (276).

Up to HBEFA V3.1 the national differences of the fleet composition for cars were considered by the following method: The FC of the same "norm vehicle" was also calculated with PHEM for the NEDC cycle. From the EU CO_2 monitoring database these values are also available for all or most countries. These values then were aggregated to the HBEFA size classes ("size" being approximated by the 3 capacity classes for petrol resp. for diesel cars: <1.4L, 1.4 – 2L, >2L). By this comparison each size class gets a national correction factor reflecting the different size classes. Example: the PHEM model produces for the petrol "norm vehicle" a value of 176 g CO_2/km over the NEDC while, according to the monitoring database e.g. a petrol vehicle >2L in Germany emits 253 g CO_2/km, hence the corresponding German vehicles got a correction factor of 1.46. This is called "base correction". All fuel consumption factors for all HBEFA traffic situations are then corrected by this "base correction factor". An additional correction factor is applied which takes into account the change of the fuel consumption over time. For this, the yearly changing FC TA values for each vehicle category are taken as approximation using the 2002 value as an index of 100.

The future correction method can be based on the actual findings in this study. Depending on the available data on the national fleet following options exist:

a) If "only" average type approval fuel consumption, average mass and cylinder capacity of the LDV categories (cars and LCV) are available, the regression equations from model option #1 in section 5.1 can be applied to calculate the national "target in-use fuel consumption value". The standard fuel consumption factors from PHEM together with the country-specific shares of the different traffic situations results also in an in-use fuel consumption value, named here "basic HBEFA in-use fuel consumption value" Dividing the "target in-use fuel consumption value" by the "basic HBEFA in-use fuel consumption value" gives then already the national correction factor which is not speed dependent in this case. Multiplying the standard fuel consumption factors from PHEM with this national correction factor shall result in exactly the "target in-use fuel consumption value" as output from the HBEFA for the weighted traffic situations. The national correction factor certainly has to be computed for each vehicle category separately.

b) If all data is available to apply the equations for the speed dependent fuel consumption (model option #3 in section 5.1), then for each vehicle category (cars and LCV) the speed dependent fuel consumption can be computed with the national data as well as with the data for the basic vehicles in PHEM. Dividing the results for the national fleet by the results from the PHEM vehicle data gives a speed dependent correction function. This correction function can then be applied to the fuel consumption factors for each traffic situation as function of the average cycle speed of this traffic situation. An example for such a correction function is shown in Figure 5-1, where the vehicle mass was increased by 200 kg and the frontal area by 10% against the basic gasoline vehicle in PHEM.

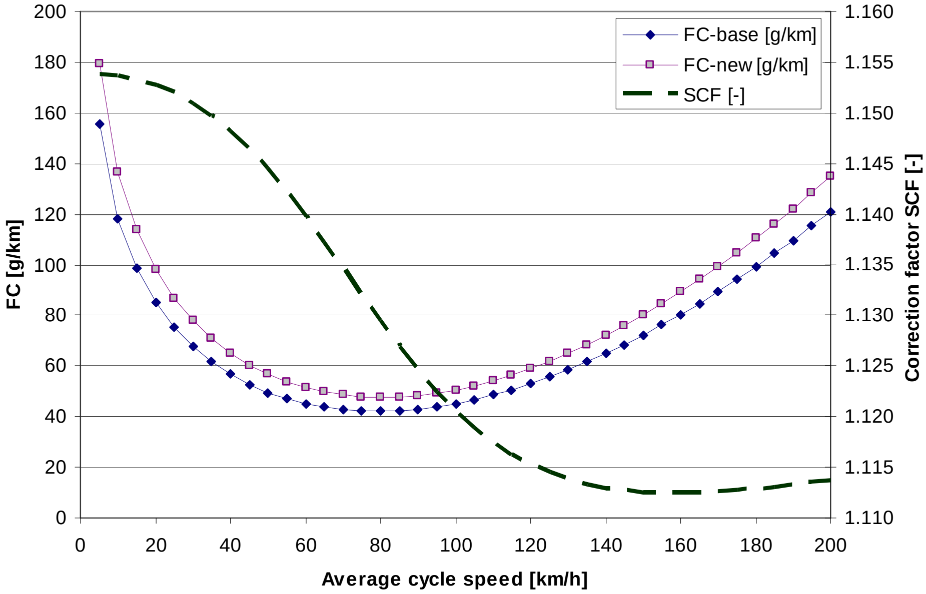


Figure 5-1: Schematic results for the speed dependent fuel consumption of passenger cars Euro 5 as defined in the PHEM data set and for a variation of vehicle parameters (right picture) and the resulting speed dependent correction function.

5.3 Impact and application to COPERT

COPERT 4 already contains CO_2 functions of speed for five diesel and gasoline passenger car types and two light commercial vehicle classes. Based on the findings from this study, the diesel car classes will gradually be extended from two to three. The reason is that the European market receives now a large number of small diesel cars (~1.4 l). However, COPERT 4 only distinguishes in two capacity classes, i.e. <2.0 l and >2.0 l. This is for historic reasons, as in the past, the <2.0 l class in principle contained only vehicles in the 1.8-1.9 l range. Now that even smaller diesel vehicles are popular, this class is further split to take this wide range into account. This can be performed calculating fuel consumption values using model option #3 from section 5.1 directly. Typical ranges for the parameters in model #3 will be provided, based on literature data. These will be 'default' fuel consumption factors. The user may then change these values to come up with modified functions that better represent the national stock.

COPERT also includes only one LCV category per fuel. However, LCVs can be split in three types per fuel, i.e. N1-I, N1-II and N1-III. New speed-dependent baseline consumption factors for LCVs have been developed in section 3.4.3. These can be directly introduced in COPERT. Then, the same methodology with passenger cars will be applied. That is, model #3 can be applied with modified parameters, than the ones we used to develop the baseline consumption factors, to reflect national stock specifications.

One key question is whether COPERT 4 users feel comfortable with model #3 relative complexity and whether reliable input data for the national stocks can be collected. If this is not the case, then a simplified method may have to be adopted, even if this produces some biased results under some circumstances. Specifically, if the users prefer only to use data included in the CO_2 monitoring database, then one could introduce a correction based on model option #1. That is, the vehicle sample used for the development of the baseline consumption factors will be attributed a type-approval fuel consumption, a mean vehicle mass and mean capacity value. These values will then lead to an in-use fuel consumption ("default in-use fuel consumption") based on model option #1 in section 5.1. If the national stock specifications differ, then a corrected in-use fuel consumption will be calculated with model #1 and the new specifications ("national in-use fuel consumption"). Using these two values, the baseline COPERT function will be corrected according to the national/default in-use fuel consumption ratio. This method is straightforward but has the disadvantage that makes the implicit assumption that fuel consumption in all speeds behaves similar. This is not necessarily true and may introduce a bias, especially when national driving patterns differ substantially from the assumed driving patterns used in developing the in-use fuel consumption in model #1.

5.4 In-Use vs Type-Approval fuel consumption

The results of this study demonstrated that type approval and in use fuel consumption differ substantially. The exact difference is a function of vehicle type (fuel, size, technology) and driving situation considered.

Table 5-1 shows an example of the effect for the new passenger cars sold in Germany in 2008. Using the correction functions developed in this report, the in-use fuel consumption of the vehicle stock is found 13-15% higher than the type-approval value for gasoline passenger cars, and 14-16% higher for diesel cars. The different estimates originate from the fact that different correlations have been developed depending on the sample "All" or the sample "A". The higher fuel consumption results to equally higher CO_2 emissions. Differences of the same order of magnitude can be calculated for all Member-States using the mean specifications of the vehicle stock in each country.

Table 5-1: Illustrative application of the correction function for Germany 2008 (data source see section 2.1.1 resp. Annex 2)

Gemany 2008	Petrol		Diesel	
FC TA (L/100km)	7.00		6.36	
mass (+75 kg)	1355		1684	
CC	1634		2088	
FC corrected (V42), (L/100km)				
- Sample all	7.91	113%	7.27	114%
- Sample A	8.07	115%	7.38	116%

The impacts of this difference may potentially be very important. This shows that the real-world performance does not replicate the type-approval fuel consumption values. Could the same be true for the relative reductions for future vehicle technologies, i.e. the ones expected to be introduced as the output of the implementation of Regulation 443/2009? Therefore, could reductions achieved over the type-approval cycle not be equally reflected to real-world fuel consumption reductions? This is discussed in the following section.

5.5 Vehicle specifications impact on fuel consumption

The fact that in-use and type-approval fuel consumption differ depending on vehicle specifications, has an impact on how the decreasing type-approval CO_2 reported in the monitoring databases is reflected to in-use fuel consumption reductions.

The following example tries to illustrate a representative example for a typical N1-II diesel Euro 5 light commercial vehicle. A potential mix of technical measures to reach lower type-approval fuel consumption could be:

- Weight increase by 6%: This is not a measure to reduce fuel consumption but it is in line with observed increasing trends in vehicle mass over the recent years, as a result of trim and safety equipment.
- Aerodynamic resistance decrease by 6%: Although frontal area is rather unlikely to be reduced based on recent trends, aerodynamic coefficient might be improved.
- Decrease of final transmission ratio by 5%: This means that the engine operates at lower speed hence increased efficiency. Performance may also drop though.

