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THE IMPACT OF OFFICIAL VERSUS REAL-WORLD ROAD LOADS ON CO_2 EMISSIONS AND FUEL CONSUMPTION OF EUROPEAN PASSENGER CARS

Jörg Kühlwein

icct
THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

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International Council on Clean Transportation Europe
Neue Promenade 6, 10178 Berlin

+49 (30) 847129-102

communications@theicct.org | www.theicct.org | @TheICCT

EXECUTIVE SUMMARY

Driving resistances of a moving vehicle, such as rolling resistance and aerodynamic drag, have a strong impact on its CO_2 emissions and fuel consumption. To properly simulate these resistance forces when testing stationary vehicles tied down on a chassis dynamometer, the vehicle's road loads have to be determined beforehand. European legislation includes provisions on how to determine the road loads using coastdown runs. The current rules include high tolerances and systematic errors and do not cover all technical aspects. This leads in practice to a general underestimation of vehicles' official road loads and the corresponding CO_2 emissions.

In this report, realistic road load data were determined on 29 light-duty vehicles from four independent (non-industrial) labs in Europe. The results were compared to the official road loads determined by manufacturers for certification emission tests. Nine of the vehicles are also sold in the United States; for these vehicles the lab road load data was also compared with official EPA road load values. Directly comparing the road load coefficients is not meaningful, due to different influences for each coefficient and the effect of mass. Thus, the observed road load differences were translated into total NEDC cycle energy and CO_2 emissions by applying a numeric vehicle emission model.

With the introduction of Euro 5 emission standards for passenger cars in September 2009, manufacturers are required to submit their official coastdown parameters as part of the type-approval documentation. However, there is no EU-wide database collecting all official emission test results or the related road load data of the certified vehicles. Hence, when requesting coastdown data for selected vehicles each individual national agency has to be contacted separately. For this study, only two member states (Germany and France) provided the relevant data - four member states (Italy, Great Britain, Luxembourg and Spain) refused to provide the road load data upon request. Official road load data for 15 of the 29 vehicles were obtained from Germany and France and data for four additional vehicles were obtained from the test labs. The other 10 vehicles had to be discarded because of missing official road load data.

The application of realistic road loads instead of the official EU road loads increased total NEDC cycle energy by 15.0% and CO_2 emissions under the NEDC driving regime by 7.2%, on average. Car road loads under realistic conditions were higher than the EU data for all 19 vehicles, with corresponding CO_2 increases of 0.7% to 14.5%. Regarding the observed load and CO_2 gaps, no significant differences between manufacturers were observable. A biased reference ambient temperature during the coastdown test (20 °C instead of 14 °C) and additional coastdown tolerances on the chassis dynamometer further contribute to the overall CO_2 gap by 2.3%. Altogether, assuming an overall divergence between official and real-world CO_2 emissions of 25% in 2010, more than one third of this gap can be explained by exploited tolerances and errors of the road load procedures.

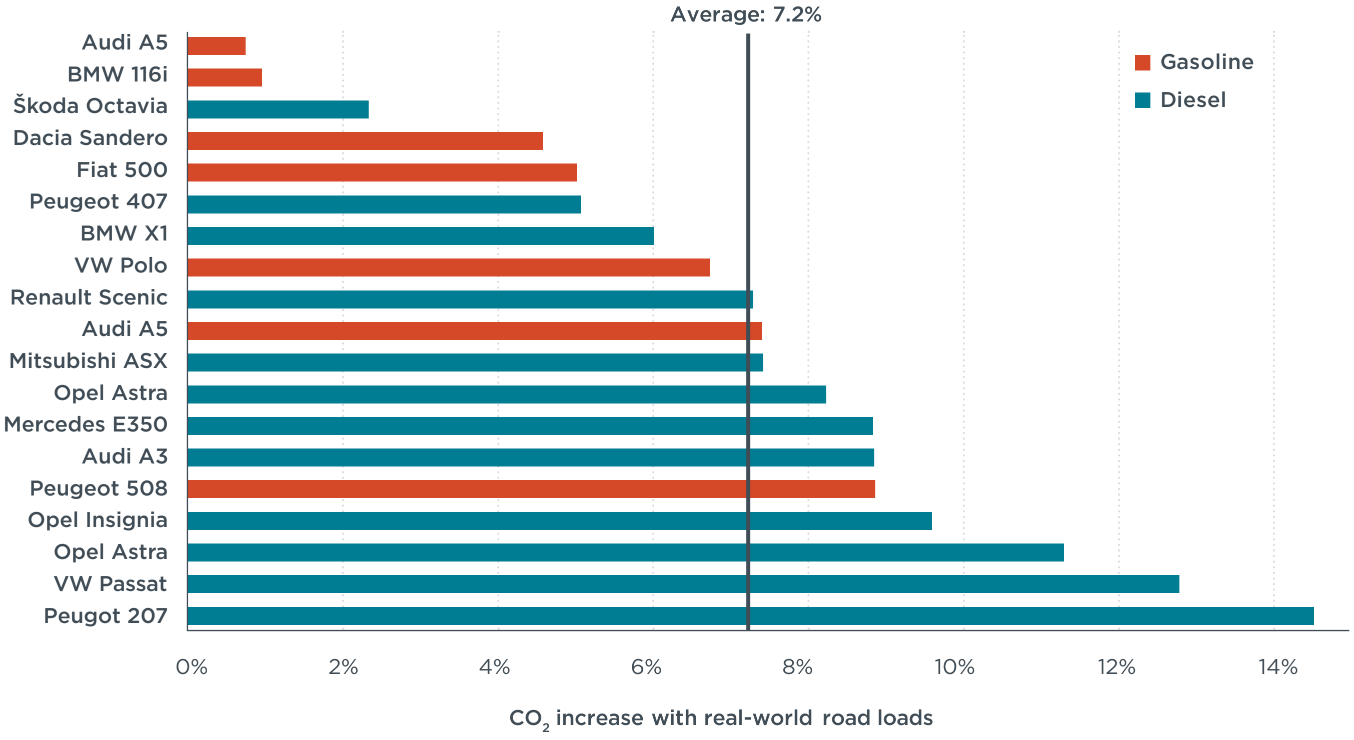

Figure ES-1. Increase of CO_2 emissions with real-world road loads compared to official loads.

The reasons for the observed deviations are manifold. The actual European legislation (NEDC) is based on a directive from 1970 and was last updated in 1998. The current rules do not adequately consider improvement in dynamometer and vehicle technology. They include a large variety of technical tolerances and imprecise definitions, which still reflect the poor technical standards and imprecision of technologies in the 1970s. Manufacturers take advantage of the outdated tolerances to adjust the relevant parameters close to the lower boundary of the tolerance bandwidth and to create artificially modified vehicles for the official coastdown runs. Furthermore, the legislation includes systematic errors and outdated assumptions that lead to a biased calculation of the vehicles' road loads, which alone can result in CO_2 underestimations of more than 7%.

Compared to the situation in Europe, road load data determined under the U.S. certification requirements (for the same vehicles) are higher and closer to reality. The average NEDC cycle energy increase was only 4.2% and the CO_2 increase was only 1.8% compared to the official U.S. road load data. That is because of a better enforcement system and a higher risk of manufacturers getting caught, as EPA periodically conducts its own road load tests. EPA also releases all of the manufacturer road load data to the public, allowing anyone to verify the accuracy of the manufacturer data. The danger of vehicle recalls and the financial consequences in the U.S. are much greater.

The replacement of the current emission legislation in the EU by the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), planned for 2017, will entail improvements and eliminate some of the existing methodological errors. Manufacturers will be directly responsible for the officially declared road loads. On the other hand, the WLTP offers completely new options on road load determination, increasing complexity, and the corresponding descriptions of these new methods are rather vague.

Transparency and independent control measures will become even more important than today. The vehicles' driving resistance data relevant for CO_2 type-approval tests should be included in the certificate of conformity (CoC) and summarized in a public database, together with all certified fuel consumption and emission data. Free access to the official road load forces is a vital precondition for any independent verification measures. Furthermore, official in-use compliance measurements must be extended, and distorted official CO_2 emissions based on false assumptions on road load forces must be discovered and corrected. This requires the establishment of a completely new road load validation procedure under the WLTP regime.

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ABBREVIATIONS

a	Vehicle acceleration
A, B, C	Road load coefficients (U.S. labeling)
A_F	Frontal area
Acc	Acceleration
A_D	Aerodynamic Drag (= Cd * A), with m^2 as the unit
AT	Automatic transmission
CADC	Common Artemis Driving Cycle
C_d	Aerodynamic drag coefficient
CoC	Certificate of Conformity
CO_2	Carbon dioxide
DRIRE	Centre National de Reception des Vehicules (France)
DVT	Data Visualization Tool
EEA	European Environmental Agency
EPA	United States Environmental Protection Agency
EU	European Union
f	Front axle driven
F	Force
FC	Fuel Consumption
f_{RR}	Rolling resistance coefficient
f0, f1, f2	Road load coefficients (European labeling)
g	Gravity constant
GTR	Global technical regulation
HBEFA	Handbook Emission Factors for Road Transport
I_{RP}	Inertia of rotating parts (expressed as mass equivalent)
KBA	Kraftfahrtbundesamt (Germany)
lbf	Pound-force
LDV	Light-duty vehicle
mass iro	Mass in running order (EU definition)
mph	Miles per hour
MT	Manual transmission
m_V	Vehicle mass
MY	Model Year
N	Newton
N1	Light Commercial Vehicles with a maximum mass not exceeding 3.5 tonnes
NEDC	New European Driving Cycle

PHEM	Passenger Car and Heavy Duty Emission Model
q	Two-axle driven
r	Rear axle driven
RG	Road Gradient
RM	Reference mass (mass iro + 25 kg)
RR	Rolling Resistance
RRC	Rolling Resistance Coefficient
RW	Reference weight (= reference mass)
SNCH	Société Nationale de Certification et d'Homologation (Luxembourg)
t	Time
TA	Type-approval
TAN	Type-approval number
TMH	Test Mass High (WLTP)
TML	Test Mass Low (WLTP)
TU	Technical University
UNECE	United Nations Economic Commission for Europe
UTAC	L'Union Technique de l'Automobile du Motocycle et du Cycle (France)
v	Vehicle velocity
VCA	Vehicle Certification Agency (United Kingdom)
WLTC	Worldwide harmonized Light-duty Test Cycle
WLTP	Worldwide harmonized Light vehicles Test Procedure
α	Road gradient
ρ_{Air}	Air density

1 INTRODUCTION

Driving resistances of a moving vehicle, such as rolling resistance and aerodynamic drag, have a strong impact on its CO_2 emissions and fuel consumption. To properly simulate these resistance forces when testing stationary vehicles tied down on a chassis dynamometer, the vehicle's road loads have to be determined beforehand. European legislation includes provisions on how to determine the road loads using experimental coastdown runs. It was previously reported that the current rules include tolerances and systematic errors and do not cover all technical aspects, thereby in practice resulting in a general underestimation of official road load data and the corresponding official CO_2 emissions (Kadijk & Ligterink, 2012; Stewart et al., 2015).

This report aims to better quantify the discrepancy between official type-approval and real-world CO_2 emissions caused by inaccurate road load data, by:

- Comparing real road loads measured by independent labs with official road loads used for EU type approval for selected light-duty vehicles, and
- Quantifying the impact of systematic errors in the road load determination procedure and the biased use of tolerances on CO_2 emissions by applying a vehicle emissions simulation tool.

1.1 PHYSICAL PRINCIPLES OF DRIVING RESISTANCES

The actual fuel consumption and CO_2 emissions of a vehicle depend on the vehicle's driving resistances, the powertrain efficiency, and the energy demand of potentially activated auxiliary consumers. The efficiency of the powertrain describes those parts of the total fuel's energy content that can be used for the mechanical propulsion of the vehicle. The majority of the employed chemical energy is lost by heat dissipation and friction of the powertrain. Engine efficiencies vary among different types of engines and also among different loads within the engine maps, described by engine speed and engine power (or torque). Accurate engine efficiency maps are essential for accurate numerical simulations of vehicles' fuel consumption and CO_2 emissions.

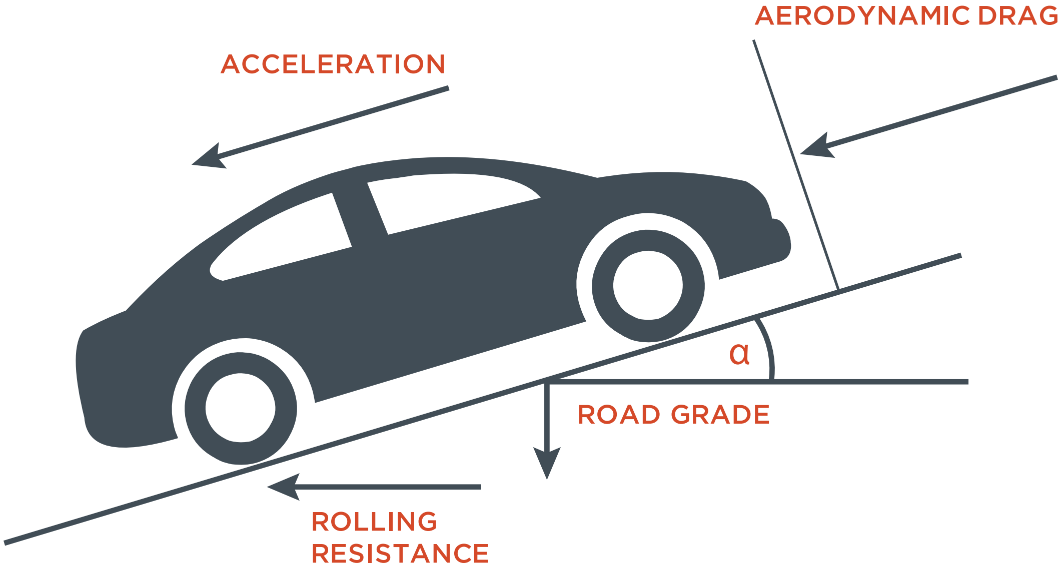

Figure 1. Forces affecting a moving vehicle.

