WORKING PAPER 2014-9
OCTOBER 2014

The WLTP: How a new test procedure for cars will affect fuel consumption values in the EU

Authors: Peter Mock, Jörg Kühlwein, Uwe Tietge, Vicente Franco, Anup Bandivadekar, John German

Date: 29 October 2014

Keywords: Fuel economy, fuel consumption, CO_2 standards, vehicle test procedures, Worldwide Harmonized Light Vehicles Test Procedure

Executive Summary

The current European type-approval procedure for fuel consumption and CO_2 emissions of cars (NEDC) includes a number of tolerances and flexibilities and no longer accurately reflects state-of-the-art technologies. The European Union (EU) is planning to replace it with the newly developed WLTP in 2017. The new procedure will deviate in some details from the current one, which will have an impact on the determination of the official EU type-approval emission values. This also has consequences on the NEDC-based CO_2 passenger cars' emission target for 2020-2021 (95 g CO_2/km), which will need to be adapted to the new testing procedure. This paper identifies the main influencing parameters and quantifies their impacts. The effects of the new driving cycle and the new definition of the vehicles' test masses result in a new WLTP-based target of 100 g CO_2/km for 2020. If the ambient test temperature is also changed for the EU-WLTP (to 14 °C instead of 23 °C), an additional correction of 2 g CO_2/km would be appropriate, making the target 102 g CO_2/km.

1. Introduction

For more than fifty years, vehicles have been tested in controlled laboratory environments to determine their official emission values. There is a good reason for this: In a vehicle laboratory, technicians can control important influencing factors, such as ambient temperature and vehicle speed trace, and thereby ensure reproducibility and comparability of results.

However, as recent analyses by the ICCT and other research institutes demonstrate, official laboratory test results reflect less and less the actual experience of average drivers on the road[1]. For example, based on an analysis of real-world driving data from the German website *spritmonitor.de*, ICCT concludes that the difference between official laboratory and real-world fuel consumption and CO_2 values[2] was around 7% in 2001. This discrepancy has increased continuously since then to around 30% in 2013. Furthermore, notable differences were found between individual manufacturers and between vehicle models.

This growing gap between official laboratory and real-world on-road emission values negatively affects consumers (who spend more on fuel), governments (whose vehicle tax revenue drops), vehicle manufacturers (which have no level playing field and lose credibility) and society as a whole (not meeting emission reduction targets as anticipated). Hence, there is common agreement that a revision of the vehicle test procedures is needed in order to make them better reflect real-world driving.

A lot of hope is riding on the *Worldwide Harmonized Light Vehicles Test Procedure* (WLTP), which was developed at the United Nations level through UNECE in recent years and is now ready for implementation at the regional and country level. The objective of this paper is to provide some background on the WLTP and an assessment of its expected impacts on CO_2 emissions. The guiding questions for the following sections are as follows:

- How was the WLTP developed at UNECE and how will it be implemented at the regional level? (Section 2)

1 Mock, P. et al., "From Laboratory to Road: A 2014 update of official and 'real-world' fuel consumption and CO_2 values for cars in Europe" (ICCT 2014), http://www.theicct.org/laboratory-road-2014-update; Ntziachristos, L. et al., "In-use vs. type-approval fuel consumption of current passenger cars in Europe" (Energy Policy 2013), http://dx.doi.org/10.1016/j.enpol.2013.12.013i

2 For reasons of clarity, in this paper only CO_2 values are reported, with CO_2 being an excellent proxy for fuel consumption.

- What is the expected impact of the WLTP on vehicle CO_2 emission levels in 2020-2021? (Section 3)
- What are the next steps for the practical implementation of the WLTP in the EU? (Section 4)

The focus of this Working Paper is on the EU, as that is the region closest to implementing the WLTP.