- Rolling resistance decrease by 5%: This can be achieved by better low-resistance tyres.

Figure 5-2 shows the impact of these changes on fuel consumption expressed by different driving cycles. The type-approval fuel consumption drops by ~5%. However, the fuel consumption improves mainly during the high-speed EUDC. Operation of the vehicle at lower speeds, which are expected in the mostly urban driving of such urban vans, would lead to marginal or even slight increases in fuel consumption. This shows that establishing reductions in type-approval conditions does not necessarily lead to equal reductions of in-use consumption.

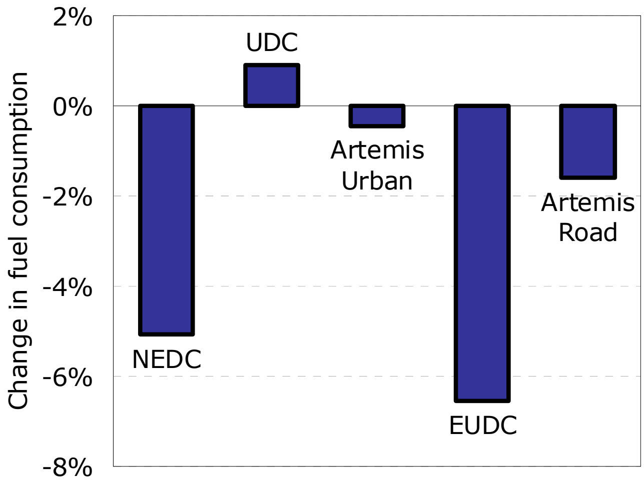


Figure 5-2: Real-world effect of reducing type approval fuel consumption of future LCVs.

5.6 Type-Approval optimization

Although this is not directly an outcome of the study, this is an important conclusion from relevant work that should be re-iterated. Type-approval tests of fuel consumption are conducted on chassis dynamometer using resistance settings provided by the manufacturer. These settings are derived from coast-down vehicle tests. It appears that resistance of actual vehicles measured by independent test centres are higher than the ones submitted by the manufacturers for the type-approval tests. There are several reasons why this can be happening, i.e. manufacturers test vehicles in ideal conditions (tarmac condition, weather, vehicle run-in, configuration such as tyre dimensions, trained drivers to perform the test, etc.). Unfortunately, type-approval resistance settings are confidential.

Using of real vehicle resistances instead of type-approval resistances has been shown to lead to fuel consumption increases of up to 17%. This is even beyond the in-use over type-approval fuel consumption ratio developed in this report. As a minimum impact this means that maybe the NEDC is not a bad (underpowered) cycle to report fuel consumption but that maybe the actual test is an idealistic one. It can be recommended that vehicle resistance settings become public together with the type-approval fuel consumption value, so that independent authorities can check both whether these represent reality and whether the type-approval test has been conducted as required.

6 Literature

AEA (2009). Assessment of options for the legislation of CO_2 emissions from light commercial vehicles. Final report to European Commission. Framework contract No. ENV/C.5/FRA/2006/0071.

Hausberger, S., Rexeis, M., Zallinger, M., & Luz, R. (2009). Emission Factors from the Model PHEM for the HBEFA Version 3. Graz: Report Nr. I-20/2009 Haus-Em 33/08/679.

Hausberger, S. (2003). Simulation of Real World Vehicle Exhaust Emissions (Bde. VKM-THD Mitteilungen; Heft/Volume 82 - ISBN 3-901351-74-4). (V. d. Graz, Hrsg.) Graz.

Hausberger, S. (2002). Update of the Emission Functions for Heavy Duty Vehicles in the Handbook Emission Factors for Road Traffic. Graz: Institute for Internal Combustion Engines and Thermodynamics.

Luz, R., & Hausberger, S. (2009). User Guide for the Model PHEM, Version 10. Graz: Institute for Internal Combustion Engines and Thermodynamics TU Graz.

Rexeis, M. (2009). Ascertainment of Real World Emissions of Heavy Duty Vehicles. Dissertation, Institute for Internal Combustion Engines and Thermodynamics. Graz: Dissertation, Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology.

Rexeis, M., Hausberger, S., & Riemersma, I. (2005). Heavy duty vehicle emissions. In Report of WP 400 in ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems). Graz: DGTREN Contract 1999-RD.10429.

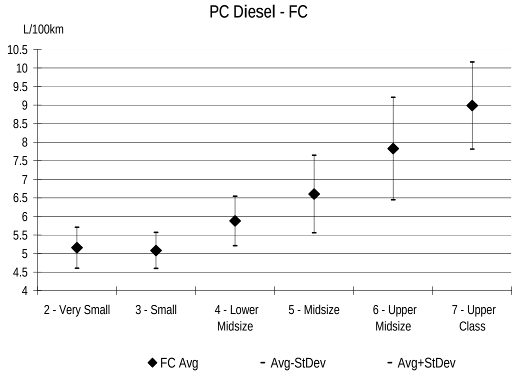
Schmitzberger M. (2007): Emissionsverhalten von SUV’s und Potential einer Hybridisierung; Diploma Thesis at the Institut for INternal Combustion Engines at the TU-Graz; 2007

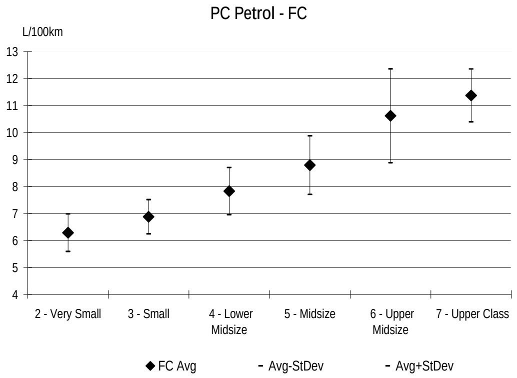
Zallinger M., Hausberger S. (2010): CO2- and fuel consumption from cars
in the NEDC and in real-world-driving cycles; Report Nr. I-21/09 Zall-Em 34/09/676 from 17.12.2009; edited for the BMLFUW; Institute for Internal Combustion Engines and Thermodynamics. University of Technology Graz (TUG)

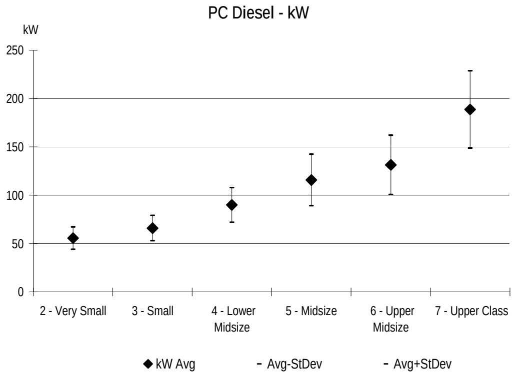
Zallinger, M. (2010-2). Mikroskopische Simulation der Emissionen von Personenkraftfahrzeugen. Graz: Dissertation, Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology.

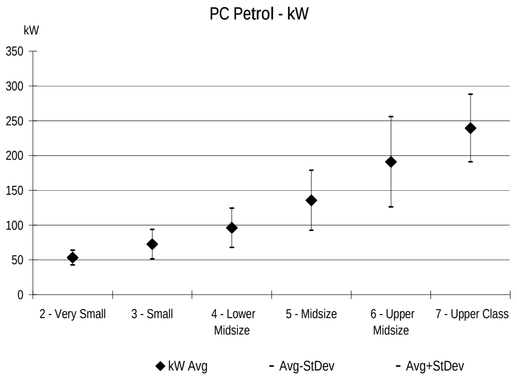
Zallinger, M., Hausberger, S., Ajtay, D., & Weilenmann, M. (2005). Instantaneous emission modeling applications. In Final Report of WP 300 in ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems). Graz: DGTREN Contract 1999-RD.10429.