The driving resistances of a vehicle are directly linked to the vehicle's body characteristics and follow basic physical principles. The total force occurring at the contact area between tires and road surface consists of four parts: aerodynamic drag, rolling resistance, acceleration, and a gravity component, which varies based on the road grade (Figure 1). These forces can be calculated by the following formula:

Total force:

$$F_{TOTAL} = F_{AD} + F_{RR} + F_{Acc} + F_{RG}$$

The aerodynamic drag (F_{AD}) of a vehicle consists of the aerodynamic shape of the body, described by the drag coefficient (C_d), and by the projected frontal area of the vehicle (A_F). The aerodynamic force increases with the square of the vehicle's velocity:

$$F_{AD} = C_d * A_F * \rho_{Air} /2 * v^2$$

The rolling resistance forces (F_{RR}) are mainly determined by the tires, but also by parts of the driveline. They are characterized by the rolling resistance coefficient, f_{RR}, which is dependent on the vehicle's velocity. The mass of the vehicle (perpendicular to the road) also has a linear influence:

$$F_{RR} = m_V * g * f_{RR} * \cos(\alpha)$$

The acceleration forces (F_{Acc}) increase proportionally with the vehicle's mass. The inertias of the rotating parts (I_{RP}, in particular of the wheels) also must be considered:

$$F_{Acc} = (m_V + I_{RP}) * a$$

The slope forces (F_{RG}) can be calculated directly based on the road gradient and the vehicle mass:

$$F_{RG} = m_V * g * \sin(\alpha)$$

With:

C_d	Aerodynamic drag coefficient
A_F	Frontal area
ρ_{Air}	Air density
v	Vehicle velocity
m_v	Vehicle mass
g	Gravity constant
f_{RR}	Rolling resistance coefficient
α	Road gradient
I_{RP}	Inertia of rotating parts (mass equivalent)
a	Vehicle acceleration

Fuel consumption and CO_2 emissions of a light-duty vehicle normally are measured on a chassis dynamometer under standardized conditions, such as defined driving patterns and constant ambient conditions. The resistances of the rollers of a chassis dynamometer have to be adjusted to the vehicle's driving resistances in the real world and its mass. For this adjustment, measured rolling resistance and aerodynamic drag are used. The acceleration forces occurring during the driving cycle are adjusted by applying the matching inertia. Road gradients are currently not considered on chassis dynamometers under statutory conditions, but can be simulated by adjusting the inertia.

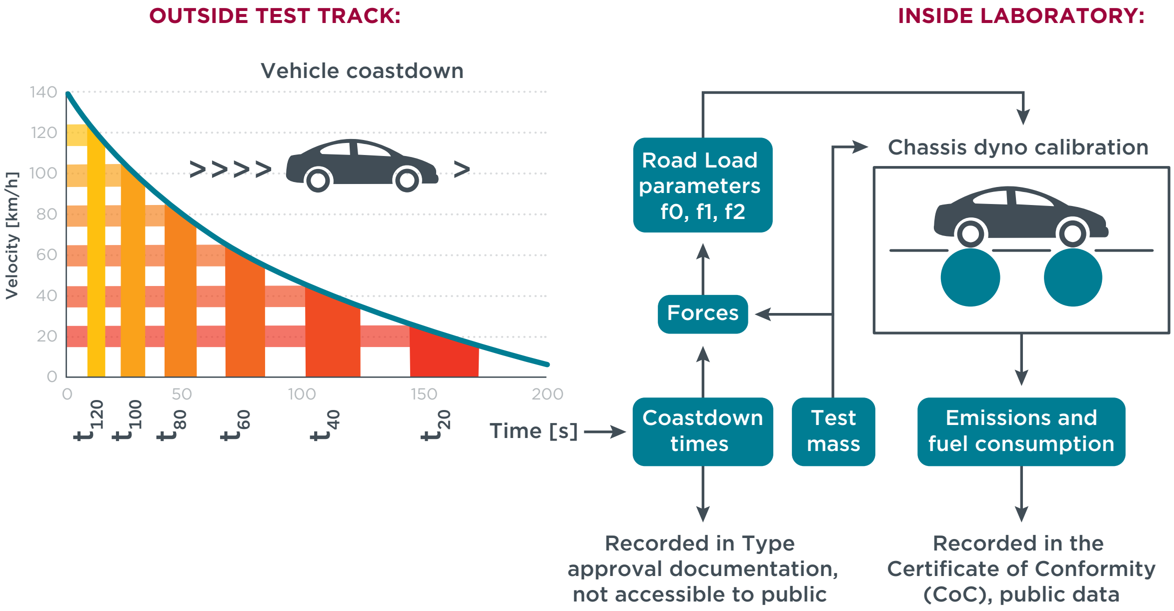

Figure 2. Schematic illustration of the road load determination procedure in the EU.

For the experimental determination of rolling resistance and aerodynamic drag a coastdown run with the test vehicle normally is performed beforehand. The vehicle is accelerated on a flat and straight road to a certain velocity (e.g., 130 km/h). The engine then is decoupled from the drivetrain by switching the gearbox into neutral position, and the vehicle coasts to a standstill. The velocities and times during this coastdown run are monitored continuously. A typical velocity-time course and the principle road load determination procedure are depicted in Figure 2.

The balance of forces during the coastdown deceleration of the vehicle is described by the following formulae:

- $F_{Acc} = F_{RR} + F_{AD}$

- $(m_V + I_{RP}) * a = m_V * g * f_{RR} + C_d * A_F * \rho_{Air} / 2 * v^2$

Because of the velocity dependency of the rolling resistance coefficient (f_{RR}), it is difficult to derive the relevant resistance coefficients (f_{RR} and $C_d * A_F$) directly from the experimental data. Aerodynamic drag increases with the square of the velocity, whereas rolling resistance is rather constant at low velocities, but increases strongly at high speeds. The distribution of the forces and their absolute values strongly depend on the characteristics of the vehicle's body and tires.

Instead, the deceleration forces are calculated at certain velocity points, and a quadratic correlation with the velocity as independent variable following the principle of the least squares deviation is applied. European regulations prescribe the use of six fixed-velocity intervals for this correlation (see Appendix C). The basic formula for this approach is:

$F_{RR} + F_{AD} = f0 + f1 * v + f2 * v^2$

The derived correlation factors f0, f1 and f2 are called the "road load coefficients." In the U.S., these are labeled as A, B and C "target" coefficients. In practice, these three factors are used together with the vehicle test mass to calibrate the dynamometer rollers' resistances. Finally the vehicle on the chassis dynamometer has to overcome the same forces as on the road during normal driving. This is controlled by additional dynamometer coastdown runs where the deceleration forces and the times needed for the predefined velocity intervals have to be identical to the coastdown behavior on the road. Some tolerances are permitted in the EU, but not in the U.S.

1.2 TERMINOLOGY

Coastdown describes the practical test where the vehicle accelerates to a maximum velocity and afterward decelerates with a decoupled gearbox. The test can be performed on an outdoor test track, a chassis roller or a flat belt dynamometer. The velocity-time course is recorded, and time intervals for certain velocity ranges are calculated. These time intervals are seen as "coastdown parameters." In addition, the exact mass of the vehicle as driven during the experiment (including driver) is essential for the subsequent data evaluation.

Road load refers to the deceleration forces of the vehicle during coastdown testing on a test track. The road load is equivalent to the sum of the rolling resistance and aerodynamic forces and is calculated at certain velocity points by the measured time intervals and vehicle mass, including the additional equivalent mass of the rotational inertia, which is caused primarily by the tires. The force-time curve is approximated by a quadratic correlation approach, following the least squares method. The three resulting correlation coefficients are referred to as "road load parameters." Note that the road load parameters depend on vehicle mass. The usual symbols and units in EU and the U.S. are summarized in Table 1.

Table 1. Road load parameters in EU and U.S.

EU			U.S.	
Symbols	Units		Symbols	Units
f0	N	N	A	lbf
f1	N/(m/s)	N/(km/h)	B	lbf/mph
f2	N/(m/s)^2	N/(km/h)^2	C	lbf/mph^2

The road load parameters reflect the driving forces of the vehicle on the test track and are not to be confused with the dynamometer brake loads (U.S.: Dynamometer set coefficients). The brake loads of the rollers or the flat belt are important in simulating realistic driving forces on the chassis dynamometer. They compensate for the missing aerodynamic drag and the different rolling resistance of the vehicle on the test bench compared to driving on the road. The brake loads are determined by the difference of the road loads of the tested vehicles driven on the road and on the chassis dynamometer.

Driving resistances in this report refer to the physical parameters acting in opposition to the vehicle's driving forces. These are:

- Rolling resistance coefficient, in kg/t
- Aerodynamic drag (as the product of aerodynamic drag coefficient and frontal area), in m^2
- Vehicle mass, in kg (responsible for acceleration forces)
- Road gradient (currently not considered in EU legislation)

1.3 COASTDOWN RUNS AND ROAD LOAD DETERMINATION – LEGAL REQUIREMENTS

1.3.1 New European Driving Cycle (NEDC) / United Nations Economic Commission for Europe (UNECE)

The legal requirements for the official coastdown runs and the mathematical derivation of road load parameters are laid down in the EU Regulation EC/692/2008. This regulation corresponds to the UNECE Regulation R83 (United Nations Economic Commission for Europe [UNECE], 2015b). A summary of the main legal features is given in Appendix C.

The European legislation is based on a 1970 directive last updated in 1998 (Council Directive of 20 March 1970). The coastdown legislation's original intent was to determine the road loads of a vehicle in the condition that it is driven on the road. However, the current rules do not adequately consider advances in technology. They include a large variety of technical tolerances and imprecise definitions that still reflect the poor technical standards and precision of technologies in the 1970s, for example when adjusting the rollers' braking forces of the chassis dynamometer. However, modern technologies and control devices are much more precise, and today vehicle manufacturers take advantage of the outdated tolerances by adjusting the relevant parameters close to the lower boundary of the tolerance bandwidth, disregarding the statistical nature of measurement tolerances.

Furthermore, the legislation includes systematic errors and outdated assumptions that lead to a biased calculation of vehicles road loads. Some of these distortions are addressed in this report, and their impact on NEDC total cycle energies and CO_2 emissions are quantified (see section 4.4.2). These include:

- Road inclination of the test track
- Inertia of rotating parts
- Tire tread depth
- Missing humidity in the air density calculation
- Shifted share of rolling resistance and aerodynamic drag

As an alternative to the velocity–time measurements made during the coastdown run, the NEDC legislation also allows for direct torque measurements at the wheels. The measured torques have to be registered at the predefined vehicle velocities and must be reproduced during the control coastdown on the chassis dynamometer. However, under practical aspects, measuring torque of a moving vehicle is still a rather sophisticated methodology and normally not preferred by manufacturers.

1.3.2 World Harmonized Light Vehicles Test Procedure (WLTP)

A new type-approval procedure, the Worldwide Harmonized Light Vehicles Test Procedure (*WLTP*), is currently under development. Its EU introduction is planned for 2017 (Mock et al., 2014). The current version of the Global Technical Regulation (GTR) also includes a section on road load determination procedures. In general, the WLTP rules about the road load issue are much more extensive than the current NEDC regulation. The WLTP is more precise in the classic road coastdown methodology and eliminates most of the systematic NEDC errors, with the exception of the air humidity issue. On the other hand, the WLTP offers completely new options on road load determination, although the corresponding descriptions of these new methods are rather vague. Appendix D summarizes the main WLTP road load topics.

It is remarkable that the WLTP regulation clearly states that the manufacturer shall be responsible for the accuracy of the road load coefficients. Compared to the NEDC, this is a completely new approach that is meant to prevent large discrepancies between a coastdown test vehicle and a regular series vehicle, as they are currently observed. Another new provision in the WLTP is that tolerances within the procedure shall not be used to underestimate the derived road load coefficients.

In addition to coastdown runs that measure velocities or wheel torques, there are three new options in the WLTP that can be applied by vehicle manufacturers to derive vehicle road loads:

- Road coastdown with on-board anemometry
- Aerodynamic drag measured in a wind tunnel, with rolling resistance measured on a chassis roller or flat belt dynamometer
- By calculation (interpolation approach) from vehicle H (high load) and L (low load)

The procedures for these new determination options are either highly complex (e.g., a complicated correlation process included in the on-board anemometry methodology) or in the current form are imprecisely defined (e.g., the measurement and calculation procedure for determining the aerodynamic drag in a wind tunnel is not described).

Other examples for new “flexibilities” in the WLTP include the following:

- The criteria of vehicle selection for the interpolation method are not clearly defined. The introduction of “road load families” makes the situation even more opaque.
- There is no clear definition of a “vehicle coastdown mode” and no clear rationale for the use of such a software modification. The full functionality of such a device is not scrutinized. Hence, a high risk of misuse during the exhaust measurements, which is to say hidden software modifications, must be expected.
- The tolerances of the torque meter method are much more lax under WLTP than under NEDC (6 Nm measurement accuracy compared to 1 Nm with NEDC). The higher tolerances might increase the attractiveness of this method for vehicle manufacturers.
- The method to measure rolling resistance on a chassis roller dynamometer includes a correction formula to consider the higher resistances of the tires on a curved roller than on a flat road. The suggested correction is rather general, and its source is unclear.
- The procedure of load adaptation on the chassis dynamometer is complex, still erroneous and difficult to figure out. The point of time and number of load setting adjustments are not prescribed.
- A description of a control coastdown after the emission test is missing. Differentiated tolerances for the vehicle forces are no longer included.

Summarizing, these new features of the WLTP are expected to make the process of road load determination even more complex and difficult to control. Compared to the limited options in the NEDC, this also could entail new flexibilities and distortions of reality.

On the other hand, the WLTP will eliminate some of the systematic errors included in NEDC/UNECE legislation, and it makes vehicle manufacturers directly responsible for the accuracy of their declared road load data. At this moment in time, these pros and cons make it difficult to assess if the introduction of the WLTP will lead to more realistic official road load data overall.