2. History of the WLTP and current status

Vehicle emission regulations were first introduced in the EU in the 1960s and 1970s. At that time a first version of a European drive cycle for vehicle testing under laboratory conditions was developed. This test cycle[3] included only urban driving and only to a maximum speed of 50 km/h[4]. CO_2 emissions were not yet tested, only air pollutant emissions. In the 1990s, the EU amended the test cycle to also include an extra-urban part, which reaches a maximum speed of 120 km/h for 11 seconds[5]. The test was then called the *New European Drive Cycle* (NEDC). An initial 40-second idle period for engine warm-up before the bag sampling start was removed with the transition to Euro 3 standards. Measurements of CO_2 emissions gained special relevance during the 1990s when the EU car manufacturers entered a voluntary agreement for reducing CO_2 emissions of new vehicles, and even more so from 2009 on, when the EU adopted a mandatory CO_2 regulation that includes a penalty payment in the case of exceedingly high CO_2 emissions[6].

It is important to understand this historical context of the NEDC, which was introduced at a time when vehicle CO_2 emissions were not even tested and did not have any impact on a vehicle manufacturer's economic performance. This is very different from the situation today, where CO_2 emissions of vehicles need to be determined very accurately as they have competitive impacts and potentially lead to millions of Euros of penalty payments if a manufacturer does not meet its CO_2 emission targets. Other key vehicle markets throughout the world follow their own specific testing procedures. For example, the FTP test was introduced in the U.S. in 1975 and the supplemental US06/SC03 tests were phased in starting in 2000[7]. Similarly the 10-15 test was introduced in Japan in 1983 and was replaced by the JC08 test in 2008[8].

In 2007 a technical working group of the U.N. decided to develop a worldwide harmonized test procedure for light-duty vehicles. Previously, the same working group had successfully developed a worldwide harmonized test procedure for motorcycles and one for heavy-duty vehicles. A key reason put forward by the U.N. for developing a new test procedure was "reflecting the actual driving conditions in real-world"[9]. Another key aspect mentioned in the original documents of the group is the economic benefit to the industry, as it would be easier and cheaper for manufacturers to offer vehicles in different markets if the testing conditions were harmonized worldwide. The group concluded that "these savings will benefit not only the manufacturer, but also more importantly, the consumer" and would "enable manufacturers to develop new environmentally friendly models more effectively and within a shorter time".

In June 2008, the U.N. WLTP working group had its first meeting in Geneva. Around the same time, the transport ministers of the leading vehicle market countries agreed at their annual International Transport Forum (ITF) meeting in Leipzig on a statement urging the U.N. "to accelerate the work to develop common methodologies, test cycles and measurement methods for vehicles"[10].

The development of the WLTP sparked a lot of interest among various stakeholders. The number of attendees to the biannual meetings of the U.N. Working Party on Pollution and Energy (GRPE) increased from about 50 in 2006 to 100 in 2007, when the first discussions around the WLTP began, then to about 130 in 2008, when the first formal WLTP meeting was held. Toward the end of the WLTP development process, the number of attendees increased further to around 150 per GRPE meeting (Figure 1). The majority (about 70%–80%) of attendees were from Europe, and around 15%–20% from Asia. North America was relatively poorly represented throughout the entire process, typically accounting for less than 5% of all attendees (Figure 1).

In terms of stakeholder groups, industry representatives accounted for the majority of participants (about 50% –60%). Government representatives typically made up about 20%–30% of attendees. Technical institutes, a majority of them being representatives of vehicle testing facilities, accounted for another 15%–25% of participants. ICCT and the Brussels based NGO umbrella organization Transport&Environment were the only independent non-governmental/non-industry groups (summarized here under the term 'NGO') present during the WLTP development process (Figure 2).

3 We use the phrase "test cycle" here when referring to a speed trace that the vehicle's driver has to follow during the test, whereas the phrase "test procedure" is used referring not only to the test cycle but all other test conditions (e.g., ambient temperature) as well.