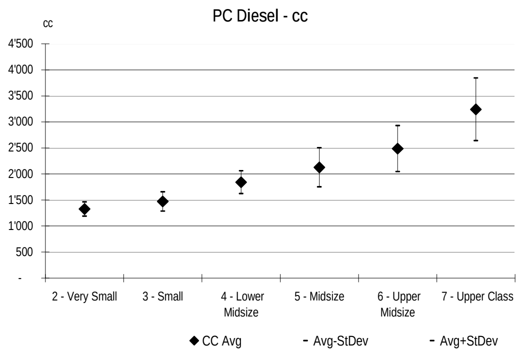
Annex 1: Characteristics of ADAC dataset (~1000 vehicles)

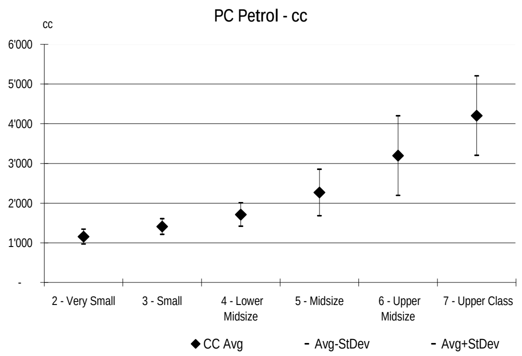












Fuel Type	Class	Count	AvgOfFC	StDevOfFC	AvgOfkW	StDevOfkW	AvgOfcc	StDevOfcc
D	2 - Very Small	13	5.15	0.55	55.5	11.6	1'327	138
D	3 - Small	80	5.08	0.49	65.9	13.1	1'472	185
D	4 - Lower Midsize	156	5.88	0.67	89.9	17.9	1'842	220
D	5 - Midsize	170	6.60	1.05	115.6	26.6	2'127	375
D	6 - Upper Midsize	91	7.83	1.38	131.4	30.6	2'486	441
D	7 - Upper Class	16	8.99	1.18	188.6	39.9	3'242	602
P	2 - Very Small	39	6.29	0.70	53.4	10.6	1'155	188
P	3 - Small	111	6.88	0.63	72.6	21.2	1'409	197
P	4 - Lower Midsize	164	7.83	0.87	96.1	28.3	1'711	294
P	5 - Midsize	136	8.79	1.09	135.7	43.2	2'268	586
P	6 - Upper Midsize	42	10.62	1.74	191.0	64.8	3'197	1'003
P	7 - Upper Class	23	11.38	0.98	239.4	48.5	4'204	1'002

Annex 2: Passenger car specifications from CO_2 Monitoring Database

Nr of Vehicles (in 1000)

Fuel	MS	2001	2002	2003	2004	2005	2006	2007	2008
Diesel	Austria	193	195	215	220	200	192	177	160
Diesel	Belgium	306	300	313	339	349	392	404	423
Diesel	Cyprus				1	1	1	2	3
Diesel	Czech Republic				34	30	32	34	35
Diesel	Denmark		22	23	29	34	40	63	67
Diesel	Estonia				1	3	6	8	6
Diesel	Finland	15	15	20	20	23	27	34	67
Diesel	France	1'246	1'333	1'335	1'377	1'420	1'414	1'511	1'571
Diesel	Germany	1'077	1'192	1'265	1'395	1'382	1'506	1'472	1'331
Diesel	Greece	1	1		7	4	6	9	10
Diesel	Hungary				39	38	45	44	47
Diesel	Ireland	17	27	25	29	38	45	52	52
Diesel	Italy	870	969	1'081	1'314	1'308	1'352	1'388	1'094
Diesel	Latvia				3	4	8	11	7
Diesel	Lithuania				4	4	6	9	9
Diesel	Luxembourg	25	27	29	35	37	39	40	40
Diesel	Malta				1	2	1	1	1
Diesel	Netherlands	121	109	110	118	122	129	140	124
Diesel	Poland				74	74	73	101	129
Diesel	Portugal		84	90	117	134	130	142	148
Diesel	Romania							131	114
Diesel	Slovakia					11	12		13
Diesel	Slovenia				19	31	27	29	28
Diesel	Spain	195	580	816	959	1'021	1'042	963	729
Diesel	Sweden		5	8	20	25	54	102	87
Diesel	UK	400	617	692	809	870	876	944	906
Petrol	Austria	101	85	86	91	108	117	121	132
Petrol	Belgium	183	167	146	145	131	134	120	113
Petrol	Cyprus				18	17	19	23	21
Petrol	Czech Republic				80	74	76	87	99
Petrol	Denmark		91	79	94	112	114	96	79
Petrol	Estonia				6	13	18	22	18
Petrol	Finland	91	98	125	120	123	116	90	70
Petrol	France	981	785	651	617	636	569	536	463
Petrol	Germany	2'086	1'928	1'885	1'744	1'859	1'903	1'616	1'688
Petrol	Greece	245	240		235	261	266	276	266
Petrol	Hungary				191	159	149	122	116
Petrol	Ireland	99	124	118	124	133	132	133	98
Petrol	Italy	1'528	1'298	1'155	937	896	943	1'015	915
Petrol	Latvia				8	11	17	20	12
Petrol	Lithuania				6	7	9	12	13
Petrol	Luxembourg	18	17	15	13	12	12	12	12
Petrol	Malta				3	5	5	5	4
Petrol	Netherlands	405	398	377	361	331	349	354	358
Petrol	Poland				222	150	150	163	176
Petrol	Portugal		148	104	85	74	67	61	66
Petrol	Romania					167	167	167	171
Petrol	Slovakia				42	34	42	42	42
Petrol	Slovenia				18	32	36	39	43
Petrol	Spain	196	390	503	489	454	450	393	316
Petrol	Sweden		76	101	238	242	223	198	160
Petrol	UK	1'830	1'992	1'862	1'702	1'514	1'419	1'408	1'178
Diesel	EU	4'466	5'477	6'023	6'964	7'165	7'454	7'814	7'203
Petrol	EU	7'762	7'835	7'205	7'593	7'557	7'500	7'131	6'629
All	EU	12'228	13'312	13'229	14'557	14'722	14'954	14'945	13'832

Avr. G CO2 / km

Fuel	MS	2001	2002	2003	2004	2005	2006	2007	2008
Diesel	Austria	160.8	160.7	161.3	159.3	160.5	164.1	164.1	160.2
Diesel	Belgium	158.0	156.3	154.3	152.5	152.3	152.2	151.4	146.5
Diesel	Cyprus				201.1	165.7	171.9	179.8	179.5
Diesel	Czech Republic				151.3	153.2	155.5	154.8	157.9
Diesel	Denmark		141.3	144.0	144.1	145.5	149.5	151.8	140.2
Diesel	Estonia				181.0	187.5	185.6	185.4	182.6
Diesel	Finland	155.7	159.1	166.5	167.7	173.6	177.0	173.8	159.1
Diesel	France	154.7	151.9	150.8	149.0	148.7	147.6	147.9	139.3
Diesel	Germany	168.2	169.1	170.1	170.5	171.3	173.5	171.0	166.6
Diesel	Greece	173.9	161.6		165.4	181.5	183.4	182.7	177.4
Diesel	Hungary				153.0	153.5	152.2	153.3	154.1
Diesel	Ireland	170.9	163.5	165.4	170.6	170.7	172.9	165.7	155.1
Diesel	Italy	158.6	156.4	152.5	148.5	148.5	149.5	148.5	148.2
Diesel	Latvia				187.9	186.0	180.5	181.7	177.4
Diesel	Lithuania				172.3	183.7	162.2	172.5	164.7
Diesel	Luxembourg	164.9	163.1	165.7	162.5	161.6	162.8	160.4	154.8
Diesel	Malta				149.2	156.8	154.8	154.5	160.8
Diesel	Netherlands	158.1	160.7	162.8	160.9	160.8	163.2	162.7	157.4
Diesel	Poland				148.9	150.5	154.0	151.7	150.7
Diesel	Portugal		151.7	145.7	143.6	142.6	145.3	144.9	137.3
Diesel	Romania							145.6	147.9
Diesel	Slovakia					165.7	126.6		148.4
Diesel	Slovenia				148.6	154.1	152.9	156.2	157.6
Diesel	Spain	147.8	148.5	150.9	150.1	151.0	152.8	150.2	145.0
Diesel	Sweden		179.9	189.9	190.4	187.6	183.2	174.7	166.6
Diesel	UK	164.5	162.4	164.6	164.3	165.1	166.1	163.8	157.1
Petrol	Austria	174.9	172.6	170.3	168.2	164.9	162.8	160.8	155.4
Petrol	Belgium	173.6	170.5	166.9	165.1	162.9	159.0	157.2	152.7
Petrol	Cyprus				172.4	173.4	169.8	169.5	163.7
Petrol	Czech Republic				156.4	155.7	153.5	153.0	153.1
Petrol	Denmark		176.8	176.4	172.6	169.2	167.1	164.9	151.8
Petrol	Estonia				181.5	182.8	180.7	180.2	175.7
Petrol	Finland	181.8	180.0	180.2	181.7	180.8	180.0	178.9	166.4
Petrol	France	166.5	165.2	163.6	162.3	160.5	155.6	154.0	142.8
Petrol	Germany	185.8	182.6	179.8	178.1	174.7	171.8	168.1	163.6
Petrol	Greece	166.5	167.8		168.8	167.2	166.0	164.7	160.1
Petrol	Hungary				159.5	157.1	155.3	155.6	153.1
Petrol	Ireland	167.0	165.3	167.0	167.0	165.6	164.2	160.0	157.6
Petrol	Italy	158.2	156.7	153.3	152.1	150.6	148.4	144.8	142.9
Petrol	Latvia				194.4	187.8	205.7	184.0	182.2
Petrol	Lithuania				196.5	187.8	164.1	179.6	171.5
Petrol	Luxembourg	192.8	191.4	188.6	188.8	189.8	186.9	184.6	175.1
Petrol	Malta				148.6	148.7	143.3	145.4	143.2
Petrol	Netherlands	178.8	175.7	176.5	174.2	173.3	167.8	165.5	157.9
Petrol	Poland				155.8	157.1	156.8	155.0	154.1
Petrol	Portugal		155.4	153.5	151.7	149.2	144.8	142.7	140.0
Petrol	Romania							162.1	161.2
Petrol	Slovakia					154.8	128.4		160.3
Petrol	Slovenia				156.9	160.2	157.3	156.3	154.8
Petrol	Spain	168.7	168.1	167.2	165.4	165.2	162.1	160.7	155.8
Petrol	Sweden		198.4	199.6	197.6	194.4	190.1	184.9	178.1
Petrol	UK	180.9	178.6	175.7	174.7	172.3	168.7	165.4	159.2
Diesel	EU avrg.	160.0	158.1	157.7	156.2	156.5	157.8	156.3	151.2
Petrol	EU avrg.	174.7	172.9	171.3	168.9	164.3	161.1	160.6	156.6
All	EU avrg.	169.3	166.8	165.1	162.8	160.5	159.4	158.4	153.8