2 EVALUATED COASTDOWN RUNS FROM INDEPENDENT LABS

Realistic coastdown data from 29 light-duty vehicles were collected from independent research laboratories across Europe. In total, four labs contributed data for this study. The criteria of the considered vehicles were:

- Light-duty vehicle (car or van)
- Certified under Euro 5 or Euro 6 emission standard
- Minimum standards of coastdown procedure fulfilled following the NEDC regulations

2.1 TNO

TNO, Netherlands, performed an experimental study on cars' road loads on behalf of the European Climate Foundation and the Dutch Ministry of Infrastructure and the Environment (Kadijk & Ligterink, 2012). Besides some Euro 4 cars, five Euro 5 and one Euro 6 cars were involved in these investigations (Table 2). TNO already evaluated the achieved coastdown data, compared them with the official manufacturers' road load parameters and draw initial conclusions on the reasons of occurring deviations.

Table 2. Available real-world road load data sets from TNO

ID	Model	Euro	Fuel	Transmission	Engine Capacity ccm	Engine Power kW	Build year	Mass in running order kg
TNO01	**VW Passat**	5	diesel	M6f	1598	77	2012	1543
TNO02	**Peugeot 207**	5	diesel	M5f	1560	68	2012	1275
TNO03	**Fiat 500**	5	gasoline	A5f	1242	51	2009	975
TNO04	**Mercedes E350 Bluetec**	6	diesel	A7r	2987	155	2009	1845
TNO05	**Renault Scenic**	5	diesel	M6f	1461	81	2010	1485
TNO06	**Peugeot 508**	5	gasoline	M6f	1598	115	2012	1475

2.2 TUG

The Technical University of Graz, Austria, Institute of Internal Combustion Engines and Thermodynamics, performs coastdown experiments of light-duty vehicles in irregular intervals for different publically funded projects. The coastdown data are used for the calibration of the chassis dynamometer rollers' brake forces to achieve accurate emission test results. TU Graz developed its own methodology for the correction of gradient forces, being applied at a small scale instead of using averaged gradients over the whole test track. Coastdown data for 10 Euro 5 vehicles were provided (Table 3).

Table 3: Available real-world road load data sets from TUG

ID	Model	Euro	Fuel	Transmission	Engine Capacity ccm	Engine Power kW	Build year	Mass in running order kg
TUG01	**Peugeot 407 SW**	5	diesel	M6f	1997	103	2010	1612
TUG02	**Opel Astra EU5 1.7CDTI**	5	diesel	M6f	1686	92	2010	1503
TUG03	**Fiat Doblo 1.6l**	5	diesel	M6f	1598	77	2010	1485
TUG04	**Fiat Punto EVO**	5	gasoline	M6f	1368	77	2010	1150
TUG05	**Audi A3 Sportback**	5	diesel	M5f	1598	66	2010	1395
TUG06	**Honda Civic 1.4 Comfort**	5	gasoline	M6f	1339	73	2010	1257
TUG07	**Mitsubishi ASX 4WD**	5	diesel	M6q	1798	110	2011	1600
TUG08	**Audi A5 2.0l TFSI**	5	gasoline	M6f	1984	155	2011	1580
TUG09	**Mazda CX-5**	5	diesel	M6q	2191	110	2012	1663
TUG10	**Peugeot Boxer 2.2 HDI**	5	diesel	M6f	2198	81	2012	2164

2.3 VTT

VTT Technical Research Centre of Finland Ltd is the largest multidisciplinary not-for-profit research organization in Northern Europe. In 2012, VTT tested the CO_2 emission performance of 10 Euro 5 cars (Table 4). The focus of this study was to determine real-world CO_2 emissions and fuel consumption. In addition to outdoors measurements at constant speeds and during normal traffic situations, VTT also aimed at reproducing the type-approval NEDC results, but had no access to the manufacturers' driving resistances and "did not want to use them, since we suspected that they were not entirely reliable" (Ahonen et al., 2012). For this study, VTT provided the measured and corrected coastdown times and the corresponding vehicle masses.

Table 4. Available real-world road load data sets from VTT

ID	Model	Euro	Fuel	Transmission	Engine Capacity ccm	Engine Power kW	Build year	Mass in running order kg
VTT01	**Audi A5 1.8 TFSI**	5	gasoline	M6f	1798	125	2012	1500
VTT02	**BMW 116i**	5	gasoline	M6r	1598	100	2011	1365
VTT03	**Citroen C1 1.0i**	5	gasoline	M5f	998	50	2012	905
VTT04	**Dacia Sandero 1.6 Hi-Flex**	5	gasoline	M5f	1598	77	2011	1157
VTT05	**Toyota Yaris Verso-S**	5	gasoline	M6f	1329	73	2012	1187
VTT06	**Fiat Punto 1.3 M-Jet**	5	diesel	M5f	1248	62	2011	1220
VTT07	**Ford Mondeo 1.6 TDCi ECOnetic**	5	diesel	M6f	1560	85	2012	1560
VTT08	**Opel Insignia Sports Tourer 2.0 CDTI EcoFlex**	5	diesel	M6f	1956	118	2011	1788
VTT09	**Škoda Octavia HB 1.6 TDI GreenLine**	5	diesel	M5f	1598	77	2011	1390
VTT10	**Volvo V70 1.6D DRIVe**	5	diesel	M6f	1560	84	2011	1714

2.4 LAT

The Laboratory of Applied Thermodynamics (LAT) of the Aristotle University in Thessaloniki, Greece, is operating a single-axle chassis dynamometer for light-duty vehicle emission measurements. Coastdown experiments have been performed on behalf of the European Commission. Available data comprise three Euro 5 cars, as described in Table 5.

Table 5. Available real-world road load data sets from LAT

ID	Model	Euro	Fuel	Trans-mission	Engine Capacity ccm	Engine Power kW	Build year	Mass in running order kg
LAT01	**Opel Astra EU5 1.3 D**	5	diesel	M5f	1248	70	2012	1393
LAT02	**VW Polo 1.2 TSI**	5	gasoline	M5f	1197	66	2012	1102
LAT03	**BMW X1 sDrive20d**	5	diesel	M6r	1995	120	2012	1565

2.5 LAB COMPARISONS

The applied procedure of deriving the vehicle forces from the measured coastdown times differs among the four labs under consideration. Hence, a harmonization and recalculation of the provided data sets was necessary to ensure that the resulting real-world road loads are based on equal boundary conditions. Table 6 summarizes the methodologies being used by the different labs and the corrections being applied for this study.

Table 6. Lab methodologies and data corrections

	Averaging of coastdown runs in opposite directions?		Correction to ambient standard conditions? (20 °C, 1 bar)	Rotating inertias taken into account for force calculation?		Measured vehicle mass?
		corrected			corrected to	
TNO	YES, times	Forces	YES	NO	3%	YES
TUG	YES, forces (small-scale)	-	YES	YES, originally 4%	3%	YES
VTT	YES, forces	-	YES	NO	3%	YES
LAT	NO, only one direction available	-	NO	NO	3%	NO

- Averaging of coastdown runs: TUG and VTT delivered data with a correct force averaging (TUG even with small-scale correction approach). TNO data originally were calculated by applying the erroneous NEDC time averaging procedure (see Chapter 4.4.2) and were translated into force averaged road load coefficients. LAT provided data in only one driving direction, assuming no inclination of the test track.
- Ambient conditions: TNO, TUG and VTT adapted the directly derived road loads to ambient standard conditions (20 °C, 1 bar). LAT could not provide information about the ambient conditions during the coastdown runs. Hence, data could not be standardized.
- Rotating inertias: TNO, VTT and LAT did not take into account the equivalent masses of the rotating inertias. TUG normally assumes an extra charge of 4% related to the total vehicle mass. All data have been recalculated to 3% extra mass

based on the suggestions of the current version of the WLTP GTR (United Nations Economic Commission for Europe [UNECE], 2015a).

- Vehicle mass: TNO, TUG and VTT weighed the coastdown vehicles and provided exact masses. LAT data did not include the real masses of the tested vehicles. Instead the “mass in running order” was used as stated in the vehicles’ registration.

3 REQUEST OF OFFICIAL COASTDOWN DATA

3.1 THE DATA SITUATION IN EUROPE

With the introduction of Euro 5 emission standards for passenger cars, mandatory for type-approval since September 2009, the official coastdown parameters are part of the technical description of the type-approval documentation as specified in EU Regulation EC/692/2008. The entries in the relevant part of the information document (see Appendix B for the details) are therefore public data and, in theory, accessible to all interested parties.

In practice, there is no central agency of the European Union being authorized for the certification of road vehicles. Instead, the national type-approval authorities are responsible. Each manufacturer chooses any technical service company in Europe that is registered in a certain member state and associated with a certain national authority (Mock & German, 2015). So, theoretically each of the 28 member states can be chosen to certify a vehicle on behalf of all other EU member states. Practically, at least six different member states currently are involved in certifications of the major manufacturers' cars (see Table 7).

The European type-approval scheme differentiates between a "whole vehicle" certification and sub-certifications for specific parts of the vehicle. The emission certification is one of these subset procedures, including all issues on the emission testing on chassis dynamometer and engine test benches and on the underlying coastdown experiments. Manufacturers may decide to commission different technical services for the specific sub-certifications. Hence, the "whole vehicle" certification can be under different responsibility than the emission certification.

The national type-approval authorities or the European Commission do not publish any type-approval data which are not already part of the Certificate of Conformity (CoC). So far, coastdown or road load data are not included in the CoC. And, in contrast to the U.S., there is no EU-wide database collecting all official emission test results or the related road load data of the certified vehicles. Hence, up to now, when requesting coastdown data for selected vehicles, researchers have had to contact each individual national agency separately.

3.2 RESPONSES FROM NATIONAL TYPE-APPROVAL AUTHORITIES

In the framework of this study, the responsible national type-approval authorities for 29 individual vehicles were identified. Their type-approval numbers (TAN for "whole vehicle" certification) and their acronyms for type, variant and version were extracted from the CO_2 monitoring database (European Environment Agency, 2015). The vehicles were clustered, and the resulting lists were sent to the authorities. Table 7 summarizes the responsible type-approval authorities in Europe and their reactions to ICCT's data request.

Table 7. Requested type-approval authorities and their reactions

Country	Authority	Number of evaluated vehicles falling within the authority's remit		Provided official coastdown data?
		Whole vehicle TA	Emissions TA	
Germany	Kraftfahrtbundesamt (KBA), Flensburg	12	7	YES
France	Centre National de Reception des Vehicules (DRIRE), Montlhery	5	5	YES (data provided by UTAC)
Great Britain	Vehicle Certification Agency, Bristol	4	5	NO, declined
Italy	Ministero della Infrastrutture e dei Trasporti, Roma	5	5	NO, declined
Luxembourg	Société Nationale de Certification et d'Homologation (SNCH), Sandweiler	2	6	NO, no response
Spain	Ministerio de industria, turismo y comercio, Madrid	1	1	NO, no response

The German Kraftfahrtbundesamt (KBA) approved a formal application, following the procedure of the German "Umweltinformationsgesetz" based on the European Environmental Information Directive (Directive 2003/4/EC). The coastdown data under French responsibility was provided directly by "L'Union Technique de l'Automobile du Motocycle et du Cycle (UTAC)" upon request by ICCT. VCA in Great Britain and the respective ministry in Italy declined to provide coastdown data, pointing to the alleged confidentiality of the data. Luxembourg and Spain did not respond to ICCT's request.

The refusal of four out of the six requested type-approval authorities led to an unintentional bias of the vehicle database, as some manufacturers could not be considered despite the availability of realistic coastdown data. Vehicles from Toyota, Honda, Ford and Škoda are usually type-approved in Great Britain; Fiat Group (and associated manufacturers) vehicles are type-approved in Italy; and the Volvo car in the database was emission type-approved in Spain. Luxembourg did not provide the official data for the Mazda car. Audi and BMW vehicles are also emission type-approved in Luxembourg, but the "whole vehicle" certification for these manufacturers is the responsibility of the German KBA. As a result, KBA was able to provide the official coastdown data for these vehicles, with the exception of one BMW X1.

In addition to the official coastdown extracts from German and French type-approval documentation, manufacturers' road load coefficients for four vehicles were also available directly from the labs that provided the realistic coastdown data for this study (two from VTT, one from LAT, and one from TNO).

Table 8 provides an overview of the sources of the official coastdown and derived road load data. In summary, 19 vehicles could be used for the road load comparisons. Ten vehicles had to be excluded because official road load data was missing.

Table 8. Availability of EU official coastdown/road load data

ID	Model	Official coastdown / road load available?	Source
TNO01	**VW Passat**	YES	KBA
TNO02	**Peugeot 207**	YES	UTAC
TNO03	**Fiat 500**	YES	TNO
TNO04	**Mercedes E350 Bluetec**	YES	KBA
TNO05	**Renault Scenic**	YES	UTAC
TNO06	**Peugeot 508**	YES	UTAC
TUG01	**Peugeot 407 SW**	YES	UTAC
TUG02	**Opel Astra EU5 1.7CDTI**	YES	KBA
TUG03	**Fiat Doblo 1.6l**	NO	
TUG04	**Fiat Punto EVO**	NO	
TUG05	**Audi A3 Sportback**	YES	KBA
TUG06	**Honda Civic 1.4 Comfort**	NO	
TUG07	**Mitsubishi ASX 4WD**	YES	KBA
TUG08	**Audi A5 2.0l TFSI**	YES	KBA
TUG09	**Mazda CX-5**	NO	
TUG10	**Peugeot Boxer 2.2 HDI**	NO 1)	
VTT01	**Audi A5 1.8 TFSI**	YES	KBA
VTT02	**BMW 116i**	YES	KBA
VTT03	**Citroen C1 1.0i**	NO 2)	
VTT04	**Dacia Sandero 1.6 Hi-Flex**	YES	VTT
VTT05	**Toyota Yaris Verso-S**	NO	
VTT06	**Fiat Punto 1.3 M-Jet**	NO	
VTT07	**Ford Mondeo 1.6 TDCi ECOnetic**	NO	
VTT08	**Opel Insignia Sports Tourer 2.0 CDTI EcoFlex**	YES	KBA
VTT09	**Škoda Octavia HB 1.6 TDI GreenLine**	YES	VTT
VTT10	**Volvo V70 1.6D DRIVe**	NO	
LAT01	**Opel Astra EU5 1.3 D**	YES	KBA
LAT02	**VW Polo 1.2 TSI**	YES	KBA
LAT03	**BMW X1 sDrive20d**	YES	LAT

1) Italy’s responsibility
2) Great Britain’s responsibility

4 COMPARISONS BETWEEN OFFICIAL AND REAL-WORLD ROAD LOADS

Both sets of road load coefficients, EU official and real-world, were collected for direct comparison of 19 vehicles. Furthermore, regarding the vehicles chassis and the related aerodynamic drag, nine cars matched equivalent U.S. models for which official road load data was available from the U.S. EPA's public database. Comparing the three road load coefficients f0, f1, f2 directly to each other is not helpful in most cases, especially with high values of the f1 parameter that cannot be clearly assigned to one of the two types of coastdown resistances, specifically rolling resistance and aerodynamic drag. Moreover, the road load coefficients are always in relation to a specific vehicle mass, affecting rolling resistance and acceleration forces, which is different in most cases for the two related road load sets and needs to be harmonized first.