4 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31970L0220&from=de

5 http://transportpolicy.net/index.php?title=EU:_Light-duty:_NEDC

6 http://theicct.org/eu-co2-standards-passenger-cars-and-lcvs

7 http://transportpolicy.net/index.php?title=US:_Light-duty:_FTP-75

8 http://transportpolicy.net/index.php?title=Japan:_Light-duty:_JC08

9 http://www.unece.org/fileadmin/DAM/trans/doc/2007/wp29/ECE-TRANS-WP29-2007-98e.pdf

10 http://www.bmvi.de/SharedDocs/DE/Anlage/VerkehrUndMobilitaet/Fahrrad/international-transport-forum-key-messages-englisch.pdf?__blob=publicationFile, http://www.unece.org/fileadmin/DAM/trans/doc/2009/wp29grpe/ECE-TRANS-WP29-GRPE-57e.pdf

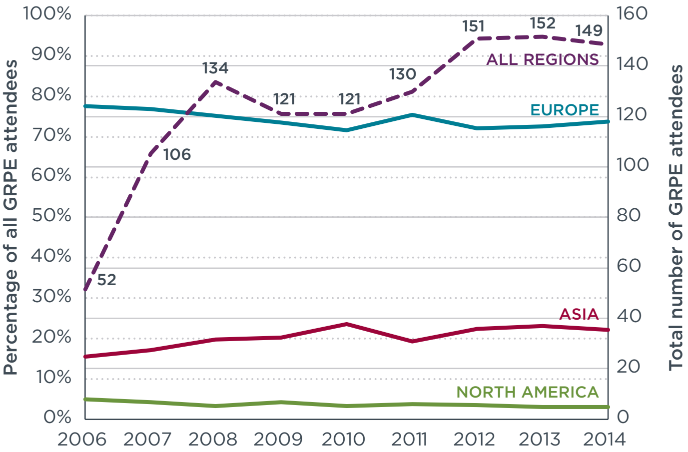

Figure 1. Share of participants of the 2006-2014 WLTP development meetings, by region[11].

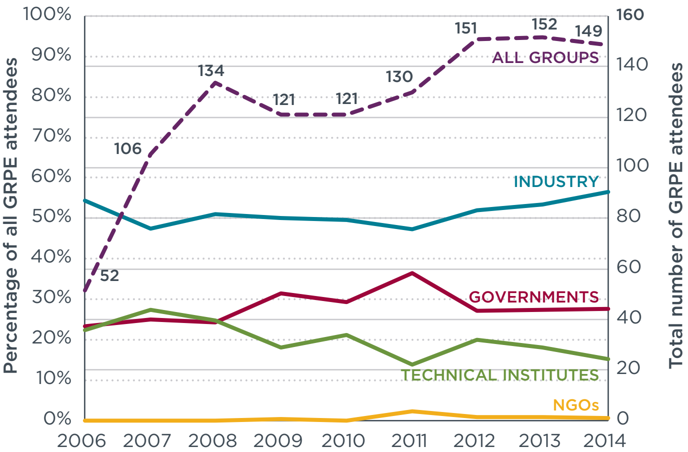

Figure 2. Share of participants of the 2006-2014 WLTP development meetings, by type of organization.

In 2010, the U.S. Environmental Protection Agency (EPA) decided to withdraw its "active participation and sponsorship" of the WLTP, given the resource-intensive preparations for the 2012-2016 and 2017-2025 U.S. greenhouse gas standards[12]. With this decision by the U.S., it became clear that the WLTP could not become a truly worldwide harmonized test procedure as originally envisioned. Nevertheless, the group decided to continue its work, and the European Commission emphasized once more that it wanted to finish the WLTP development by 2014, as foreseen by EU regulations.

In 2012-2013 the focus of the WLTP working group shifted from debating technical details in the specific sub-working groups toward developing a regulatory draft text, the so-called GTR (*Global Technical Regulation*). To speed up this process, the European Commission sponsored the position of a GTR draft coordinator who took on the responsibility for summarizing the various technical details in a single text document. In November 2013, this GTR text was adopted by the GRPE[13]. In March 2014, as a last formal step, it was approved by the next higher U.N. group, the so-called WP.29, where all of the U.N. member organizations were asked to vote on the proposal[14]. The representative of Germany, being also chairman of the GRPE, welcomed the adoption of the WLTP[15].

With the adoption of the WLTP GTR by WP.29, the WLTP is ready to be implemented in regional and national law. At the same time, there are still some open issues around technical details of the WLTP, mostly with respect to testing electrified vehicles. The working group decided to extract these into a WLTP "Phase 1b" and to close these open issues by early 2015 so that the decisions can be included in the final WLTP text before it is transformed into a UNECE regulation. It is expected that the WLTP will be adopted as UNECE regulation by WP.29 in early 2016, with a publication of the final regulation in all U.N. languages by early 2017 (Figure 3).