Capacity

Fuel	MS	2001	2002	2003	2004	2005	2006	2007	2008
Diesel	Austria	1'992	1'977	1'967	1'922	1'916	1'930	1'946	1'934
Diesel	Belgium	1'938	1'916	1'891	1'844	1'814	1'793	1'795	1'778
Diesel	Cyprus				2'186	1'817	1'862	1'986	2'034
Diesel	Czech Republic				1'898	1'907	1'894	1'909	1'953
Diesel	Denmark		1'825	1'849	1'822	1'804	1'809	1'811	1'717
Diesel	Estonia				2'034	2'103	2'132	2'150	2'165
Diesel	Finland	2'005	2'013	2'062	2'059	2'082	2'121	2'074	1'957
Diesel	France	1'953	1'919	1'891	1'836	1'797	1'760	1'765	1'688
Diesel	Germany	2'047	2'056	2'080	2'072	2'070	2'086	2'094	2'088
Diesel	Greece	2'058	2'000		2'085	2'129	2'112	2'080	2'049
Diesel	Hungary				1'782	1'769	1'792	1'802	1'828
Diesel	Ireland	2'051	2'027	2'013	2'033	1'999	2'009	1'988	1'883
Diesel	Italy	1'960	1'926	1'867	1'778	1'759	1'755	1'750	1'767
Diesel	Latvia				2'135	2'124	2'086	2'110	2'108
Diesel	Lithuania				2'039	2'060	2'077	2'007	1'980
Diesel	Luxembourg	2'034	2'016	2'041	1'995	1'973	1'973	1'971	1'957
Diesel	Malta				1'707	1'803	1'777	1'747	1'828
Diesel	Netherlands	1'980	1'996	2'021	1'983	1'952	1'959	1'960	1'947
Diesel	Poland				1'854	1'830	1'849	1'810	1'825
Diesel	Portugal		1'866	1'774	1'723	1'681	1'692	1'696	1'685
Diesel	Romania							1'717	1'766
Diesel	Slovakia					1'908	1'898		1'871
Diesel	Slovenia				1'853	1'896	1'867	1'886	1'911
Diesel	Spain	1'914	1'901	1'908	1'868	1'844	1'838	1'821	1'821
Diesel	Sweden		2'135	2'225	2'233	2'231	2'168	2'108	2'054
Diesel	UK	2'024	1'997	2'014	2'002	2'006	2'014	2'010	1'964
Petrol	Austria	1'570	1'565	1'555	1'538	1'513	1'509	1'512	1'484
Petrol	Belgium	1'524	1'508	1'483	1'478	1'474	1'460	1'476	1'453
Petrol	Cyprus				1'541	1'562	1'533	1'570	1'561
Petrol	Czech Republic				1'384	1'366	1'360	1'366	1'392
Petrol	Denmark		1'662	1'664	1'638	1'612	1'597	1'593	1'479
Petrol	Estonia				1'702	1'752	1'772	1'812	1'777
Petrol	Finland	1'709	1'688	1'702	1'741	1'747	1'753	1'754	1'655
Petrol	France	1'487	1'488	1'482	1'478	1'470	1'441	1'449	1'359
Petrol	Germany	1'707	1'731	1'700	1'701	1'683	1'668	1'654	1'634
Petrol	Greece	1'393	1'432		1'523	1'523	1'523	1'535	1'521
Petrol	Hungary				1'353	1'374	1'399	1'421	1'422
Petrol	Ireland	1'461	1'475	1'473	1'488	1'493	1'491	1'500	1'484
Petrol	Italy	1'323	1'319	1'305	1'315	1'315	1'324	1'313	1'320
Petrol	Latvia				1'884	1'829	1'839	1'867	1'842
Petrol	Lithuania				1'832	1'783	1'818	1'808	1'770
Petrol	Luxembourg	1'816	1'851	1'838	1'872	1'938	1'948	1'947	1'876
Petrol	Malta				1'275	1'278	1'269	1'315	1'337
Petrol	Netherlands	1'616	1'596	1'623	1'621	1'639	1'595	1'597	1'534
Petrol	Poland				1'362	1'416	1'435	1'448	1'456
Petrol	Portugal		1'307	1'293	1'286	1'282	1'256	1'271	1'274
Petrol	Romania							1'405	1'433
Petrol	Slovakia					1'397	1'376		1'394
Petrol	Slovenia				1'405	1'452	1'435	1'448	1'458
Petrol	Spain	1'515	1'517	1'542	1'535	1'552	1'536	1'536	1'524
Petrol	Sweden		1'952	1'964	1'957	1'950	1'908	1'882	1'811
Petrol	UK	1'641	1'632	1'630	1'636	1'639	1'633	1'625	1'579
Diesel	EU	1'984	1'961	1'948	1'904	1'886	1'885	1'880	1'856
Petrol	EU	1'560	1'569	1'572	1'571	1'573	1'561	1'547	1'518
All	EU	1'714	1'730	1'743	1'730	1'727	1'724	1'719	1'690

Mass in kg

Fuel	MS	2001	2002	2003	2004	2005	2006	2007	2008
Diesel	Austria	1'405	1'422	1'508	1'517	1'542	1'576	1'583	1'591
Diesel	Belgium	1'380	1'408	1'446	1'453	1'470	1'479	1'488	1'485
Diesel	Cyprus				1'602	1'501	1'608	1'680	1'729
Diesel	Czech Republic				1'931	1'442	1'464	1'492	1'534
Diesel	Denmark		1'359	1'396	1'420	1'447	1'479	1'510	1'445
Diesel	Estonia				1'611	1'687	1'697	1'708	1'693
Diesel	Finland	1'882	1'925	1'523	1'546	1'605	1'638	1'633	1'560
Diesel	France	1'354	1'364	1'383	1'402	1'420	1'426	1'448	1'453
Diesel	Germany	1'488	1'512	1'546	1'565	1'582	1'603	1'605	1'609
Diesel	Greece	1'501	1'544	1'572	1'593	1'724	1'735	1'752	1'726
Diesel	Hungary				1'410	1'450	1'467	1'486	1'524
Diesel	Ireland	1'501	1'490	1'500	1'575	1'596	1'643	1'662	1'630
Diesel	Italy	1'867	1'871	1'859	1'389	1'403	1'426	1'431	1'451
Diesel	Latvia				1'654	1'678	1'687	1'698	1'681
Diesel	Lithuania				1'567	1'626	1'680	1'627	1'614
Diesel	Luxembourg	1'940	1'948	1'522	1'527	1'535	1'553	1'545	1'542
Diesel	Malta				1'616	1'616	1'616	1'616	1'616
Diesel	Netherlands	1'423	1'459	1'496	1'502	1'521	1'544	1'567	1'559
Diesel	Poland				1'393	1'425	1'468	1'464	1'425
Diesel	Portugal		1'417	1'398	1'405	1'424	1'456	1'457	1'439
Diesel	Romania							1'411	1'445
Diesel	Slovakia					1'387	1'387	1'387	1'387
Diesel	Slovenia				1'373	1'446	1'489	1'520	1'557
Diesel	Spain	1'221	1'806	1'387	1'399	1'436	1'464	1'484	1'468
Diesel	Sweden	1'648	1'671	1'719	1'719	1'715	1'688	1'654	1'631
Diesel	UK	1'523	1'522	1'556	1'568	1'569	1'588	1'582	1'549
Petrol	Austria	1'138	1'138	1'219	1'225	1'236	1'241	1'244	1'235
Petrol	Belgium	1'135	1'158	1'179	1'194	1'198	1'195	1'205	1'200
Petrol	Cyprus				1'192	1'264	1'300	1'320	1'324
Petrol	Czech Republic				1'606	1'161	1'158	1'170	1'182
Petrol	Denmark		1'293	1'304	1'299	1'286	1'276	1'279	1'212
Petrol	Estonia				1'304	1'336	1'347	1'373	1'372
Petrol	Finland	1'730	1'733	1'305	1'324	1'337	1'345	1'364	1'329
Petrol	France	1'126	1'136	1'146	1'162	1'165	1'159	1'170	1'164
Petrol	Germany	1'249	1'252	1'269	1'281	1'285	1'283	1'276	1'280
Petrol	Greece	1'171	1'221	1'257	1'268	1'280	1'294	1'300	1'295
Petrol	Hungary				1'136	1'144	1'168	1'184	1'193
Petrol	Ireland	1'196	1'214	1'213	1'250	1'270	1'282	1'335	1'347
Petrol	Italy	1'452	1'451	1'451	1'075	1'091	1'103	1'096	1'102
Petrol	Latvia				1'361	1'351	1'369	1'393	1'397
Petrol	Lithuania				1'350	1'345	1'358	1'364	1'361
Petrol	Luxembourg	1'686	1'693	1'288	1'322	1'342	1'337	1'338	1'319
Petrol	Malta				1'240	1'240	1'240	1'240	1'240
Petrol	Netherlands	1'211	1'210	1'244	1'252	1'270	1'254	1'264	1'241
Petrol	Poland				1'110	1'160	1'181	1'204	1'139
Petrol	Portugal		1'122	1'130	1'144	1'156	1'154	1'153	1'156
Petrol	Romania							1'155	1'179
Petrol	Slovakia				1'106	1'106	1'106	1'106	1'106
Petrol	Slovenia				1'116	1'169	1'186	1'203	1'218
Petrol	Spain	1'068	1'606	1'202	1'210	1'236	1'236	1'252	1'241
Petrol	Sweden	1'436	1'438	1'451	1'445	1'444	1'440	1'424	1'409
Petrol	UK	1'288	1'290	1'306	1'297	1'257	1'263	1'264	1'244
Diesel	EU	1'507	1'564	1'536	1'463	1'479	1'501	1'509	1'508
Petrol	EU	1'280	1'304	1'291	1'237	1'235	1'238	1'235	1'228
All	EU	1'346	1'364	1'413	1'402	1'347	1'356	1'372	1'379