Instead, the vehicle simulation tool PHEM (discussed in Chapter 4.3) was applied to perform NEDC cycle runs under the different vehicle load conditions. The model runs result in total cycle energies (including the relevant driving forces, i.e., rolling, aerodynamic and acceleration resistances) and in total CO_2 emissions, which can be directly compared to each other. Average Euro 5 gasoline and diesel car specifications were used as technical input parameters for the model runs (see Appendix E for technical details). These specifications correspond to the average definitions for Euro 5 cars from the Handbook Emission Factors for Road Transport (INFRAS, 2014).

4.1 DIFFERENCES OF ROAD LOAD FORCES

In Table 9 all realistic road load data for the 19 selected vehicles and their equivalent official EU data sets are summarized. The corresponding reference masses for each set of road load coefficients are also included. To make them comparable, the road load data have to be converted into sets of a unique vehicle mass (see Chapter 4.3), identified in the table as "Test Mass." This mass was used for the simulation runs to achieve the vehicle's energy demand over the NEDC cycle. The calculated cycle energies clearly show that the official EU road load sets are less demanding than the realistic road loads for all 19 of the vehicles examined.

Table 9. Road load parameters applied for type-approval measurements and derived from real-world coastdown experiments

Vehicle ID	Test Mass kg	Road loads EU type approval					Road loads real-world				
		f0 N	f1 N/(m/s)	f2 N/(m/s)^2	Reference Mass kg	NEDC cycle energy Wh	f0 N	f1 N/(m/s)	f2 N/(m/s)^2	Reference Mass kg	NEDC cycle energy Wh
TNO01	1810	115.0	1.33	0.366	1360	1269	218.2	-0.97	0.462	1470	1483
TNO02	1250	78.4	1.29	0.383	1250	1246	149.0	2.08	0.488	1130	1423
TNO03	1020	86.0	0.61	0.415	1590	1590	126.4	1.07	0.435	1590	1852
TNO04	1930	157.0	2.23	0.382	1590	1532	305.0	-0.42	0.478	1360	1560
TNO05	1470	74.4	1.92	0.487	1360	1256	213.9	-0.48	0.519	1360	1389
TNO06	1470	78.6	3.01	0.312	1810	1507	159.6	6.56	0.298	1566	1856
TUG01	1590	111.9	2.81	0.348	1250	1217	170.2	1.78	0.461	1277	1538
TUG02	1470	56.8	4.34	0.341	1020	1149	166.1	6.91	0.353	1124	1266
TUG05	1590	109.0	1.33	0.377	1930	1759	73.4	9.84	0.215	1962	2134
TUG07	1700	147.5	3.12	0.420	1470	1463	173.1	6.24	0.463	1652	1697
TUG08	1700	123.1	1.60	0.344	1470	1335	100.5	4.73	0.284	1523	1679
VTT01	1700	110.0	1.62	0.340	1590	1501	170.9	0.00	0.499	1700	1688
VTT02	1360	125.1	1.19	0.410	1470	1361	154.4	0.00	0.478	1640	1706
VTT04	1130	69.7	1.84	0.440	1590	1414	120.7	0.00	0.562	1460	1617
VTT08	1700	97.7	1.29	0.365	1700	1752	186.2	0.00	0.507	1620	2048
VTT09	1360	84.0	1.33	0.353	1700	1487	112.6	0.00	0.408	1660	1529
LAT01	1360	69.5	1.04	0.407	1700	1431	161.8	-3.68	0.614	1605	1705
LAT02	1250	84.9	1.34	0.390	1360	1395	123.2	1.23	0.426	1595	1428
LAT03	1590	140.4	1.11	0.445	1130	1266	317.2	-8.47	0.681	1240	1413
					Average cycle energies [Wh]:	**1410**					**1622 (+15.0%)**

4.2 COMPARISON WITH OFFICIAL U.S. ROAD LOADS

In contrast to Europe, in the U.S. road load coefficients applied at official emission tests are published in large databases and freely accessible on the EPA website (epa.gov). For the purpose of this study, where appropriate, equivalent U.S. models were identified and their U.S. road loads were extracted from EPA's test database (U.S. Environmental Protection Agency, 2014b). The criteria for the U.S. road load selection were that the vehicle model should belong to the same vehicle generation and have the same bodywork as its European counterpart. This ensures equivalent aerodynamics between U.S. and EU models. In most cases vehicle models and their names were identical. Sometimes one will find different model names for similar vehicles in the different markets (e.g., Mitsubishi ASX and Outlander; Opel Insignia and Buick Regal). It should be noted that the test masses (equivalent inertias) for the same vehicle model may differ between official EU and U.S. emission tests – they are mostly higher in the U.S. This has been taken into account when deriving the rolling resistance coefficients.

Table 10 includes the selected U.S. models, their model year, engine size and type of transmission, and their related European matches. Altogether matching criteria were found for nine vehicles, including two matches for the Audi A5, for a net of eight different model matches.

Table 10: European vehicle models with real-world coastdown data and U.S. equivalents

Vehicle ID	EU vehicle model	Build year	Engine	Transmission	US vehicle model	Model Year	Engine	Transmission
LAT03	**BMW X1 sDrive20d**	2012	2.0 D	M6q	**BMW X1 xDrive28i**	2013	2.0 G	A8q
TNO04	**Mercedes E350 Bluetec**	2009	3.0 D	A7r	**Mercedes E350 Bluetec**	2011	3.0 D	A7r
TUG05	**Audi A3 Sportback**	2010	1.6 D	M5f	**Audi A3 Sportback**	2009	2.0 G	M6f
TUG06	**Honda Civic Comfort**	2010	1.4 G	M6f	**Honda Civic**	2008	1.8 G	M5f
TUG07	**Mitsubishi ASX**	2011	1.8 D	M6q	**Mitsubishi Outlander**	2012	2.0 G	A6q
TUG08	**Audi A5**	2011	2.0 G	M6f	**Audi A5**	2013	2.0 G	A8f
TUG09	**Mazda CX-5**	2012	2.2 D	M6q	**Mazda CX-5**	2013	2.0 G	M6f
VTT01	**Audi A5**	2012	1.8 G	M6f	**Audi A5**	2013	2.0 G	A8f
VTT08	**Opel Insignia Sports Tourer EcoFlex**	2011	2.0 D	M6f	**Buick Regal**	2012	2.0 G	M6f

Table 11 directly compares the official U.S. road load coefficients of the selected U.S. vehicle models and the related reference masses (as tested on the chassis dynamometer) with the equivalent road loads derived from the real-world coastdown experiments. In addition, as a result from the simulation runs, the total cycle energies needed for a NEDC test run are given. It can be seen that the energy demands when applying the U.S. road loads are much closer to the real-world energies (sometimes even higher) than is the case for the EU official road loads from Table 9.

Table 11. Road load parameters applied for U.S. certification and derived from real-world coastdown experiments

Vehicle ID	Test Mass kg	Road loads, U.S. certification					Road loads, real-world				
		f0 N	f1 N/(m/s)	f2 N/(m/s)^2	Reference Mass kg	NEDC cycle energy Wh	f0 N	f1 N/(m/s)	f2 N/(m/s)^2	Reference Mass kg	NEDC cycle energy Wh
LAT03	1590	220.2	-3.84	0.566	1758	1657	317.2	-8.47	0.681	1590	1852
TNO04	1930	181.7	3.35	0.347	2041	1836	305.0	-0.42	0.478	1962	2134
TUG05	1590	137.9	1.49	0.445	1644	1555	73.4	9.84	0.215	1460	1617
TUG06	1250	104.1	3.95	0.326	1361	1358	156.3	0.00	0.424	1300	1432
TUG07	1700	194.9	-2.00	0.616	1644	1851	173.1	6.24	0.463	1620	2048
TUG08	1700	164.0	4.43	0.387	1814	1733	100.5	4.73	0.284	1660	1529
TUG09	1700	98.0	2.89	0.513	1588	1722	81.5	9.82	0.313	1720	1767
VTT01	1700	164.0	4.43	0.387	1814	1715	170.9	0.00	0.499	1605	1705
VTT08	1700	178.4	1.88	0.459	1814	1735	186.2	0.00	0.507	1800	1724
Average cycle energies [Wh]:						**1685**					**1756 (+4.2%)**

4.3 VEHICLE SIMULATION AND IMPACT ON CO$_2$ EMISSIONS

To make the different road loads more comparable to each other, their direct impact on CO$_2$ emissions for passenger cars was determined by the application of an emission simulation tool. The applied “Passenger car and heavy duty emission model” (PHEM) is an emission map-based instantaneous tool, which has been developed by TU Graz since the late 1990s (Luz & Hausberger, 2014). It calculates the fuel consumption and emissions of road vehicles in 1 Hz temporal resolution for a given driving cycle based on the vehicle longitudinal dynamics and emission maps (Figure 3). The engine emission maps are generated based on emission measurements on engine test stands or more frequently by chassis dynamometer tests or portable emissions measurement systems (PEMS).

In the frame of this study, the specific CO_2 emission maps for each individual vehicle with available realistic coastdown data were not available. Instead, the latest average Euro 5 emission maps for gasoline and diesel passenger cars included in the PHEM database were applied. These emission maps were derived from instantaneous emission measurements of 18 gasoline and 27 diesel vehicles, driven at different driving cycles also covering high load conditions, for example under the regime of the Common Artemis Driving Cycle (CADC). Applying the same CO_2 emission maps for all examined gasoline respectively diesel cars when simulating NEDC results might lead to some over- or under-estimations of the absolute CO_2 test result. However, the focus of this exercise is to quantify the relative difference when applying two different sets of road loads. For this purpose, the absolute emission levels are immaterial.

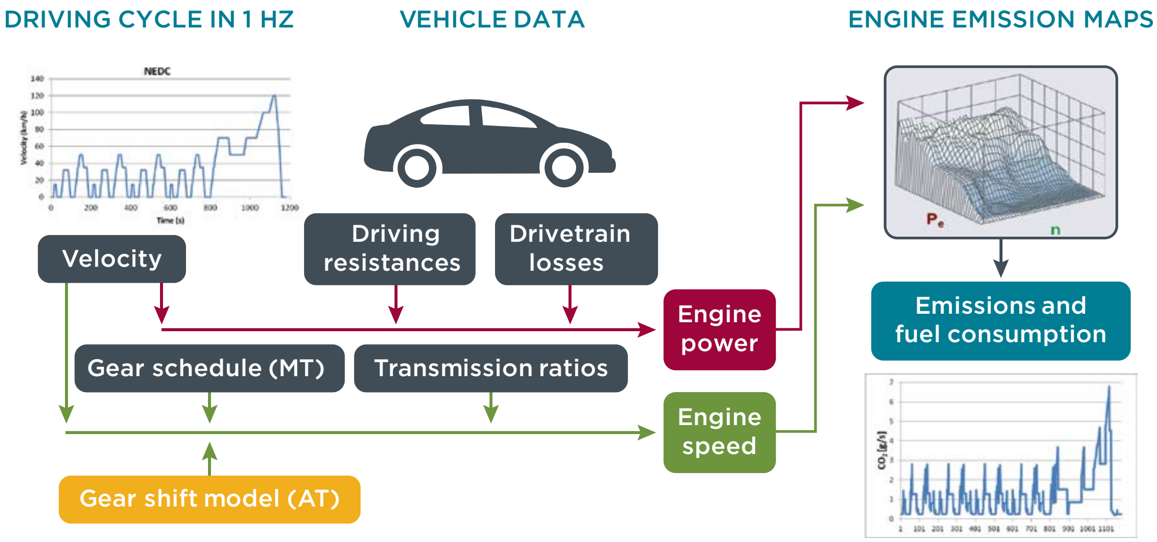

Figure 3. Scheme of the applied simulation tool PHEM.

Specific technical data for each vehicle model was used as input for the PHEM simulation runs (see Appendix E):

- Mass
- Rated engine power
- Transmission ratios
- Tire dimensions

Idle and rated engine speeds were not known in detail for every vehicle model. Instead, the Euro 5 averages of the PHEM database were applied. Also standard values were used for required energy losses of the drivetrain.

The PHEM model requires the driving resistance parameters as input to describe the vehicles' resistance forces. Hence, before starting the model runs, both sets of calculated road load parameters (official and realistic) were translated into rolling resistance coefficients (from f0 and f1 parameters) and aerodynamic drag (from f2 parameter). This procedure enables a fully accurate usage of the road load data, although the derived driving resistance parameters themselves include some uncertainties, especially with high f1 values that cannot be clearly assigned to rolling resistance or aerodynamic drag. An advantage of this transformation of road load coefficients into driving resistance parameters is the mass independency of the latter, allowing for direct comparisons between official and realistic driving resistance-based simulated cycle energy and CO_2 emissions. For each vehicle model, a unique vehicle test mass was applied in the simulation runs for both compared load variants.

CO_2 emissions over the complete NEDC driving cycle were simulated. Starts with a hot engine were considered, assuming that the relative cold start effect on CO_2 is not affected by varying vehicle road loads. Note that the only target of these simulation studies was to identify the relative effect of altered road load parameters. The resulting absolute CO_2 levels are not necessarily realistic, are not relevant here, and must not be compared with CO_2 emission data from other sources, like type-approval or other measurement values.

Table 12 includes the NEDC CO_2 results as achieved from the PHEM model runs. Only those vehicle models with available realistic road loads and at least one comparable set of official road loads (EU or U.S.) were considered. The relative deviations between CO_2 emissions based on realistic road loads compared to those based on official load data are given in the last two columns. The vehicle models and their results in this table are sorted by decreasing relative differences based on the official EU load data, that is, vehicles with the largest gaps are listed at the top. Figure 4 gives an overview on the resulting CO_2 increases.