After the U.S. withdrew from the WLTP working group, the process was driven forward mostly by the EU, Japan, India and South Korea. It is likely that the WLTP eventually will be implemented in these markets and possibly other markets as well (for example, China also regularly participated in the WLTP working group meetings). If other markets decide to implement the WLTP, they have the possibility to adapt it within certain framework settings. For example, Japan and India already have announced they will not apply the high-speed phases of the WLTP, so that the overall test cycle applied in Japan and India will still be different from the cycle applied in the EU even after introduction of WLTP in both markets.

Similarly, the EU is planning to adapt the UN-WLTP regulation by some regional certification aspects. For example, the EU is planning to determine CO_2 emissions at an ambient temperature of 14 °C instead of the 23 (±5) °C foreseen by the UN-WLTP, in order to better reflect average ambient temperature levels in the EU. Another EU endeavour comprises normalization procedures to achieve more reproducible test results and to reduce testing flexibilities. The European Commission is currently drafting an EU-WLTP regulatory

11 ICCT analysis, based on lists of participants for the years 2006-2014, kindly provided by the UNECE Secretariat. 2013 was the only year in which three meetings took place instead of two—the November 2013 meeting was therefore excluded from the analysis. It should be noted that the reduction in the number of participants starting at the end of 2008 was due to the economic crisis and cuts in travel budgets for all groups of participants. During this time some delegates joined the meetings by phone, but were not included in the list of participants.

12 http://www.unece.org/fileadmin/DAM/trans/doc/2010/wp29grpe/ECE-TRANS-WP29-GRPE-60e.pdf

13 http://www.theicct.org/wltp-november2013-update

14 The GTR was adopted by a consensus vote of the following U.N. Contracting Parties: Australia, China, European Union (voting for Cyprus, Finland, France, Germany, Hungary, Italy, Lithuania, Luxembourg, Netherlands, Romania, Slovakia, Spain and United Kingdom), India, Japan, Norway, Republic of Korea, Republic of Moldova, Russian Federation, South Africa and Turkey.

15 http://www.unece.org/fileadmin/DAM/trans/doc/2014/wp29/ECE-TRANS-WP29-1108e.pdf