Power in kW

Fuel	MS	2001	2002	2003	2004	2005	2006	2007	2008
Diesel	Austria	78	79	80	81	84	89	92	93
Diesel	Belgium	75	76	77	78	80	81	83	83
Diesel	Cyprus				92	86	96	105	107
Diesel	Czech Republic				79	85	87	90	94
Diesel	Denmark		72	74	75	79	85	86	82
Diesel	Estonia				84	92	99	102	105
Diesel	Finland	76	81	85	90	95	102	102	97
Diesel	France	73	75	76	78	79	81	83	78
Diesel	Germany	86	89	92	95	98	103	106	107
Diesel	Greece	78	80	85	90	95	99	103	104
Diesel	Hungary				76	79	83	86	89
Diesel	Ireland	73	75	81	87	89	95	97	94
Diesel	Italy	78	80	79	78	80	83	84	87
Diesel	Latvia				85	89	89	89	89
Diesel	Lithuania				81	86	91	91	93
Diesel	Luxembourg	84	86	90	91	93	97	99	100
Diesel	Malta				69	79	82	86	91
Diesel	Netherlands	77	81	83	86	88	92	94	107
Diesel	Poland				77	78	85	86	87
Diesel	Portugal		79	76	78	80	83	85	85
Diesel	Romania							73	79
Diesel	Slovakia					81	86		88
Diesel	Slovenia				76	80	84	89	92
Diesel	Spain	76	75	77	79	82	86	86	88
Diesel	Sweden		100	102	105	112	114	110	108
Diesel	UK	83	91	94	92	98	106	101	96
Petrol	Austria	71	72	73	73	72	73	75	74
Petrol	Belgium	70	70	69	70	70	70	73	72
Petrol	Cyprus				78	80	78	83	85
Petrol	Czech Republic				59	61	61	63	66
Petrol	Denmark		80	80	80	79	80	82	77
Petrol	Estonia				84	88	91	96	96
Petrol	Finland	82	82	84	87	88	90	93	89
Petrol	France	69	70	70	71	70	70	73	68
Petrol	Germany	82	83	84	85	85	85	87	88
Petrol	Greece	66	68	72	75	76	77	81	82
Petrol	Hungary				62	65	67	69	70
Petrol	Ireland	69	66	66	72	71	73	75	75
Petrol	Italy	58	58	58	59	60	61	61	63
Petrol	Latvia				95	92	92	92	92
Petrol	Lithuania				92	90	94	96	95
Petrol	Luxembourg	91	95	95	99	105	108	114	111
Petrol	Malta				58	59	60	64	67
Petrol	Netherlands	76	75	78	79	81	79	81	78
Petrol	Poland				61	65	68	70	73
Petrol	Portugal		59	59	59	60	60	62	62
Petrol	Romania							63	67
Petrol	Slovakia					61	63	66	66
Petrol	Slovenia				65	68	68	71	73
Petrol	Spain	66	70	73	73	75	76	77	78
Petrol	Sweden		101	103	103	102	101	102	99
Petrol	UK	85	83	87	94	82	84	81	77
Diesel	EU	78	81	82	83	85	89	90	90
Petrol	EU	72	75	76	77	76	77	77	77
All	EU	75	77	79	80	81	83	84	84

Annex 3: Passenger cars in the detailed analysis (Sample "B")

No	Make	Model	Type	Typ-code	Engine	EURO	Mass [kg]	Power [kW]
1	VW	Polo 1.6 TDI	small car	1	Diesel	5	1207	55
2	VW	Polo 1.6 TDI	small car	1	Diesel	5	1207	55
3	VW	Polo 1.2 TSI	small car	1	Gasoline	5	1220	77
4	VW	Golf VI 2.0 TDI	limousine	2	Diesel	5	1291	77
5	VW	Golf V 1.6 TDI	limousine	2	Diesel	5	1438	77
6	VW	Golf V 1.6 TDI Blue Motion	limousine	2	Diesel	5	1438	77
7	VW	Golf GT TDI	limousine	2	Diesel	4	1438	125
8	VW	Golf V	limousine	2	Diesel	4	1280	59
9	VW	Golf V 1.4 TSI	limousine	2	Gasoline	5	1365	90
10	VW	Golf V 1.4 TSI	limousine	2	Gasoline	5	1421	118
11	VW	Golf GTI	limousine	2	Gasoline	5	1468	155
12	VW	VW Passat 2.0 TDI Blue Motion(?)	estate	3	Diesel	5	1567	103
13	VW	VW Passat 1.6 TDI Blue Motion and others	estate	3	Diesel	5	1570	77
14	VW	VW Passat TDI 2.0	estate	3	Diesel	5	1647	103
15	VW	VW Passat 1.4 TSI Blue Motion + Comfort Line	estate	3	Gasoline	5	1503	90
16	VW	VW Passat CC 1.8TSI	estate	3	Gasoline	5	1544	118
17	VW	Touran 2.0 TDI	Van	4	Diesel. EU5?	5	1700	103
18	VW	Touran 1.4 TSI	Van	4	Gasoline	5	1590	103
19	VW	Touran 1.6	Van	4	Gasoline	5	1590	75
20	VW	Tiguan 2.0 TDI	SUV	5	Diesel	5	1700	103
21	VW	Tiguan 1.4 TSI	SUV	5	Gasoline	5	1700	110
22	VW	Tiguan 2.0 TSI	SUV	5	Gasoline	5	1700	147
23	VW	Tuareg V6 3.0 TDI	SUV	5	Diesel	5	2270	177
24	VW	Tuareg V6 FSI	SUV	5	Gasoline	5	2270	206
25								
26	Toyota	Aygo	small car	1	Gasoline	5		50
27	Toyota	Avensis 1.8 Sol (etc)	estate	3	Gasoline	5	1360	108
28	Toyota	Avensis 2.0D Wagon (etc)	estate	3	Diesel	5	1470	93
29	Toyota	Avensis 2.2 D-4D (etc)	estate	3	Diesel	5	1470	110
30	Toyota	RAV 2.0	SUV	5	Gasoline	5	1470	116
31	Toyota	RAV 2.2 D-4D	SUV	5	Diesel	5	1580	110
32	Toyota	Prius Hybrid 3	limousine	2	Gasoline	5	1520	100
33								
34	BMW	118d	small car	1	diesel	5	1470	105
35	BMW	116i	small car	1	Gasoline	5	1360	90
36	BMW	318d Efficient dynamics	estate	3	diesel	5	1590	105
37	BMW	318i	estate	3	gasoline	5	1360	105
38	BMW	120d	small car	1	diesel	5	1470	130
39	BMW	520d	limousine	2	diesel	5	1590	130
40	BMW	523i	limousine	2	gasoline	5	1590	140
41	BMW	X3 2.0 D	SUV	5	diesel	5	1880	130
42	BMW	X5 3.0 d	SUV	5	diesel	5	2150	173
43	BMW	X5 3.0 sd	SUV	5	diesel	5	2150	210
44								
45	Mazda	2 (1.3)	small car	1	gasoline	5	1105	55
46	Mazda	2 MZ 1.4 CD	small car	1	diesel	5	1130	50
47	Mazda	3 20i (MZR 2.0?)	Limousine compact	2	gasoline	5	1360	110
48	Mazda	3 MZR 1.6	Limousine	2	gasoline	5	1250	77