Table 12. Differences between simulated NEDC (hot start) CO2 emissions applying EU type-approval road loads, U.S. certification road loads and real-world road loads, sorted by relative deviations real-world against EU

Vehicle ID	Vehicle Model	Test Mass kg	CO_2 EU road loads g/km	CO_2 US road loads g/km	CO_2 real road loads g/km	delta CO_2 EU real/EU-1	delta CO_2 US real/US-1
TNO02	**Peugeot 207**	1250	104.3		119.4	14.5%	
TNO01	**VW Passat**	1810	126.0		142.1	12.8%	
TUG02	**Opel Astra EU5 1.7CDTI**	1470	132.3		147.3	11.3%	
VTT08	**Opel Insignia Sports Tourer 2.0 CDTI EcoFlex**	1700	142.8	157.0	156.5	9.6%	-0.3%
TNO06	**Peugeot 508**	1470	178.6		194.4	8.8%	
TUG05	**Audi A3 Sportback**	1590	111.1	118.1	120.9	8.8%	2.4%
TNO04	**Mercedes E350 Bluetec**	1930	192.0	197.3	209.0	8.8%	5.9%
LAT01	**Opel Astra EU5 1.3 D**	1360	117.1		126.8	8.2%	
TUG07	**Mitsubishi ASX 4WD**	1700	183.5	187.7	197.1	7.4%	5.0%
VTT01	**Audi A5 1.8 TFSI**	1700	172.7	185.8	185.5	7.4%	-0.2%
TNO05	**Renault Scenic**	1470	142.7		153.1	7.3%	
LAT02	**VW Polo 1.2 TSI**	1250	126.5		135.0	6.7%	
LAT03	**BMW X1 sDrive20d**	1590	165.9	168.5	175.8	6.0%	4.4%
TUG01	**Peugeot 407 SW**	1590	146.5		154.0	5.1%	
TNO03	**Fiat 500**	1020	109.9		115.4	5.0%	
VTT04	**Dacia Sandero 1.6 Hi-Flex**	1130	151.0		157.9	4.6%	
VTT09	**Škoda Octavia HB 1.6 TDI GreenLine**	1360	112.9		115.6	2.3%	
VTT02	**BMW 116i**	1360	157.2		158.7	0.9%	
TUG08	**Audi A5 2.0l TFSI**	1700	203.4	214.7	204.9	0.7%	-4.5%
TUG06	**Honda Civic 1.4 Comfort**	1250		152.3	155.7		2.3%
TUG09	**Mazda CX-5**	1700		180.3	181.9		0.9%
					Average EU (19 vehicles):	**7.2%**	
					Average US (9 vehicles):		**1.8%**
					Averages EU and US (7 vehicles):	**7.0%**	**1.8%**

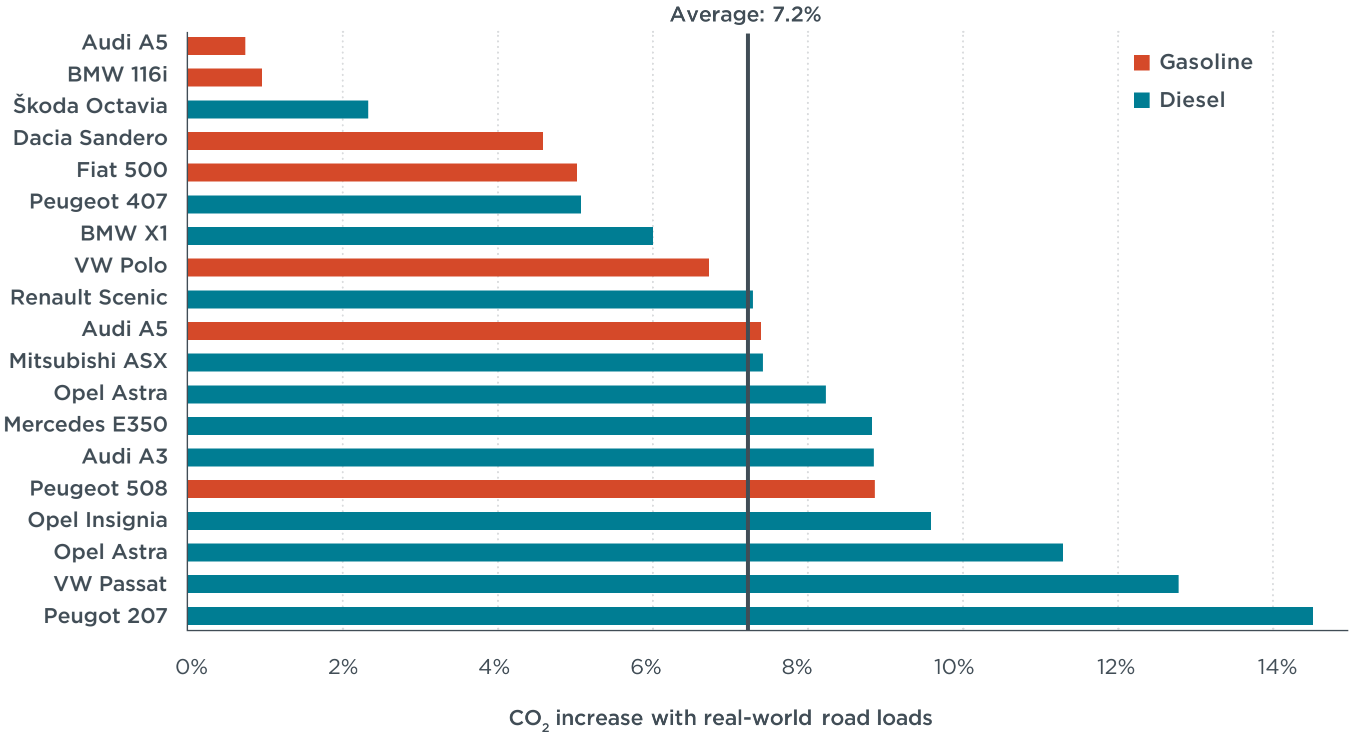

Figure 4. Increase of CO$_2$ emissions with real-world road loads compared to official loads.

The main results of this study are:

- The application of realistic road loads instead of official EU road loads on average leads to 15.0% higher total NEDC cycle energy and 7.2 % higher CO$_2$ emissions under the NEDC driving regime.
- Realistic road loads are higher than official EU road loads for all examined cars. CO$_2$ increases ranged from 0.7% to 14.5%. The highest gaps can be observed for a Peugeot 207, a VW Passat and an Opel Astra.
- Concerning the quantified CO$_2$ gaps, no significant differences are observable between manufacturers.
- Comparing realistic to official U.S. road loads leads to just 1.8% higher CO$_2$ emissions on average. This value should be compared to the EU average of 7.0%, where only those vehicles with all three available road load data sets (real, EU and U.S.) are considered.
- Some vehicle models offered in the U.S. show even higher road loads under U.S. testing conditions than derived from the real-world coastdowns, with CO$_2$ impacts ranging from a decrease of 4.5% to an increase of 5.9% overall.
- Regarding the calculated gaps, no lab specific systematic differences are observable after applying data corrections and harmonization of the data evaluation methods.

4.4 REASONS FOR ROAD LOAD DEVIATIONS

The results clearly indicate that the current NEDC regulation is not adequate to establish realistic road load parameters to be applied at the official type-approval measurements. The potential reasons for the observed gaps between realistic and official road loads are diverse. The NEDC procedure is rather imprecise and the flexibilities and shortcomings of unregulated issues it contains are exploited, and in some cases misinterpreted, by vehicle manufacturers. This results in modifications of the coastdown test vehicle deviating from a regular series vehicle and in the use of special coastdown testing conditions. Furthermore, some systematic errors implemented in the NEDC regulation since its introduction in the 1970s have never been corrected.

Chapter 5 discusses additional testing deficiencies that do not contribute to the observed road load gap, but additionally contribute to the increasing gap between realistic and official CO_2 emissions.

4.4.1 Legal flexibilities and shortcomings of the NEDC procedure

The intention of the NEDC regulation as created in the 1970s was to test a vehicle in the same condition as it is driven on the road. However, technical specifications and details have not been addressed comprehensively. Over time, these missing definitions were increasingly exploited by vehicle manufacturers, establishing artificial test cars and applying unusual testing conditions to lower the official road load values. Some of these measures violate the actual regulation. For example, tire pretreatment is in clear contrast to the legislation stating that "the rolling resistance characteristics of the tires fitted to production vehicles shall reflect those of the tires used for type approval."

Some of the possible measures used by manufacturers are:

- Pretreatment of tires, baking them in an oven such that they are thermally hardened and/or shaving them so they are almost bald.
- Optimizing aerodynamics by modifying the vehicle's chassis, such as closing or making new openings, removing exterior mirrors, and adapting the suspension system to reduce vehicle ride height.
- Optimizing the warm-up procedure of the test vehicle and relevant parts: Tires, bearings, gearbox and differential oil can be preheated, which reduces rolling resistance and friction losses of mechanical parts and lubricants.
- Elongated running-in period of the vehicle: Additional driving before testing results in lower friction of the relevant rotating parts (gearbox, driveshaft, wheels).
- Optimizing wheel alignments: Toe and camber can be adjusted to minimize tires' rolling resistance, deviating from the regular adjustment that incorporates safety and comfort aspects.
- Manually opening brake calipers: The NEDC test procedure explicitly allows manual brake opening before the coastdown test to eliminate parasitic losses caused by grinding friction pads.
- Optimizing resistance of the road surface of the test track: A smooth, hard and clean road surface reduces tires' rolling resistance.

All of these listed items potentially contribute to the observed road load gap. However, their use is not documented in the official type-approval records and is not reported by vehicle manufacturers elsewhere. Hence, it is unknown which of these measures, and perhaps others, are applied by which manufacturers and to what extent. This also makes it difficult to quantify the effect of each of these individual measures in terms of reduced CO_2 emissions, as measurement data is not published by manufacturers and data from independent sources are rare.

4.4.2 Systematic errors of the NEDC coastdown procedure

The current NEDC regulation includes systematic errors, which lead to underestimations of the derived vehicle road loads. This report quantifies the impact on CO_2 emissions of average gasoline and diesel cars for five of these errors: faulty averaging method of test runs in opposite directions, missing rotating inertias, faulty wording regarding tire preconditioning, biased shares of rolling resistance and aerodynamic drag, and missing humidity in air density calculations. These systematic deficiencies of the NEDC have existed since its introduction in the 1970s and have never been officially addressed and corrected.

Road inclination of the test track

The NEDC regulation includes a faulty calculation procedure regarding the method of averaging the coastdown runs in opposite directions. It prescribes an average of the measured coastdown times from the opposite runs instead of averaging the calculated forces. This error is especially relevant at sloping test tracks, as it increases overproportionally with the track's gradient. Table 13 shows the effect of the miscalculations for stepwise road inclinations. Already a small gradient of 1% leads to a dramatic distortion of the resulting forces and the vehicle's energy demand at the dynamometer test, resulting in CO_2 underestimations of approximately 5%. The NEDC allows gradients up to 1.5%, but gradients of more than 1% are not applicable for vehicles with low rolling resistance, as explained in the footnote to Table 13.

Table 13. The effect of a faulty averaging procedure in NEDC on cycle energy and CO_2

Gradient of test track	Average gasoline car			Average diesel car		
	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error
0.0%	1477	133.2		1620	132.1	
0.1%	1475	133.1	0.0%	1618	132.1	-0.1%
0.2%	1470	132.9	-0.2%	1612	131.9	-0.2%
0.3%	1460	132.6	-0.4%	1601	131.5	-0.5%
0.4%	1447	132.2	-0.8%	1587	131.0	-0.8%
0.5%	1431	131.6	-1.2%	1568	130.4	-1.3%
0.7%	1386	130.0	-2.4%	1518	128.6	-2.6%
1.0%	1291	126.7	-4.9%	1412	125.0	-5.4%
1.5%[1]	1072	116.3	-12.7%[1]	1164	111.5	-15.6%[1]

1. On test tracks with a gradient of more than 1.0%, during downhill coasting the final stationary velocity of the average cars is above the required minimum velocity of 15 km/h. Hence, the road load procedure cannot be applied, and the tabulated values are only theoretical.

Inertia of rotating parts

In the NEDC regulation, the equivalent masses of the inertias of the vehicle's rotating parts (mainly wheel assemblies, consisting of tires, rims, and mounted brake discs or drums) are not added to the vehicle mass for the calculation of the driving forces. This produces an underestimation of the total effective mass of the tested coastdown vehicle and consequently results in underestimating resistance forces and cycle energies. Table 14 summarizes the effect on the NEDC cycle energy and CO_2 emissions, assuming a share of the rotational equivalent mass in the total vehicle mass of 3%.[1] For averaged gasoline and diesel cars, the CO_2 emissions are underestimated by 0.8%.

Table 14. The effect of missing equivalent masses for inertias of rotating parts on cycle energy and CO_2

Inertias considered?	Average gasoline car			Average diesel car		
	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error
YES	1477	133.2		1620	132.1	
NO	1452	132.1	-0.8%	1593	131.0	-0.8%

Tire tread depth

The NEDC regulation wording is deficient regarding the accepted run-in procedure of the tires used for the coastdown experiment. It reads, "Run-in at the same time as the vehicle or tread depth 50-90%." This wording allows manufacturers the option to use tires with low tread or even completely treadless tires, not even complying with security regulations for driving on public roads, as long as they are mounted during the run-in of the test vehicle. Assuming an average tire tread depth for new summer tires of 8 mm, a regular baseline tire with 70% tire tread and a reduction of the rolling resistance of 1% with a reduced tread depth of 1 mm, the "benefit" of a treadless tire in terms of CO_2 is 0.6% (European Commission, 2015b). Table 15 summarizes the model results.