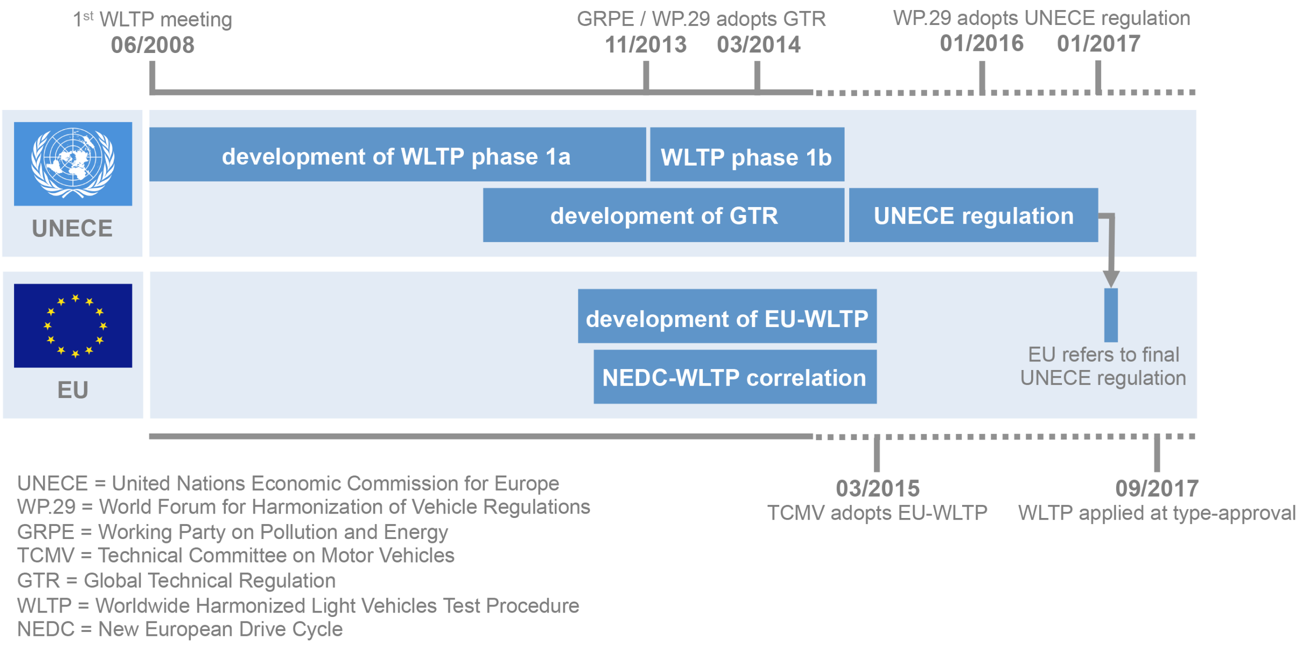

Figure 3. Timeline for developing the WLTP and implementing it into an EU regulation.

text based on the UN-WLTP GTR that adds the respective European certification aspects. The 28 EU member states will have to adopt the EU-WLTP in one of the meetings of the *Technical Committee on Motor Vehicles* (TCMV) to turn it into EU regulation. This is currently foreseen as happening in early 2015, one year later than originally required by EU regulation[16]. The EU will then have to wait for publication of the final UNECE WLTP regulation before the WLTP can be applied for new vehicle type approvals, as currently foreseen for September 2017 (when Euro 6 stage c goes into effect). In parallel, the European Commission is currently working on a translation of the 2020-2021 CO_2 emission targets from NEDC into WLTP. This so-called *correlation exercise* is expected to be completed by early 2015 (Figure 3).

3. Impact of the WLTP on CO_2 emissions and fuel consumption

The introduction of the WLTP as standard procedure for type approvals in the EU will bring some fundamental regulatory changes compared to the previous NEDC-based approach. Some of these changes will have an impact on CO_2 emissions and fuel consumption values[17].

Table 1 lists the most important parameters with a potential influence on CO_2 emissions for which the definitions will change with the transition from the NEDC to the WLTP regulation. All parameters are classified (YES or NO) indicating whether the impact of a specific parameter should be quantified and considered for the calculation of a WLTP-NEDC conversion factor. The rationales for a NO decision are:

- **Effect on CO_2 negligible:** There are obvious differences in the test procedures, but the impact of these on CO_2 emissions are expected to be rather marginal (<1%). These parameters would not affect a total conversion factor between the two procedures.
- **Equal demands of NEDC intention:** Some parameters received a rather precise definition in the WLTP, while under the NEDC there were only very weak defaults or no standards at all. In this case, the original intention of the NEDC regulators has to be considered which is in many cases identical to the more detailed WLTP standards. For example, the road load of a vehicle consists of physical parameters (mass, aerodynamic drag, rolling resistance) that can be measured very accurately for every given vehicle. NEDC imprecision allows for modifications of a vehicle that is used for official coast-down experiments, for example, replacement of normal road tyres by conditioned low resistance tyrses, atypically high tyre pressures, manual adjustment of brakes, etc. These artificial measures do not appear during real-world driving of normal production vehicles, were never intended by the NEDC regulator and should therefore not be included in official WLTP-NEDC CO_2 conversion factors.
- Some **errors in the NEDC regulation** were corrected by the WLTP.
- Some issues are still to be defined in **future stages of the WLTP**, for example, improved measurement standards for hybrid vehicles.