			compact					
49	Mazda	3 MZ CD 1.6 Diesel	Limousine compact	2	diesel	5	1410	80
50	Mazda	5 2.0	Limousine upper class	2	gasoline	5	1545	107
51	Mazda	5 2.0 CD	Limousine upper class	2	diesel	4	1610	105
52								
53	Opel	Corsa 1.2	small car	1	gasoline	5	1109	60
54	Opel	Corsa 1.4 16V (etc)	small car	1	gasoline	5	1020	66
55	Opel	Corsa 1.3	small car	1	diesel	5	1250	55
56	Opel	Corsa 1.3 cdti	small car	1	diesel	5	1250	66
57	Opel	Astra 1.4 Ecoflex (usw.)	medium car	2	gasoline	5	1250	66
58	Opel	Astra 1.6 Caravan (usw.)	medium car	2	gasoline	5	1360	85
59	Opel	Astra 1.7 cdti Caravan (usw.)	medium car	2	diesel	5	1360	81
60	Opel	Astra 1.9 cdti Caravan (usw.)	medium car	2	diesel	5	1470	110
61	Opel	Zafira 1.7 cdti	Van	4	diesel	5	1613	81
62	Opel	Zafira 1.9 cdti	Van	4	diesel	5	1590	110
63	Opel	Zafira 1.6 Ecoflex (etc.)	Van	4	gasoline	5	1470	85
64	Opel	Zafira 1.8 Innovation (etc.)	Van	4	gasoline	5	1470	103
65	Opel	Vectra 1.9 cdti	estate	3	diesel	5	1590	110
66	Opel	Insignia 1.8 Cosmo	estate	3	gasoline	5	1503	103
67	Opel	Insignia 2.0 cdti sport (etc.)	estate	3	diesel	5	1503	118
68	Opel	Insignia 2.0 cdti sport (etc.)	estate	3	diesel	5	1503	96

Annex 4: Technical data of LCVs selected for the simulations

LCV category	Engine Capacity [cm^3]	Max Power [PS]	Max Torque [Nm/rpm]	Fuel Type	Emission Standard	Frontal Area [m^2]	Drag coefficient	Weight [kg]	Fuel Consumption [l/100km]
N1-I									
Opel Combo 1.6 Cargo	1597	87	138/ 3000	G	4	2.58	0.35	1210	7.8
Opel Combo 1.7 Cargo	1686	70	130/ 2000	D	3	2.58	0.35	1285	5.4
Opel Combo 1.7 Cargo	1686	75	165/ 1800	D	3	2.58	0.35	1285	5.4
Nissan NV200 Van	1461	85	200/ 2000	D	4	3.74	0.35	1250	5.2
Fiat Fiorino 1.4 8v	1360	75	118/ 2600	G	4	2.65	0.32	1070	6.9
Fiat Fiorino 1.3 16v Multijet	1248	75	190/ 1750	D	4	2.65	0.32	1090	4.5
Renault Kangoo Express 1.6 90hp	1598	90	128/ 3000	G	4	3.9		1213	8.2
Renault Kangoo Express 1.6 16V 105hp	1598	105	148/ 3750	G	4	3.9		1213	7.7
Renault Kangoo Express 1.5 dCi 85hp	1461	85	200/ 1750	D	4	3.9		1251	5.2
Renault Kangoo Express 1.5 dCi 105hp	1461	105	240/ 2000	D	4	3.9		1287	5.4
Peugeot Partner	1560	70	170/ 1750	D	4	3.52		1130	5.4
Citroen Nemo 1.4i 8V 75hp	1360	75	118/ 2600	G	4	3.47		1165	6.6
Citroen Nemo 1.4HDi 8V 70hp	1399	70	160/ 1750	D	4	3.47		1185	4.5
Average N1 I gasoline	1479	85	128	G	4	3.36		1163	7.5
Average N1 I diesel	1467	80	185	D	4	3.34		1221	5.2
N1-II									
Fiat Doblo 1.4 95hp	1368	95	127/ 4500	G	5	3.38	0.32	1340	5.2
Fiat Doblo 1.3 MJT 90hp	1248	90	200/ 1000	D	4	3.38	0.32	1370	4.9
Fiat Doblo 1.6 MJT 105hp	1598	105	290/ 1500	D	5	3.38	0.32	1410	5.2
Opel Vivaro 2.0CDTI 16v SWB (90hp)	1995	90	240/ 1500	D	4	4.3	0.35	1700	8.2
Opel Vivaro 2.0CDTI 16v SWB (115hp)	1995	115	290/ 1600	D	4	4.3	0.35	1700	8.2

Opel Vivaro 2.0CDTI 16v SWB (145hp)	2464	145	320/ 1500	D	4	4.3	0.35	1750	8.7
Opel Vivaro 2.0CDTI 16v LWB (90hp)	1995	90	240/ 1500	D	4	4.3	0.35	1750	8.2
Opel Vivaro 2.0CDTI 16v LWB (115hp)	1995	115	290/ 1600	D	4	4.3	0.35	1750	8.2
Opel Vivaro 2.0CDTI 16v LWB (145hp)	2464	145	320/ 1500	D	4	4.3	0.35	1800	8.7
Fiat Ducato X250 Short WB 100MJT Cab 30	2198	100	250/ 1500	D	4	4.9	0.31	1590	7.9
Fiat Ducato X250 Medium WB 100MJT Cab 30	2198	100	250/ 1500	D	4	4.9	0.31	1620	8.1
Fiat Scudo Van 90 Multijet SW	1560	90	180/ 1750	D	4	3.35	0.325	1661	7.2
Fiat Scudo Van 90 Multijet LW	1560	90	180/ 1750	D	4	3.35	0.325	1700	7.2
Fiat Scudo Van 120 Multijet SW	1997	120	300/ 2000	D	4	3.35	0.325	1702	7.4
Fiat Scudo Van 120 Multijet LW	1997	120	300/ 2000	D	4	3.35	0.325	1732	7.4
Citroen Berlingo Multispace 1.6i 16V 90hp	1587	90	132/ 2500	G	4	4.46		1397	8.2
Citroen Berlingo Multispace 1.6 VTi 120hp	1598	120	160/ 4250	G	4	4.46		1405	7.3
Citroen Berlingo Multispace 1.6HDi 75hp	1560	75	185/ 1750	D	4	4.46		1407	5.7
Citroen Berlingo Multispace 1.6HDi 90hp	1560	90	215/ 1750	D	4	4.46		1407	5.7
VW Caddy 1.4 petrol (59kW)	1390	80	132/ 3800	G	4	3.78		1433	7.9
VW Caddy 1.6 petrol (75kW)	1598	100	148/ 3800	G	4	3.78		1456	8.2
VW Caddy 2.0 SDi (51kW)	1968	70	140/ 2300	D	4	3.78		1491	6
VW Caddy 1.9 TDi (51kW)	1896	75	210/ 1900	D	4	3.78		1526	6
VW Caddy 1.9 TDi (77kW)	1896	105	250/ 1900	D	4	3.78		1535	6
VW Caddy 2.0 TDi (77kW)	1968	140	320/ 2200	D	4	3.78		1554	6.2
Renault Traffic 2.0 16V 120hp SWB	1998	120	190/ 3750	G	4	3.72		1660	10.3
Renault Traffic 2.0 16V 120hp LWB	1998	120	190/ 3750	G	4	3.74		1660	10.3
Renault Traffic 2.0 dCi 115hp SWB	1998	115	190/ 1600	D	4	3.72		1668	7.9
Renault Traffic 2.0 dCi 115hp LWB	1998	115	190/ 1600	D	4	3.74		1724	7.9
N1-III									
Ford Transit SWB Low Roof	2399	105	285/ 1600	D	4	4.6	0.4	1849	9.5

Ford Transit SWB Mid Roof	2399	105	285/ 1600	D	4	5.6	0.4	1874	9.5
Ford Transit LWB Mid Roof	2399	145	375/ 2000	D	4	5.6	0.4	1979	10.4
Ford Transit LWB High Roof	2399	145	375/ 2000	D	4	6.1	0.4	2006	10.4
Ford Transit Jumbo 350 Mid Roof	2399	145	375/ 2000	D	4	6.2	0.4	2141	10.4
Ford Transit Jumbo 460 High Roof	2399	145	375/ 2000	D	4	6.2	0.4	2280	10.4
Ford Transit Chassis Cab 350	2399	145	375/ 2000	D	4	5.1	0.4	1777	10.4
Ford Transit Chassis Cab EF 460	2399	145	375/ 2000	D	4	5.1	0.4	1873	10.4
Ford Transit Bus 12 Seat	2399	145	375/ 2000	D	4	5.65	0.4	2306	10.4
Ford Transit Bus 14 Seat	2399	145	375/ 2000	D	4	5.65	0.4	2306	10.4
Mercedes Sprinter 210CDI	2143	95	250/ 1400	D	5	4.8	0.4	2060	8.9- 9.4
Mercedes Sprinter 316CDI	2143	120	360/ 1900	D	5	4.8	0.4	2060	7.9- 8.4
Peugeot Boxer L1H1 100hp	2198	120	250/ 1500	D	4	4.6	0.4	1845	7.6
Peugeot Boxer L1H1 120hp	2198	120	320/ 2000	D	4	4.6	0.4	1860	7.6
Peugeot Boxer L2H1 120hp	2198	120	320/ 2000	D	4	4.6	0.4	1900	7.6
Peugeot Boxer L2H2 120hp	2198	120	320/ 2000	D	4	5.2	0.4	1925	7.5
Peugeot Boxer L3H2 120hp	2198	120	320/ 2000	D	4	5.2	0.4	1975	7.57
Peugeot Boxer L3H3 120hp	2198	120	320/ 2000	D	4	4.5	0.4	2000	7.58
Iveco Daily S12	2300	115	270/ 2300	D	4	4.3		2080	8.05
Iveco Daily S14	2300	136	320/ 2350	D	4	4.3		2155	8.0
Iveco Daily S18	3000	175	400/ 2150	D	4	4.7		2190	9
VW Transporter TDI (62kW)	1968	88	220/ 2200	D	4	4.5		1970	7.35
VW Transporter TDI (75kW)	1968	102	250/ 2500	D	4	4.5		1970	7.35
VW Transporter TDI (103kW)	1968	102	340/ 2200	D	4	4.5		1971	7.55
VW Transporter TDI (103kW) 4motion	1968	102	340/ 2200	D	4	4.5		2125	8.15
Mercedes Vito 115CDi Crew Bus	2148	150	330/ 2100	D	4	3.6		1885	8.1
Mercedes Vito 109CDi	2148	95	250/ 2000	D	4	3.6		1885	9