Table 15. The affect of using treadless tires on cycle energy and CO_2

Tire tread depth	Average gasoline car			Average diesel car		
	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error
70% / 5.6 mm	1477	133.2		1620	132.1	
0% / 0.0 mm	1457	132.4	-0.6%	1598	131.3	-0.6%

Biased share of rolling resistance and aerodynamic drag

The formula to correct total driving forces for changed ambient conditions (atmospheric temperature and pressure) in the NEDC regulation includes an estimate of shares for rolling resistance and aerodynamic drag, depending on vehicle mass and actual velocity. That is because air pressure only affects air density and aerodynamic drag, while temperature also has an influence on tires' rolling resistance (see Appendix C). These tabulated shares are outdated, as rolling resistances of tires have improved more in recent decades than vehicle chassis aerodynamics. Actual vehicle resistance data show that NEDC overestimates the share of rolling resistance by approximately 5%, especially at higher driving speeds. This bias leads to underestimated correction factors if the coastdown is performed at low ambient temperature and at low atmospheric pressure (high altitudes). NEDC includes a tolerance margin of 7.5% for air density only under reference conditions (20 °C, 1 bar). It does not specify tolerances for temperature and pressure.

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[1] For measurements on the chassis dynamometer, 1.5% extra mass is added to the reference mass on a one-axle driven dynamometer, reflecting the rotating inertia of the non-rotating wheels, that is, half of the 3% contribution of rotating inertia for all driven wheels. On a two-axle driven dynamometer no extra charge is applied as all wheels have to be driven by the vehicle and the required energy is reflected directly by the test results.

Table 16 summarizes the effects of optimized ambient conditions. Two scenarios were evaluated against the reference condition: 5 °C at 950 mbar (an approximate altitude of 500 meters altitude) and -10 °C at 900 mbar (an approximate altitude of 1000 meters). With the use of regular tires, that is, market products as driven on the road, CO_2 underestimations of 0.6% (gasoline) and 0.7% (diesel) were found. Note that the application of optimized tires as described above will increase the negative impact on derived CO_2 emissions. Furthermore, the NEDC regulation also explicitly allows manufacturers to specify their own values for the shares of driving resistances. These values are not published and can easily contribute to further distortions.

Table 16: The effect of biased shares of rolling resistance and aerodynamic drag on cycle energy and CO_2

Ambient conditions	Average gasoline car			Average diesel car		
	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error
20 °C, 1000 mbar	1477	133.2		1620	132.1	
5 °C, 950 mbar	1469	132.8	-0.3%	1610	131.7	-0.3%
-10 °C, 900 mbar	1461	132.4	-0.6%	1599	131.2	-0.7%

Missing humidity in air density calculation

The NEDC algorithm assumes dry air, that is, a relative humidity of 0%. In reality, water molecules are lighter than nitrogen and oxygen. Therefore, water vapor decreases the air density and the vehicle's aerodynamic drag. As quantified in Table 17, missing humidity has only a minor impact, with a maximal 0.1% CO_2 underestimation in the case of 100% relative humidity at an ambient temperature of 20 °C.

Table 17. The effect of not considering humidity in air density calculation on cycle energy and CO_2

Relative humidity (at 20 °C)	Average gasoline car			Average diesel car		
	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error
0%	1477	133.2		1620	132.1	
50%	1475	133.1	-0.05%	1618	132.0	-0.05%
100%	1477	133.0	-0.1%	1616	131.9	-0.1%

Sum of systematic errors

The full exploitation of the identified systematic NEDC errors by a manufacturer – selection of a test track with 1.0% gradient, omitting rotational inertias, completely bald tires, optimized ambient temperature and pressure, omitting humidity – leads to total CO_2 underestimations of 7.0% for the average gasoline car and for 7.6% for the average diesel car. Table 18 summarizes the total effects under the most "optimized" conditions.

Table 18. Summary of systematic errors in the NEDC/UNECE coastdown procedure

Factor	Assumption	CO_2 underestimation	
		Gasoline car	Diesel car
Road inclination of the test track	1% gradient	-4.9%	-5.4%
Inertia of rotating parts	omitted	-0.8%	-0.8%
Tire tread depth	0% / 0 mm	-0.6%	-0.6%
Biased share of rolling resistance and aerodynamic drag	-10 °C, 900 mbar	-0.6%	-0.7%
Missing humidity in air density calculation	100% humidity	-0.1%	-0.1%
	SUM:	**-7.0%**	**-7.6%**

4.4.3 Additional considerations – simulation approaches

From informal sources it is known that for the majority of all vehicle models, the official road load data used are from computer simulations, not direct measurements from physical coastdown trials. The effort required to perform coastdown experiments is rather high, and the large variety of vehicle models and variants requires the generation of large road load databases. Hence, manufacturers enable numerical data processing based on existing data of similar vehicle models.

The technical process of simulating road load data for slightly modified vehicles from already existing data sets should principally be under the control of the technical services companies. But the procedure of applying numerical instead of experimental approaches is not regulated at all. There are no criteria about the accuracy of such simulation tools, nor are there any external validations of the models' results foreseen. The methodologies and achieved results are not included in the official type-approval documentation and are therefore not reproducible by third parties. Hence, the total process is vulnerable to additional distortions. The impact of these additional flexibilities caused by simulation processes on CO_2 emissions cannot be assessed here because of missing information.

4.5 NEDC DEFICIENCIES NOT CONTRIBUTING TO THE ROAD LOAD DEVIATIONS

Other deficiencies of the NEDC road load regulations do not contribute to the road load gap, but further increase the overall gap between official and real-world CO_2 emissions. For the sake of completeness, these factors are discussed in this section.

Tolerances of control coastdown

In the course of the emission certification process, the experimentally derived road loads are transferred to the chassis dynamometer test bench where they are reproduced by the calibration of the roller brakes. A control coastdown on the chassis dynamometer is performed regularly after the NEDC emission test to check if the driving forces of the dynamometer test vehicle match the original coastdown forces. Regarding the alignment of test track and dynamometer forces, the NEDC regulation allows tolerances, which are exploited by vehicle manufacturers in systematically setting the vehicle road loads as close as possible to the lower boundary of the tolerance bandwidth. In practice, the given force tolerances (±5% at 120, 100, 80, 60 and 40 km/h; ±10% at 20 km/h) cannot be exploited completely, as the brake forces for the six speed ranges cannot be adjusted separately. However, an exploitation of -4% at 120, 100, 80, 60 and 40 km/h and -8% at 20 km/h seems to be achievable. Table 19 summarizes the results of such a deliberately biased calibration of dynamometer forces. The level of CO_2 emissions can be cut by approximately 1.2%.

Table 19. The impact of exploitation of dynamometer load tolerances on cycle energy and CO_2

Exploitation of lower boundary	Average gasoline car			Average diesel car		
	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error
0%	1477	133.2		1620	133.2	
- 4% / - 8%	1439	131.6	-1.2%	1580	130.5	-1.2%

Ambient reference temperature

The ambient temperature during the coastdown experiment affects both resistance types. A higher air temperature decreases the air density and, hence, decreases the vehicle's aerodynamic drag. A higher tire temperature also decreases the tires' rolling resistance. Realistic road loads must be harmonized to be comparable to the official road loads. Hence, in this report all road load data have been normalized to NEDC ambient reference conditions (1000 mbar, 20 °C). However, the average European ambient temperature weighted by driven mileage is lower than 20 °C. The European Commission assumes 14 °C to be a more realistic European average (European Commission, 2015a). This lower temperature is going to be established as the reference for the emission tests under the WLTP regime, but not for the related coastdown tests, which perpetuates the inconsistency.

In Table 20 the effects of applying a more realistic ambient temperature of 14 °C instead of 20 °C are shown. The higher aerodynamic drag corresponds to an increase of CO_2 by 0.35%, while the tires' higher rolling resistances result in 0.75% higher CO_2 emissions. Altogether the 6 °C reduction of the ambient temperature increases road loads and CO_2 increase, the latter by 1.1%.

Table 20: The effect of ambient temperature on cycle energy and CO_2

Ambient Temperature	Effect on	Average gasoline car			Average diesel car		
		NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error	NEDC cycle energy Wh	NEDC CO_2 emissions g/km	Systematic error
20 °C		1477	133.2		1620	132.1	
14 °C	Aerodynamic drag	1487	133.7	-0.35%	1630	132.6	-0.35%
14 °C	Rolling resistance	1500	134.1	-0.75%	1645	133.1	-0.75%
14 °C	Both	1510	134.6	-1.1%	1655	133.5	-1.1%

5 CONCLUSIONS

The driving resistances of a vehicle (rolling resistance, aerodynamic drag, mass) have a strong effect on total energy consumption. Hence, derived road loads used for the official emission measurements on a chassis dynamometer strongly impact the vehicles' CO_2 emissions. The official road loads of the European type-approval emission procedure are clearly and systematically lower than for vehicles in the real world. Consequently, the certified CO_2 emission data based on the NEDC/UNECE rules underestimate any real-world emission behavior. Even clear standards in the current legislation do not prevent manufacturers from applying deceptive measures.

The current legislation in Europe and the associated control system by technical services companies is not suitable to achieve realistic road loads. There are incentives for manufacturers to exploit given tolerances and undefined issues in order to minimize official road loads and CO_2 emissions. Systematic errors in the rules further contribute to this gap. The determination of road load coefficients is a largely opaque procedure. The technical services cannot act as an independent institution as they are directly commissioned by the manufacturers and do not have full access to the manufacturers' internal processing.

The official coastdown data for light-duty vehicles are part of the emission type-approval documentation and are available from the responsible national type-approval authorities. In practice, these data sets are not published and must be requested by interested third parties by following a time consuming process. Despite the public character of these data, only Germany and France are willing to provide the data. All other national agencies contacted (Italy, Great Britain, Luxembourg, and Spain) did not provide the data upon request. For 29 vehicles with realistic road load sets in this study, official coastdown data was provided on only 19 vehicles (66%). The refusal of the data release and the irregular behavior among the different EU member states reflects a major problem with the European type-approval process.

The application of realistic road loads instead of the official EU road loads increased total NEDC cycle energy by 15.0% and CO_2 emissions by 7.2 % on average under the NEDC driving regime. Car road loads under realistic conditions were higher than the EU data for all 19 vehicles, with corresponding CO_2 individual increases between 0.7% and 14.5%. A biased reference ambient temperature during the coastdown test (20 °C instead of 14 °C) and additional coastdown tolerances on the chassis dynamometer further contribute to the overall CO_2 gap by 2.3%. Altogether, assuming an overall divergence between official and real-world CO_2 emissions of 25% in 2010 (Tietge et al., 2015), more than one third of this gap can be explained by exploited tolerances and errors of the road load procedures.

Compared to the situation in Europe, road load forces derived for the U.S. certification for the same vehicles are higher and closer to reality. The average NEDC cycle energy increase was only 4.2% and the CO_2 increase was only 1.8% compared to the official U.S. road load data. That is not because of a more precise and detailed methodology to determine the road load coefficients, but because of a better enforcement system and a higher risk of manufacturers getting caught. The danger of recalls and the financial consequences are much more distinct in the U.S. (U.S. Environmental Protection Agency, 2014b).

The replacement of the current emission legislation in the EU by the WLTP planned for 2017 will entail improvements and eliminate some of the existing methodological errors. The manufacturers will be directly responsible for the officially declared road loads. This could largely eliminate the current practice of using artificially modified vehicles for the official coastdown runs. On the other hand, the WLTP will offer new methodologies for road load determination with higher complexity. The standards foreseen for these new methodologies are rather imprecise, which makes the whole regulation confusing.

Transparency and independent control measures will become even more important in the future. Vehicle driving resistance data relevant for CO_2 type-approval tests must be made easily accessible to all interested parties. Coastdown times, test masses and derived road load parameters of all type-approved light-duty vehicle versions should be included in the CoC and summarized in a public database together with all certified fuel consumption and emission data. Free access to the official road load forces is a vital precondition for any independent verification measures. Furthermore, official in-use compliance measurements must be extended by including coastdown testing, and the results should be published in comprehensive reports. Distorted official CO_2 emissions based on false assumptions regarding road load forces must be discovered and corrected. This requires the establishment of a completely new road load validation procedure under the WLTP regime.

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APPENDIX A ADMINISTRATIVE AND TECHNICAL VEHICLE DATA

Table 21. Type-approval CO_2 emissions and certification numbers

Vehicle ID	Vehicle Model	TA CO_2 g/km	Type	Variant	Version	TAN	Emission certificate
TNO01	**VW Passat**	116	3C	ACCAYCX0	FM6FM62S027STP17MQSNVR2O	e1*2001/116*0307*32	e1*715/2007*00189*02
TNO02	**Peugeot 207**	110	W*****	WE9HP*	WE9HP0/1	e2*2001/116*0340*23	e2*715/2007*692/2008A*9090*04
TNO03	**Fiat 500**	110	312	AXA11	03C	e3*2007/46*0064*00	
TNO04	**Mercedes E350 Bluetec**	184	212	J0BAP0	NZAAB501	e1*2001/116*0501*11	e1*715/2007*692/2008N*0071*02
TNO05	**Renault Scenic**	135	JZ	JZ1G	JZ1GA6	e2*2001/116*0379*09	e2*715/2007*692/2008A*9096*04
TNO06	**Peugeot 508**	144	8	D5FV	8	e2*2007/46*0080*07	e2*715/2007*692/2008A*10218*02
TUG01	**Peugeot 407 SW**	150	6*RHF*	6ERHF*	6ERHF8	e2*2001/116*0369*08	e2*715/2007*692/2008A*8174*05
TUG02	**Opel Astra EU5 1.7CDTI**	125	P-J	BF11	1A06AAAVFFE5	e1*2007/46*0141*00	e1*715/2007*692/2008A*0110*00
TUG05	**Audi A3 Sportback**	116	8P	SCAYBF1	FM5A4051R8P607MGEM1	e1*2001/116*0217*30	e13*715/2007*692/2008A*0043*05
TUG07	**Mitsubishi ASX 4WD**	150	GA0	GA721	ABAAA6A5AAAC	e1*2007/46*0368*02	e1*715/2007*692/2008A*0160*01
TUG08	**Audi A5 2.0l TFSI**	152	B8	SCDNCF1	FM6B1004R8S607MGEM1	e1*2001/116*0430*18	e13*715/2007*692/2008F*0011*08
VTT01	**Audi A5 1.8 TFSI**	134	B8	CCJEBF1	FM6B1004RB8T1S47MGEM1	e1*2001/116*0430*24	e13*715/2007*566/2011F*6353*01
VTT02	**BMW 116i**	132	1K4	1A11	H2	e1*2007/46*0283*04	
VTT04	**Dacia Sandero 1.6 Hi-Flex**	153	SD	BSDBS	BSDBSP	e2*01/116*0314*45	e2*715/2007*692/2008A*10187*00
VTT08	**Opel Insignia Sports Tourer 2.0 CDTI EcoFlex**	119	0G-A	FM11	4AALB2BVGKK5	e1*2007/46*0374*05	e1*715/2007*566/2011J*0617*00
VTT09	**Škoda Octavia HB 1.6 TDI GreenLine**	99	1Z	AACAYCX01	GFM5FM5A40540	e11*2001/116*0230*40	
LAT01	**Opel Astra EU5 1.3 D**	104	P-J	CACBC11	BA1J1EGTA5	e1*2007/46*0141*12	e1*715/2007*00189*02
LAT02	**VW Polo 1.2 TSI**	119	6R	ABCBZC	FM5FM52T106LLNVR07MQ	e1*2001/116*0510*11	e1*715/2007*00189*02
LAT03	**BMW X1 sDrive20d**	119	X1	VZ91	5H0VC	e1*2007/46*0275*06	