16 Regulation (EC) No 443/2009, article 13

17 Air pollutants are also expected to be impacted by the introduction of WLTP but are not in the scope of this paper.

Table 1. Parameters with potential impact on CO_2 with different definitions in NEDC and WLTP

Parameter	Definition in NEDC (Euro 6)	Definition in EU WLTP	To be considered for a WLTP-NEDC conversion factor?	
TEST CYCLE				
Driving cycle	NEDC	WLTC	YES	Revised driving cycle
Gear shift strategy for manual transmission vehicles	fixed gear positions	vehicle specific gear positions	YES	Part of revised driving cycle
ROAD LOAD DETERMINATION				
Tyre size and type	worst tyre (2nd worst if >3 tyres with different rolling resistances)	vehicle specific	NO	Equal demands of NEDC intention (NEDC slightly more stringent)
Tyre tread depth	>3,000 km running-in or 50%–90%	80%–100%	NO	Equal demands of NEDC intention (WLTP slightly more stringent)
Tyre pre-treatment	not defined	no heating or ageing	NO	Equal demands of NEDC intention
Tyre pressure	not defined	as specified	NO	Equal demands of NEDC intention
Wheel alignment	no definitions on adjustments of toe and camber	as production vehicle	NO	Equal demands of NEDC intention
Aerodynamics	worst bodywork, no definitions on movable parts	vehicle specific, use of movable parts as under test conditions	NO	Equal demands of NEDC intention (NEDC slightly more stringent)
Brakes	not defined	no manual adjustment	NO	Equal demands of NEDC intention
Calculation procedure	erroneous	corrected	NO	NEDC procedure deficient
Warm-up	not defined	>20 min at 118 km/h	NO	Effect on CO_2 negligible
TEST TEMPERATURES				
Soak area	20 °C–30 °C	14 °C / 23 °C	YES/NO	Effect on CO_2 negligible for 23 °C
Test cell	20 °C–30 °C	14 °C / 23 °C	YES/NO	Effect on CO_2 negligible for 23 °C
VEHICLE MASSES				
Test mass	Kerb weight + 100 kg	Kerb weight + 100 kg + extras + payload	YES	Revised definition
Inertia	discrete classes	step-less, vehicle specific	NO	On fleet average: Effect on CO_2 negligible
Rotating masses (wheels)	simulation of total inertia of the vehicle as driven on the road	+ 1.5% for 1-axle dynamometers	NO	Equal demands of NEDC intention
OTHER				
Vehicle running in	>3,000 km	3,000 km–15,000 km	NO	Effect on CO_2 negligible
Pre-conditioning cycle	diesel: 3x EUDC petrol: 1x UDC, 2x EUDC (opt., only PFI)	WLTC	NO	Effect on CO_2 negligible
Battery state of charge	not defined	no battery charging before emission test	NO	Equal demands of NEDC intention
Procedure for hybrids	not defined	not yet defined	NO	WLTP definitions to follow
Four wheel drive vehicles	1-axle dynamometer possible	2-axle dynamometer only	NO	Effect on CO_2 negligible

Within the procedure of the road load determination (RLD) of the tested vehicle (from coast-down experiments on the road), there are several input parameters with definitions that differ between NEDC and WLTP. Two of them (tyre type and aerodynamics) are defined less stringently under the new WLTP, where individual vehicle characteristics will be considered, while under the NEDC at Euro 6 standards the worst case vehicle (or second worst) within each vehicle family is tested. The effects of these two parameters are difficult to quantify, as they depend on manufacturers' strategies on grouping different vehicle bodies in one family and on the range of tyre types offered. The WLTP standard for the minimum tyre tread depth is slightly more stringent than under

NEDC and will lead to an averaged overestimation of about 0.3% in terms of CO_2 emissions[18]. Altogether, it is expected that the impact of the new definitions of these three RLD parameters taken together will be very small (they might even slightly decrease CO_2 emissions in WLTP) and will not contribute to a WLTP-NEDC conversion factor.

In addition, the NEDC regulation provides tolerances for some of the parameters that also have impacts on CO_2 emissions, for example, tolerances around the speed schedule of the driving cycle (±2 km/h and ±1 second), tolerances of dynamometer control coast-down times (±5% and ±10%), temperatures, differences between measured and official CO_2 values (±4%), tolerances of measurement devices, etc. Because of improved testing technologies and newly developed correction algorithms, some of these tolerance ranges will be tightened or even eliminated under the EU WLTP implementation. However, the intention of NEDC tolerances was always to cushion unwanted variation and never to systematically deviate from the envisaged target values. Therefore, one-sided divergences occurring within a tolerance interval should not be misinterpreted as changing the standard itself and cannot qualify for the application of a WLTP-NEDC correction.