Mercedes Vito 111CDi	2148	120	330/ 210	D	4	3.6		1885	8.1
Citroen Jumpy Combi 1.6HDi 90hp	1560	90	180/ 1750	D	4	4.2		1886	7.2
Citroen Jumpy Combi 2.0HDi 120hp	1997	120	300/ 2000	D	4	4.2		1962	7.5
Citroen Jumpy Combi 2.0HDi 140hp FAP	1997	140	320/ 2000	D	4	4.2		1977	7.6

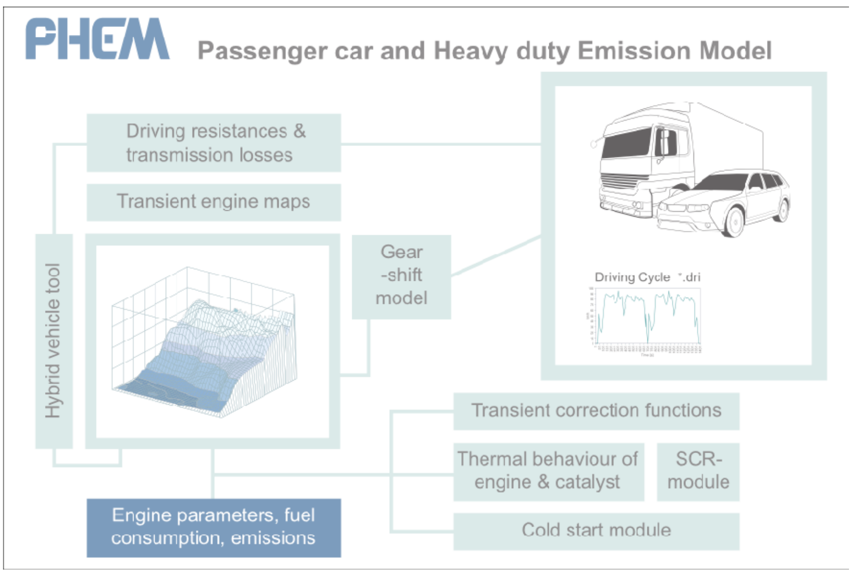
Annex 5: The PHEM model

The model PHEM (Passenger Car and Heavy Duty Emission Model) was developed since the year 1999 in several international and national projects, (Hausberger, 2002), (Hausberger, Simulation of Real World Vehicle Exhaust Emissions, 2003)e.g., (Rexeis, Hausberger, & Riemersma, 2005), (Hausberger, 2003), (Rexeis, 2005), (Zallinger, Hausberger, Ajtay, & Weilenmann, 2005), (Zallinger, Mikroskopische Simulation der Emissionen von Personenkraftfahrzeugen, 2010), (Rexeis, Ascertainment of Real World Emissions of Heavy Duty Vehicles. Dissertation, Institute for Internal Combustion Engines and Thermodynamics, 2009). The main tasks for the model PHEM are:

- Convert emission measurements from engines and vehicles into standard engine emission maps, transient correction functions and vehicle data sets.
- Simulate emission factors for national and European emission inventory tools for average vehicle categories based on the data gained from a). The results are used in the Handbook on Emission Factors, HBEFA, in COPERT and for HDV also in VERSIT.
- Simulate emissions based on speed trajectories modelled by micro scale traffic models (interface to traffic models) or for measured speed trajectories for single vehicles or for vehicle fleets, based on the data gained in a).
- R&D on vehicle propulsion systems for low emissions and high fuel efficiency (e.g. design of HEV control strategies).

PHEM calculates the fuel consumption and emissions of vehicles based on the vehicle longitudinal dynamics and on engine emission maps. For each second PHEM computes for each vehicle the actual engine power to overcome the driving resistances and the losses in the drive train. A driver model simulates the corresponding gear shift behaviour to calculate the actual engine speed. With engine speed and engine power the emissions are taken from engine maps. A transient correction module adapts the emission levels from the engine maps to the actual driving cycle. From the heat transfer from the exhaust gas to the exhaust gas after treatment systems and to the ambient the actual temperature levels are simulated with a heat balance. This allows computing effects like cold starts and cooling down of SCR-systems at low load cycles from HDV. Since all relevant values are simulated based on physical and thermodynamic relations, any imaginable driving condition can be illustrated by this approach.

The figure below shows a schematic picture of the model structure. Details of the approaches can be found in (Rexeis, 2009), (Zallinger, 2010). A general overview of the model and the actual data structure is given in (Luz & Hausberger, 2009), (Hausberger, Rexeis, Zallinger, & Luz, 2009). The engine emission maps and the vehicle data files for the average vehicle classes are based on a very extensive database from international data collection and measurement campaigns.



Annex 6: Parameters of the models presented in section 4.1

Explanation of the variables used in the following tables for “sample All” resp. “sample A” (for the definition of the samples see section 2.1).

Val: value of the parameter indicated (b=constant term)

Se: Standard error of variable

R: coefficient of correlation

m/s: used for calculating t-statistics. If m/s > t crit then the variable is considered as significant (t-statistics).

“Sample All”

"Sample all vehicles"

Petrol

V11 (FCInUse)	2 Var		
	power	mass	
Var:	m2	m1	b
val	0.01515509	0.00334308	2.20408532
Se	0.00082362	0.00018288	0.21136035
r2	0.80498142		

V21 (FCInUse)	2 Var		
	mass	FCTA	
Var:	m2	m1	b
val	0.00142438	0.75594684	0.6905289
Se	0.00016096	0.02271744	0.13895849
r2	0.89237988		

V22 (FCInUse)	3 Var			
	power	mass	FCTA	
Var:	m3	m2	m1	b
val	0.00635178	0.00109638	0.63444222	1.40547102
Se	0.00066632	0.00015413	0.02474045	0.14982605
r2	0.90639311			
m/s	9.53256066	7.11357871	25.6439238	

V23 (FCInUse)	2 Var		
	power/mass	FC_TA	
Var:	m2	m1	b
val	0.00922075	0.82848426	1.48301114
Se	0.00118111	0.01771377	0.11087012
r2	0.889586		

V31 (ratio)	1 Var	
	mass	
Var:	m	b
val	-7.718E-05	1.22618214
r2	0.69638098	
r2*	0.8608	

V32 (ratio)	2 Var		
	power	mass	
Var:	m2	m1	b
val	5.6095E-05	-8.63E-05	1.2329388
r2	0.05154667		
r2*	0.8612		

V33 (ratio)	1 Var		
	power/mass		
Var:	m	b	
val	-0.0003181	1.13749841	
r2	0.49233309		
r2*	0.8714		

V41 (FCInUse)	4 Var				
	CC	power	mass	FCTA	
Var:	m4	m3	m2	m1	b
val	-0.0001137	0.00723526	0.00111731	0.65021168	1.37187895
Se	9.3511E-05	0.00098592	0.00015502	0.02792768	0.15229617
r2	0.90662073	0.65423943			
m/s	-1.2153884	7.33858986	7.20732734	23.2819807	

V42 (FCInUse)	3 Var			
0	CC	mass	FCTA	
Var:	m3	m2	m1	b
val	0.0003923	0.00119468	0.64317739	1.14973753
Se	6.5867E-05	0.00016126	0.02910106	0.15562034
r2	0.89832217			
m/s	5.95604349	7.40850317	22.1015126	

V43 (FCInUse)	3 Var			
	power/cc	mass	FCTA	
Var:	m3	m2	m1	b
val	0.01596761	0.0011414	0.75986791	0.16757113
Se	0.00219833	0.00015935	0.02181482	0.15158596
r2	0.90098591			
m/s	7.26352128	7.16288272	34.8326492	

Diesel

V11 (FCInUse)	2 Var		
	power	mass	
Var:	m2	m1	b
val	0.00485685	0.00406798	-0.1597684
Se	0.00199637	0.00023539	0.2683157
r2	0.72703231		

V21 (FCInUse)	2 Var		
	mass	FCTA	
Var:	m2	m1	b
val	0.00163998	0.69044874	0.10921698
Se	0.00020727	0.04166972	0.19125578
r2	0.85162271		