Table 22. Technical specifications – engine and masses

Vehicle ID	Vehicle Model	Build year	Euro class	Fuel	Engine capacity ccm	Rated engine power kW	Mass in running order kg	Official test inertia kg
TNO01	**VW Passat**	2012	5	diesel	1598	77	1543	1810
TNO02	**Peugeot 207**	2012	5	diesel	1560	68	1275	1250
TNO03	**Fiat 500**	2009	5	gasoline	1242	51	975	
TNO04	**Mercedes E350 Bluetec**	2009	6	diesel	2987	155	1845	1930
TNO05	**Renault Scenic**	2010	5	diesel	1461	81	1485	1470
TNO06	**Peugeot 508**	2012	5	gasoline	1598	115	1475	1470
TUG01	**Peugeot 407 SW**	2010	5	diesel	1997	103	1612	1590
TUG02	**Opel Astra EU5 1.7CDTI**	2010	5	diesel	1686	92	1503	1470
TUG05	**Audi A3 Sportback**	2010	5	diesel	1598	66	1395	1590
TUG07	**Mitsubishi ASX 4WD**	2011	5	diesel	1798	110	1600	1700
TUG08	**Audi A5 2.0l TFSI**	2011	5	gasoline	1984	155	1580	1700
VTT01	**Audi A5 1.8 TFSI**	2012	5	gasoline	1798	125	1500	1700
VTT02	**BMW 116i**	2011	5	gasoline	1598	100	1365	
VTT04	**Dacia Sandero 1.6 Hi-Flex**	2011	5	gasoline	1598	77	1157	1130
VTT08	**Opel Insignia Sports Tourer 2.0 CDTI EcoFlex**	2011	5	diesel	1956	118	1788	1700
VTT09	**Škoda Octavia HB 1.6 TDI GreenLine**	2011	5	diesel	1598	77	1390	
LAT01	**Opel Astra EU5 1.3 D**	2012	5	diesel	1248	70	1393	1360
LAT02	**VW Polo 1.2 TSI**	2012	5	gasoline	1197	66	1102	1250
LAT03	**BMW X1 sDrive20d**	2012	5	diesel	1995	120	1565	

Table 23. Technical specifications – transmission

Vehicle ID	Vehicle Model	Type of gearbox	Transmission ratios							Differential
			Gear							
			1	2	3	4	5	6	7	
TNO01	**VW Passat**	M6f	4.111	2.118	1.360	0.971	0.733	0.592		3.389
TNO02	**Peugeot 207**	M5f	3.455	1.867	1.156	0.822	0.660			3.588
TNO03	**Fiat 500**	A5f	3.909	2.158	1.480	1.121	0.897			3.438
TNO04	**Mercedes E350 Bluetec**	A7q	4.380	2.860	1.920	1.370	1.000	0.820	0.730	2.470
TNO05	**Renault Scenic**	M6f	3.727	1.947	1.323	0.975	0.763	0.638		4.125
TNO06	**Peugeot 508**	M6f	3.538	1.920	1.323	0.975	0.761	0.646		4.176
TUG01	**Peugeot 407 SW**	M6f	3.417	1.783	1.121	0.795	0.647	0.534		4.176
TUG02	**Opel Astra EU5 1.7CDTI**	Mf M32-6/3,65	3.820	2.050	1.300	0.960	0.740	0.610		3.650
TUG05	**Audi A3 Sportback**	FM5A4051(LUB)	3.778	1.944	1.185	0.816	0.625			3.647
TUG07	**Mitsubishi ASX 4WD**	M6q	3.818	2.045	1.290	0.974	0.897	0.790		4.058
TUG08	**Audi A5 2.0l TFSI**	FM6B1004	3.778	2.050	1.321	0.970	0.811	0.692		3.304
VTT01	**Audi A5 1.8 TFSI**	FM6B1004(MVQ)	3.778	2.050	1.321	0.970	0.811	0.692		3.304
VTT02	**BMW 116i**	M6r	4.552	2.548	1.659	1.230	1.000	0.830		2.813
VTT04	**Dacia Sandero 1.6 Hi-Flex**	M5f	3.727	2.048	1.393	1.029	0.795			4.214
VTT08	**Opel Insignia Sports Tourer 2.0 CDTI EcoFlex**	Mf F40-6/3,09	4.167	2.130	1.321	0.954	0.755	0.623		3.091
VTT09	**Škoda Octavia HB 1.6 TDI GreenLine**	M5f	3.778	1.944	1.185	0.816	0.625			3.647
LAT01	**Opel Astra EU5 1.3 D**	M5f F17-5ER/3,94	3.909	2.136	1.323	0.892	0.674			3.940
LAT02	**VW Polo 1.2 TSI**	M5f	3.615	1.955	1.281	0.927	0.740			3.933
LAT03	**BMW X1 sDrive20d**	M6r	5.140	2.830	1.804	1.257	1.000	0.831		2.643

Table 24. Technical specifications – tires

Vehicle ID	Vehicle Model	Type-approval coastdown				Real-world coastdown			
		Make and model	**Dimensions**	**Pressure front / rear**	**Diameter [m]**	**Make and model**	**Dimensions**	**Pressure**	**Diameter [m]**
TNO01	**VW Passat**	Michelin radial	205/55R16	220/220	0.6259	Continental Contact Premium	205/55R16	220/220	0.6259
TNO02	**Peugeot 207**	Michelin Energy Saver S1	185/65R15	240/240	0.6155	Continental Premium Contact 2E	195/55R16	230/220	0.6149
TNO03	**Fiat 500**					Michelin Energy Saver	185/55R15		0.5785
TNO04	**Mercedes E350 Bluetec**	Continental Premium Contact 2	225/55R16	260/280	0.6479	Continental Contisportcontact 3	245/45R17	260/270	0.6463
TNO05	**Renault Scenic**	Michelin Energy Saver	195/65R15	260/260	0.6285		205/60R16		0.6464
TNO06	**Peugeot 508**	Michelin Energy Saver	225/60R16	250/250	0.6704	Michelin Primacy HP	215/55R17	250/240	0.6623
TUG01	**Peugeot 407 SW**	Michelin Pilot Primacy	205/60R16	260/260	0.6464		215/55R17		0.6623
TUG02	**Opel Astra EU5 1.7CDTI**	Michelin Energy Saver	215/60R16	270/270	0.6584		235/40R19		0.6646
TUG05	**Audi A3 Sportback**	Michelin Primercy	205/55R16	250/240	0.6259		205/65R16		0.6259
TUG07	**Mitsubishi ASX 4WD**	Yokohama	215/60R17	220/220	0.6838		215/65R16		0.6799
TUG08	**Audi A5 2.0l TFSI**	Dunlop SP Sport	225/50/R17	220/210	0.6508		225/50R17		0.6508
VTT01	**Audi A5 1.8 TFSI**		225/50/R17	210/200	0.6508	Pirelli P7	245/40R18		0.6472
VTT02	**BMW 116i**						225/45R17		0.6283
VTT04	**Dacia Sandero 1.6 Hi-Flex**	Continental EcoContact 3	185/65R15	200/220	0.6155	Continental EcoContact3	185/65R15		0.6155
VTT08	**Opel Insignia Sports Tourer 2.0 CDTI EcoFlex**	Conti ECO Contact 5	225/50R17	290/320	0.6508		225/55R17		0.6733
VTT09	**Škoda Octavia HB 1.6 TDI GreenLine**					Michelin Energy Saver	195/65R15		0.6285
LAT01	**Opel Astra EU5 1.3 D**	Conti ECO Contact 5	215/60R16	270/270	0.6584		215/60R16		0.6584
LAT02	**VW Polo 1.2 TSI**	Bridgestone radial	185/60R15	220/200	0.5970		185/60R15		0.5970
LAT03	**BMW X1 sDrive20d**						225/50R17		0.6508

APPENDIX B COASTDOWN DATA AS PART OF THE EU TYPE-APPROVAL

This appendix includes an extract of the current EU type-approval documentation regarding the data on coastdown and road load to be provided by the manufacturer.

Legal source: EU Regulation EC/692/2008, Annex I, Appendix 3, Appendix to information document

Information on test conditions

1 ...
2 ...
3 ...
4 Dynamometer load setting information (repeat information for each dynamometer test)
4.1. Vehicle bodywork type (variant/version)
4.2. Gearbox type (manual/automatic/CVT)
4.3. Fixed load curve dynamometer setting information (if used)
4.3.1. Alternative dynamometer load setting method used (yes/no)
4.3.2. Inertia mass (kg):
4.3.3. Effective power absorbed at 80 km/h including running losses of the vehicle on the dynamometer (kW)
4.3.4. Effective power absorbed at 50 km/h h including running losses of the vehicle on the dynamometer (kW)
4.4. Adjustable load curve dynamometer setting information (if used)
4.4.1. Coast down information from the test track.
4.4.2. Tyres make and type:
4.4.3. Tyre dimensions (front/rear):
4.4.4. Tyre pressure (front/rear) (kPa):
4.4.5. Vehicle test mass including driver (kg):
4.4.6. Road coast down data (if used)

V (km/h)	V_2 (km/h)	V_1 (km/h)	Mean corrected coast down time (s)
120			
100			
80			
60			
40			
20			

4.4.7. Average corrected road power (if used)

V (km/h)	CPcorrected (kW)
120	
100	
80	
60	
40	
20	

APPENDIX C ROAD LOAD DETERMINATION IN NEDC/ UNECE LEGISLATION

Sources: The EU regulation EC/692/2008 corresponds to the UNECE regulation R83 (Revision 5 from 22 January 2015)

UNECE R83 Annex 4a Par. 5 and Appendix 7 describe the “Measurement of vehicle road load”

General requirements:

- Test track: level, maximum slope 1.5%, constant within ±0.1%
- Wind (measured 0.7 m above road surface): average <3 m/s, peak <5 m/s, perpendicular component <2 m/s
- Dry road

Selected vehicle:

The variant with the least aerodynamic body and tires with highest rolling resistance (second worst if more than three tire types) have to be chosen. The rolling resistance characteristics of the tires fitted to production vehicles shall reflect those of the tires used for type approval. The variant with largest heat exchanger shall be chosen.

Separate tests are foreseen for different variants regarding AT/MT transmissions and front/rear/all-wheel permanent and all-wheel switchable drive.

The testing mass shall be the reference mass (mass in running order + 25 kg) of the vehicle with the highest “inertia range.” Additional on-board weights are foreseen if the tested vehicle mass (including driver) does not reach the official test mass.

- The vehicle shall be run-in for more than 3000 km. It shall be in normal running order and adjustment.
- The tires shall be run-in at the same time as the vehicle or shall have a tread depth of 50%-90%.
- The tire pressure shall be in accordance with the manufacturer’s specifications for the use considered.
- A manual brake adjustment before coastdown is explicitly allowed (elimination of parasitic drag).
- Windows shall be closed and any covers in non-operational position.
- The vehicle shall be tested at a normal running temperature achieved “in an appropriate manner.”

Par. 5.1 Coastdown experiment:

Annex 4a, Par. 6.2.1.1 (Load determined with vehicle road test):

Table 25. EU velocity ranges for LDV coastdown

Europe:	From km/h	to km/h	mean km/h
Step 1	125	115	120
Step 2	105	95	100
Step 3	85	75	80
Step 4	65	55	60
Step 5	45	35	40
Step 6	25	15	20

Minimum measurement requirements: time ±0.1 s, speed ±2 km/h

Averaging:

- Average times (t) from both driving directions
- Statistical accuracy: repetitions until statistical security of mean t for each velocity range <2% (90% confidence) (equivalent to a variation coefficient of mean t of appromixately <1%)

Load calculation:

Par. 6.2.1.2 (load determined by applying the vehicle reference mass without rotational inertia):

- Dynamometer with fixed load curve: power @ steady 80 km/h, according to Table 3 (alternative, choice by manufacturer)
- Dynamometer with adjustable load curve: power @ steady 20, 40, 60, 80, 100, 120 km/h

Correction of power (driving forces by velocity) to ambient reference conditions: 20 °C, 1 bar, real air density shall not deviate by more than ±7.5% from reference conditions:

$$P_{corrected} = K \bullet P_{measured}$$

$$K = \frac{R_R}{R_T} \bullet (1 + K_R \bullet (T - T0)) + \frac{R_A}{R_T} - \frac{\rho 0}{\rho}$$

with:

K: Correction factor

R_R: Rolling resistance

R_A: Aerodynamic drag

R_T: $R_R + R_A$

K_R: Correction factor for ambient temperature dependency of rolling resistance (=0.00864 /K)

T: Ambient temperature (°C)

T0: Reference ambient temperature = 20 °C

ρ: Air density

ρ0: Air density at reference conditions (20 °C, 1 bar)

- Aerodynamic forces: air density correction not explicitly prescribed, but physical principles should be definite:

$$\rho 0 = \rho \bullet \frac{T}{293.2\ K} \bullet \frac{1\ bar}{p}$$

Humidity is not taken into account.