As a result, there are three key elements with different definitions that should be considered for the derivation of a WLTP-NEDC conversion factor for CO_2 emissions:

1. A longer and more dynamic **driving cycle**, including a more flexible gear shift strategy for manual transmissions
2. A higher **vehicle test mass**
3. A lower **engine temperature** at test start

In this section we investigate each of the three main elements in more detail and derive a NEDC-WLTP conversion factor that takes account the changes expected when switching from the current NEDC to the future WLTP test procedure. For our assessment we focus on a projected vehicle fleet mix in 2020/2021, which is the year when the EU's 95 g/km CO_2 target will come into effect[19].

3.1 INFLUENCE OF THE DRIVING CYCLE

Figure 4 and Figure 5 show the NEDC and WLTP driving cycles. While WLTP indicates the complete framework of the test procedure, testing conditions and the test cycle, the term WLTC (*Worldwide Harmonized Light Vehicles Test Cycle*) is used to specifically identify the test cycle only.

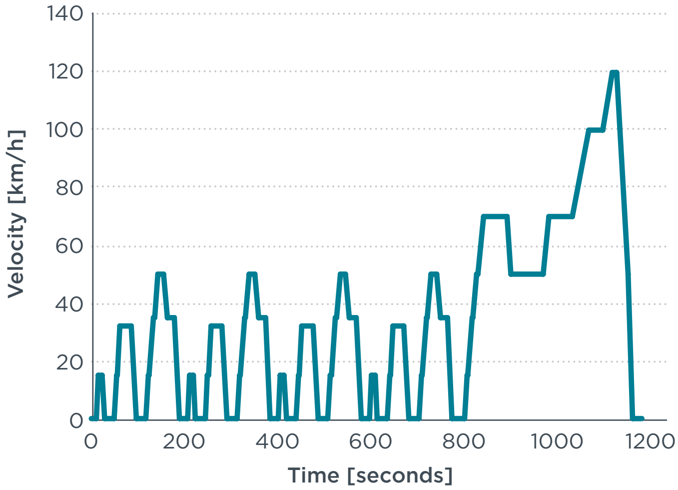

Figure 4. NEDC driving cycle

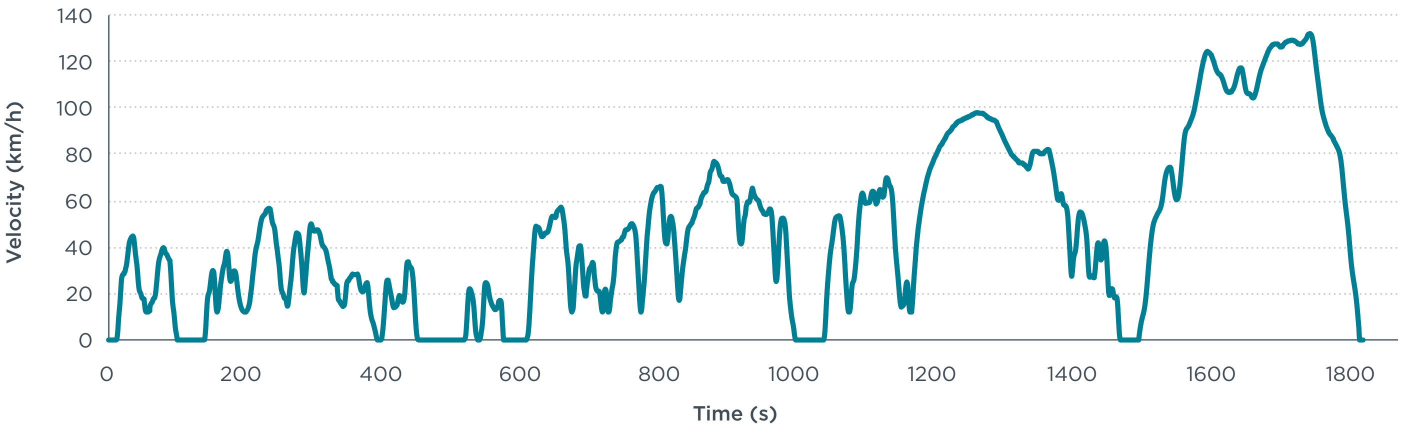

Figure 5. WLTP driving cycle (WLTC)