V22 (FCInUse)	3 Var			
	power	mass	FCTA	
Var:	m3	m2	m1	b
val	0.00321424	0.00138183	0.6842644	0.23098375
Se	0.00146642	0.00023731	0.04151554	0.19805822
r2	0.8538658			
m/s	2.19189199	5.82280778	16.4821253	

V23 (FCInUse)	2 Var		
	power/mass	FC_TA	
Var:	m2	m1	b
val	0.00746654	0.94131156	0.77953959
Se	0.00265796	0.02636665	0.19490289
r2	0.82640263		

V31 (ratio)	1 Var	
	mass	
Var:	m	b
val	-6.532E-05	1.26498657
r2	0.72188702	
r2*	0.8019	

V32 (ratio)	2 Var		
	power	mass	
Var:	m2	m1	b
val	0.00032547	-9.405E-05	1.27773308
r2	0.0262566	0.11543542	
r2*	0.8021		

V33 (ratio)	1 Var	
	power/mass	
Var:	m	b
val	-3.852E-05	1.16143498
r2	0.12175768	
r2*	0.8218	

V41 (FCInUse)	4 Var				
	CC	power	mass	FCTA	
Var:	m4	m3	m2	m1	b
val	0.00022401	0.00112982	0.00138418	0.65610846	0.17381135
Se	8.7236E-05	0.0016648	0.00023522	0.04258527	0.19757032
r2	0.8568903				
m/s	2.56784914	0.67865597	5.8845676	15.4069341	

V42 (FCInUse)	3 Var			
	CC	mass	FCTA	
Var:	m3	m2	m1	b
val	0.00025288	0.00145365	0.65413719	0.13381787
Se	7.6098E-05	0.0002116	0.04244947	0.1884143
r2	0.85667904			
m/s	3.32303465	6.86989629	15.4097855	

V43 (FCInUse)	3 Var			
	power/cc	mass	FCTA	0
Var:	m3	m2	m1	b
val	0.00241646	0.00158497	0.69572517	0.04558866
Se	0.00196389	0.00021187	0.0418559	0.19797241
r2	0.85233697			
m/s	1.2304474	7.48084621	16.6219122	

“Sample A” (reduced sample)

"Sample A" (reduced sample AMS, AR, TCS>2005, SMon)

Petrol

V11 (FCInUse)	2 Var		
	power	mass	
Var:	m2	m1	b
val	0.02267267	0.00227734	2.56335502
Se	0.00169739	0.00029944	0.3178252
r2	0.79678477		

V21 (FCInUse)	2 Var		
	mass	FCTA	
Var:	m2	m1	b
val	0.00105325	0.79313855	1.10847405
Se	0.00025977	0.03879351	0.23110481
r2	0.87134373		

V22 (FCInUse)	3 Var			
	power	mass	FCTA	
Var:	m3	m2	m1	b
val	0.01057705	0.00054548	0.6239763	1.85924218
Se	0.00147542	0.00024613	0.04237949	0.23440675
r2	0.89451157			
m/s	7.16883144	2.21622806	14.7235442	

V23 (FCInUse)	2 Var		
	power/mass	FCTA	
Var:	m2	m1	b
val	0.0116227	0.82078197	1.51781693
Se	0.00225963	0.02971457	0.17899665
r2	0.87627274		

V31 (ratio)	1 Var	
	mass	
Var:	m	b
val	-0.00012	1.33745099
r2	0.64249782	
r2*	0.843	

V32 (ratio)	2 Var		
	power	mass	
Var:	m2	m1	b
val	-7.283E-06	-0.000119	1.33689223
r2	0.08815522		
r2*	0.843		

V33 (ratio)	1 Var		
	power/mass		
Var:	m	b	
val	-0.0007262	1.21987835	
r2	0.47456128		
r2*	0.848		

V41 (FCInUse)	4 Var				
	CC	power	mass	FCTA	
Var:	m4	m3	m2	m1	b
val	-0.0002401	0.01200612	0.00064257	0.65159556	1.79381385
Se	0.00013776	0.00168245	0.00025132	0.04507481	0.2363942
r2	0.89586866				
m/s	-1.7425708	7.13609532	2.55677492	14.455869	

V42 (FCInUse)	3 Var			
	CC	mass	FCTA	
Var:	m3	m2	m1	b
val	0.00023913	0.0008882	0.74285901	1.2746932
Se	0.0001325	0.00027423	0.04761046	0.24775734
r2	0.87310999			
m/s	1.80477023	3.23895104	15.602852	

V43 (FCInUse)	3 Var			
	power/cc	mass	FCTA	
Var:	m3	m2	m1	b
val	0.0177206	0.00092011	0.76633645	0.40018665
Se	0.00307969	0.00024475	0.03668416	0.24928184
r2	0.88729093			
m/s	5.75401289	3.75940554	20.8901211	

Diesel

V11 (FCInUse)	2 Var		
	power	mass	
Var:	m2	m1	b
val	0.00613966	0.00409228	-0.3422132
Se	0.00224802	0.00027054	0.29836581
r2	0.82330661		

V21 (FCInUse)	2 Var		
	mass	FCTA	
Var:	m2	m1	b
val	0.00226405	0.55273074	0.04998162
Se	0.00030035	0.06094712	0.24637977
r2	0.87590243		

V22 (FCInUse)	3 Var			
	power	mass	FCTA	
Var:	m3	m2	m1	b
val	0.00425752	0.00192946	0.53711719	0.22390953
Seb	0.00187324	0.00033123	0.06060023	0.25514478
r2	0.87960436			
m/s	2.27281256	5.82511962	8.8632868	

V23 (FCInUse)	2 Var		
	power/mass	FCTA	
Var:	m2	m1	b
val	0.00878436	0.92652907	0.96983876
Se	0.00361527	0.03498504	0.25487666
r2	0.83977605		

V31 (ratio)	1 Var	
	mass	
Var:	m	b
val	-9.832E-05	1.36258687
r2	0.81550793	
r2*	0.8028	

V32 (ratio)	2 Var		
	power	mass	
Var:	m2	m1	b
val	0.00019206	-0.0001165	1.37128706
r2	0.05400105		
r2*	0.803		

V33 (ratio)	1 Var	
	power/mass	
Var:	m	b
val	-0.0005656	1.23774608
r2	0.17481815	
r2*	0.8299	

V41 (FCInUse)	4 Var				
	CC	power	mass	FCTA	
Var:	m4	m3	m2	m1	b
val	0.00037477	0.0010933	0.00175064	0.52365957	0.19495249
Se	0.00022567	0.00266516	0.00034666	0.06082785	0.25441851
r2	0.88156032				
m/s	1.66069214	0.41022138	5.05003747	8.60887846	

V42 (FCInUse)	3 Var			
	CC	mass	FCTA	
Var:	m3	m2	m1	b
val	0.00044095	0.00176107	0.52324322	0.16800277
Se	0.0001574	0.00034487	0.06066865	0.24518113
r2	0.88144097			
m/s	2.80146388	5.10648547	8.62460685	

V43 (FCInUse)	3 Var			
	power/cc	mass	FCTA	
Var:	m3	m2	m1	b
val	0.00292819	0.00223702	0.55249025	-0.0630364
Se	0.00557299	0.00030536	0.0610798	0.32746197
r2	0.87610602			
m/s	0.5254255	7.32573883	9.04538449	

European Commission

EUR 66088 EN – Joint Research Centre – Institute for Energy and Transport

Title: Parameterisation of Fuel Consumption and CO2 Emissions of Passenger Cars and Light Commercial Vehicles for Modelling Purposes

Authors: Mellios Giorgos, Hausberger Stefan, Keller Mario, Samaras Christos, Ntziachristos Leonidas

Editors: Dilara Panagiota, Fontaras Georgios

Luxembourg: Publications Office of the European Union

2011 – 116 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1018-5593

ISBN 978-92-79-21050-1

doi: 10.2788/58009

Abstract

CO_2 emissions of new passenger cars (PCs) registered in Europe are monitored in order to meet the objectives of Regulation EC 443/2009. This calls for an average CO_2 emission of 130 g/km for new PCs registered in Europe to be met by vehicle measures in 2015. This decreases to 95 g/km in 2020. Similar regulations are gradually promoted for other vehicle categories as well, more prominently for light commercial vehicles (LCVs).

CO_2 emissions of new vehicle types are determined during the vehicle type-approval by testing over the New European Driving Cycle (NEDC). Worries have been expressed that this driving cycle is not representative of real-world driving conditions. It is considered that fuel consumption, and hence CO_2 emissions (and air pollutant emissions), measured over this cycle under-represent reality. This report uses real-world information to compare in-use fuel consumption of PCs with type-approval CO_2.

The main objective was to develop functions that may enable prediction of in-use fuel consumption values, based on vehicle specifications. The functions can then be used in inventorying tools, such as COPERT and HBEFA, to correctly allocate fuel consumption to the different PC vehicle types.

How to obtain EU publications

Our priced publications are available from EU Bookshop (http://bookshop.europa.eu), where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents. You can obtain their contact details by sending a fax to (352) 29 29-42758.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

LB-NA-24-927-EN-C

JRC
EUROPEAN COMMISSION

ISBN 978-92-79-21050-1

Publications Office