- Rolling resistance: Regulation assumes decreasing tires' rolling resistance with increasing ambient temperature and suggests constant correction factor K_R of 0.00864 /K. Manufacturer specific values can be applied if approved by the authority.
- Shares of R_R and R_A necessary (in the NEDC) to apply correction: manufacturer data or alternatively tabulated values:

$$\frac{R_R}{R_T} = a \bullet m + b$$

  m: Vehicle mass at coastdown [kg]

v	a	b
km/h	1/kg	—
20	7.24E-05	0.82
40	1.59E-04	0.54
60	1.96E-04	0.33
80	1.85E-04	0.23
100	1.63E-04	0.18
120	1.57E-04	0.14

On the chassis dynamometer:

Corrected power (from road coastdown) shall be reproduced by adjusting the roller brakes. This may be done by correcting the measured coastdown times by K and mass differences (between reference mass on road "m" and equivalent inertia on dynamometer "I") and reproducing them by dynamometer coastdown:

$$t_{corrected} = \frac{t_{measured}}{K} \bullet \frac{I}{m}$$

Tolerances of control coastdown on the chassis dynamometer– Annex 4a, Appendix 1, 1.2.4.:

The regulation allows tolerances for matching the vehicle's road load on the chassis dynamometer by adjusting the speed dependent braking forces of the rollers:

> "The accuracy of matching dynamometer load to road load shall be 5% at 120, 100, 80, 60, and 40 km/h and 10% at 20 km/h. Below this, dynamometer absorption shall be positive." This means that braking load must not be negative, that is, rollers must not be propelled by the dynamometer motor to balance high rolling forces of the tested vehicle.

Tabulated brake loads

As an alternative to an experimental determination, a manufacturer may also decide to apply fixed load values as given in Table 26. Note that the predefined "road load" coefficients "a" and "b" in the table represent the roller brake loads, not the vehicle's road loads. The tabulated load values are normally higher than those being adjusted to experimental (“real”) vehicle loads, resulting in higher CO$_2$ emission test results if a manufacturer decides to circumvent the effort of performing experimental coastdowns.

Table 26. Alternative fixed road load parameters (A factor of 1.3 has to be applied at “a” and “b” for vehicles with permanent all-wheel drive)

Reference mass (RW: Reference weight)				**Equivalent inertia**	**“Road Load” Coefficients (i.e., roller brake loads)**	
kg				**kg**	**a (N)**	**b (N/kph)^2**
	RW	<	480	455	3.8	0.0261
480	<	RW	540	510	4.2	0.0282
540	<	RW	595	570	4.4	0.0296
595	<	RW	650	625	4.6	0.0309
650	<	RW	710	680	4.8	0.0323
710	<	RW	765	740	5	0.0337
765	<	RW	850	800	5.2	0.0351
850	<	RW	965	910	5.7	0.0385
965	<	RW	1080	1020	6.1	0.0412
1080	<	RW	1190	1130	6.4	0.0433
1190	<	RW	1305	1250	6.8	0.046
1305	<	RW	1420	1360	7.1	0.0481
1420	<	RW	1530	1470	7.4	0.0502
1530	<	RW	1640	1590	7.6	0.0515
1640	<	RW	1760	1700	7.9	0.0536
1760	<	RW	1870	1810	8.2	0.0557
1870	<	RW	1980	1930	8.5	0.0577
1980	<	RW	2100	2040	8.7	0.0591
2100	<	RW	2210	2150	8.9	0.0605
2210	<	RW	2380	2270	9.1	0.0619
2380	<	RW	2610	2270	9.5	0.0646
2610	<	RW		2270	9.9	0.0674

Par. 5.2 Torque measurements method:

As an alternative to the time and velocity measurement approach, direct torque measurements can be taken at the wheels at constant velocity on road and on the chassis dynamometer. The regulation includes defaults for measurement accuracy, which are ±1 Nm for torque and ±0.2 km/h for velocity. Measured on-road torques must be reproduced on the dynamometer with adjusted brake forces within certain tolerances.

APPENDIX D ROAD LOAD DETERMINATION IN WLTP REGULATION

Source: UNECE Global Technical Regulation (GTR) – version 22 Sept 2015

General principle: Manufacturer shall be responsible for the accuracy of the road load coefficients. Tolerances shall not be used to underestimate them.

Alternative methodologies for road load determination:

- Road coastdown with external anemometer (standard procedure like NEDC)
- Road coastdown with on-board anemometry (new)
- Road coastdown with measured torque at wheels (like NEDC)
- Measured aerodynamic drag in wind tunnel, measured rolling resistance on chassis roller or flat belt dynamometer (new)
- Predefined general load values (like NEDC, but new formula)
- Calculation approach (interpolation) from vehicle H and L (new)

Reference measurement points at velocities: 20 km/h to 130 km/h, incremental steps of 10 km/h

General requirements:

- Wind speed average < 5 m/s (7 m/s for on-board anemometry)
- Peak wind speed < 8m/s (10 m/s for on-board anemometry)
- Wind component across road < 2 m/s (4 m/s for on-board anemometry)
- Correction term if wind speed > 3 m/s that cannot be cancelled out by alternate runs
- Atmospheric temperature: 1 °C to 40 °C (35 to 45 °C on regional level)
- Road conditions: flat, clean, dry, free of obstacles or wind barriers, representative texture and composition, longitudinal average slope < 1%, local slope < 1.5%, sum of slopes of the parallel test track segments 0 – 0.1 %, camber < 1.5 %.

Vehicle selection:

- Standard: vehicle H producing the highest cycle energy demand
- Interpolation method: vehicle H with “preferably” highest cycle energy demand, vehicle L with “preferably” lowest cycle energy demand. Calculation of road loads of an individual vehicle by interpolation of H and L road loads, applying tire rolling resistance from tire labeling (class average) and $\Delta(C_d \times A_f)$ from wind tunnel measurements or from simulation approaches
- Road load families: Includes several “interpolation families,” vehicles H_R and L_R with differences of cycle energy demand between 4% and 35%. Calculation of road loads for H_R and L_R similar to the interpolation method

Test vehicle conditions:

- Run-in: between 3t and 80t km
- Vehicle must conform to manufacturer’s production vehicle specifications, regarding tire pressure, wheel alignment, ground clearance, height, drivetrain, wheel bearing lubricants, brake adjustment

- All manually-operated panels and openings shall be closed

Vehicle “coastdown mode” allowed in case of “non-reproducible forces.” Shall be engaged during both the road load determination and on the chassis dynamometer emission testing.

Condition of tires:

- Not older than 2 years (after production date)
- Not specially conditioned or treated
- Run-in > 200 km on road
- Tread depth between 100% and 80% (plus maximum 500 km driving distance after tread depth measurement)
- Pressure at lower limit as specified by manufacturer. Adjustment in case that soak and ambient temperature differ by more than 5 °C: $\Delta p_t = 8$ mbar/K x $(T_{soak} - T_{amb})$

Vehicle warm-up:

- Before warm-up: moderate braking from 80 to 20 km/h within 5 to 10 seconds. No further manual adjustment after this braking allowed.
- Warm-up at 118 km/h for at least 20 minutes.

Measurement requirements during coastdown:

- Minimum frequency of time and vehicle speed 5 Hz.
- Measurement accuracy: time ±0.01 s, speed ±0.2 km/h

Coastdown:

- Start: maximum 60 sec at 140-145 km/h
- Coastdown with transmission in neutral
- No steering, no braking during coastdown
- Runs in opposite directions, minimum of 3 times (2 repetitions)
- Split runs possible (not complete velocity range in one run)

Averaging of times:

- Harmonized average of times in both directions: Δt_j (equivalent to arithmetic average of forces)
- Relative statistical precision: ≤ 0.03 (95% confidence)

Force calculation:

$$F_j = \frac{1}{3.6} \cdot (m_{av} + m_r) \cdot \frac{2 \cdot \Delta v}{\Delta t_j}$$

m_r: Equivalent effective mass of all rotating components, measured or calculated or estimated by: = 0.03 x RM (mass iro + 25 kg)

m_{av}: Vehicle test mass

Δv: 5 km/h

Δt_j: Coastdown time at velocity interval j

Road load coefficients f0, f1, f2 to be calculated from a least squares regression analysis.

On-board anemometry (alternative to on-board vehicle velocity plus external wind measurements):

- Wind speed measurements: ≥ 1 Hz resolution, ≤ 0.3 m/s accuracy, direction: ≤ 1° resolution, ≤ 3° accuracy
- Installation of on-board anemometer: a) boom 2 meters in front of the vehicle, b) roof at vehicle's centerline, 30 cm from windshield or c) on engine compartment cover, midpoint position between front and windshield
- Aerodynamic drag correction coefficient to be determined in a wind tunnel (installed anemometer worsens vehicle's aerodynamics)
- Rolling resistance (mechanical drag) to be approximated by a three-term polynomial as a function of velocity
- Aerodynamic drag to be approximated by a five-term polynomial as a function of "yaw angle"
- Extra calibration coefficients for "vehicle blockage"
- Requires a linear least squares regression analysis with five fixed (calculated) and nine free parameters (constrained analysis possible if C_d and A_F have been previously determined.)

Torque meter method:

- Measured torque on driven wheels for ≥ 5 seconds at each reference velocity point
- Sampling frequency ≥ 10 Hz. Accuracy: ≤ ±6 Nm or ±0.5% of the maximum measured total torque (whichever is greater)
- Includes correction procedure for "drifting velocities"

Correction to reference conditions:

- Correction factor for air resistance:
  (Reference conditions: 1 bar, 20 °C)

$$K2 = \frac{T}{293\,K} \cdot \frac{100\,kPa}{p}$$

- Correction for the temperature dependency of tires' rolling resistance:

$$K0 = 8.6 \cdot 10^{-3} / K$$

- Correction of wind resistance (in case that wind speed alongside the test road cannot be cancelled out by test runs in opposite directions):

$$w1 = 3.6^2 \cdot f2 \cdot v_w^2$$

  (v_w is the "lower average wind speed" of opposite directions alongside the test road)

- Correction of test masses:

$$K1 = f0 \cdot \left(1 - \frac{TM}{m_{av}}\right)$$

  $K1 = f0 \times (1 - TM/m_{av})$
  TM: test mass on chassis dynamometer
  m_{av}: test mass during coastdown
  (Mass correction for Rolling Resistance K1 only applied to f0 (not to f1))

- Total correction formula:

$$F^* = ((f0 - w1 - K1) + f1 \cdot v) \cdot (1 + K0 \cdot (T - 20\ °C)) + K2 \cdot f2 \cdot v^2$$

- Correction of target coefficients:

  $A_t = (f0 - w1 - K1) \cdot (1 + K0 \cdot (T - 20\ °C\ ))$

  $B_t = f1 \cdot (1 + K0 \cdot (T - 20\ °C\ ))$

  $C_t = K2 \cdot f2$

Predefined general load values - Calculation method (alternative to measurements)

f0 = 0.14 x TM [N]
f1 = 0
f2 = 2.8×10^{-6} x TM + 0.017 x width [m] x height [m] [N*(h/km)^2]
TM: Test mass [kg]

(Width and height of vehicle needed, included in CoC)

Wind tunnel method

Sum of road load forces measured

a) in a wind tunnel (aerodynamic drag), repeatability ≤ 0.015 m^2

and

b) on a flat belt dynamometer or on a roller chassis dynamometer (rolling resistance and drivetrain losses)

- Eligibility of the facilities used for this method to be demonstrated by comparisons with coastdown tests (maximal 2% average deviation).
- Dynamometer measurements can be performed alternatively at constant speeds (forces measured) or by coastdown (times measured), tolerance at each speed reference point 10 N.
- Chassis dynamometer method includes correction factor for higher rolling resistance on a roller, depending on wheel diameter, which reduces measured forces by app. 5%

Dynamometer load settings:

Three different methods for dynamometer coastdown and load adjustment are provided:

A) Vehicle is accelerated under its own power:

A1) Fixed run method:

- Calculation of vehicle force ("measured road load") at each reference velocity
- Calculation of simulated road load coefficients (least squares approach)
- Calculation of the tested vehicle resistance coefficients (simulated road load coefficients minus dynamometer setting coefficients)
- (Procedure applied 3x)
- Calculation of final dynamometer setting coefficients (target road load parameters minus averaged tested vehicle resistance coefficients)

A2) Iterative method

“Calculated forces” in the specified speed ranges shall be within a tolerance of ±10 N after a least squares regression of the forces for two consecutive coastdowns.

(Method currently unclear, missing definition of “calculated forces,” adaptation of roller brake forces between the two consecutive coastdowns?)

B) Vehicle is accelerated by the dynamometer:
(Method currently unclear, wrong reference in actual GTR version)

A similar approach is foreseen for the torque meter method.

Accuracy of dynamometer force transducer ±10 N or 2%, whichever is greater, measured during unloaded coastdown (without vehicle).

APPENDIX E AVERAGE GASOLINE AND DIESEL CAR SPECIFICATIONS

The table includes the technical specifications of average Euro 5 gasoline and diesel cars as applied for the PHEM model run CO_2 calculations in this study. The specifications correspond to Euro 5 car definitions of the current version of the Handbook Emission Factors for Road Transport (INFRAS, 2014).

Average Euro 5 cars Parameter	Unit	Gasoline	Diesel
Mass	kg	1222	1547
Loading	kg	50	50
Cd	-	0.31	0.31
Frontal area	m^2	2.14	2.27
Inertia engine	$g*m^2$	0.4506	0.5458
Mass of wheels	kg	40.06	42.4578
Inertia gearbox	$kg*m^2$	0.0576	0.06134
Engine rated power	kW	80	97
Engine rated speed	1/min	5247	4014
Idle speed	1/min	706	798
Rolling resistance f_R0	-	0.00900	0.00900
Rolling resistance f_R1	s/m	0.00005	0.00005
Rolling resistance f_R4	s^4/m^4	1.600E-09	1.600E-09
Transmission losses factor	-	0.3	0.3
Axle ratio	-	3.876	3.678
Wheel diameter	m	0.607	0.6433
Transmission 1. gear	-	3.672	3.798
Transmission 2. gear	-	1.991	2.063
Transmission 3. gear	-	1.334	1.312
Transmission 4. gear	-	0.988	0.955
Transmission 5. gear	-	0.789	0.743
Transmission 6. gear	-	-	0.61