18 Assuming an average tread depth deviation of 2 mm and a corresponding increase of the rolling resistance coefficient (RRC) of 0.2 kg/t leads to 0.3% increased CO_2 for a tyre of 10 kg/t RRC (see Table 9)

19 http://theicct.org/eu-co2-standards-passenger-cars-and-lcvs

Table 2 quantifies the main descriptive parameters of these two driving cycles.

Table 2. Descriptive parameters of the driving cycles NEDC and WLTC

	Units	NEDC	WLTC
Start condition		cold	cold
Duration	s	1180	1800
Distance	km	11.03	23.27
Mean velocity	km/h	33.6	46.5
Max. velocity	km/h	120.0	131.3
Stop phases		14	9
Durations:			
• Stop	s	280	226
• Constant driving	s	475	66
• Acceleration	s	247	789
• Deceleration	s	178	719
Shares:			
• Stop		23.7%	12.6%
• Constant driving		40.3%	3.7%
• Acceleration		20.9%	43.8%
• Deceleration		15.1%	39.9%
Mean positive acceleration	m/s^2	0.59	0.41
Max. positive acceleration	m/s^2	1.04	1.67
Mean positive 'vel * acc' (acceleration phases)	m^2/s^3	4.97	4.54
Mean positive 'vel * acc' (whole cycle)	m^2/s^3	1.04	1.99
Max. positive 'vel * acc'	m^2/s^3	9.22	21.01
Mean deceleration	m/s^2	-0.82	-0.45
Min. deceleration	m/s^2	-1.39	-1.50

Comparing the NEDC and the WLTC, the following observations can be made:

- **Cold start:** The WLTC (1800 seconds and 23 km) is longer than the NEDC (1180 seconds and 11 km). Driving a vehicle with a cold engine increases CO_2 due to higher mechanical friction and higher fluid viscosities. The absolute cold start surcharge in terms of grams CO_2 is almost independent of the driving pattern. Thus, the cold start impact decreases with increasing distance of the cycle. Under the WLTC, the added cold start contribution to the total emission result (in g CO_2/km or litres/100 km) is only about half of the added cold start contribution in the NEDC.
- **Vehicle load:** The WLTC reaches higher speeds (131.3 km/h instead of 120 km/h) and has stronger acceleration forces (combined with higher vehicle inertia) and thereby, on average, higher vehicle loads than the NEDC. Partially counteracting this, engine efficiency typically increases with the engine load. The underlying reason for the increased efficiency is that losses from friction and gas flow are relatively lower. This applies particularly to current engine technologies, which have relatively low efficiency at the light loads on the NEDC. For future advanced engine designs it is expected that engine efficiency will improve more at these low load conditions than at higher loads, making the WLTC more challenging for these advanced vehicle technologies. Thus, current engines might do proportionally better than more advanced engines in the WLTC with its higher average engine loads.
- **Engine speed:** Besides the load of the engine, engine speed has a direct impact on CO_2 emissions. Generally, higher engine speeds cause higher friction and pumping losses and worsen the CO_2 performance. Therefore, gear shift strategies for automatic transmissions are designed to achieve lower engine speeds by shifting more rapidly into lower numeric gear ratios. In the NEDC, vehicles with manual transmissions have to follow strict specifications that determine at which point in time a certain gear position has to be selected. This regime will change in the WLTP where the gear shift points will be adapted to the individual characteristics of the vehicle. As the WLTP shifting points are clearly at lower engine speeds compared to the NEDC, this new method will reduce engine speeds for manual transmission vehicles and will result in proportionally lower CO_2 emissions for these vehicles in the WLTC.
- **Stop share:** In the WLTC (12.6% stop share) there are less stop phases than in the NEDC (23.7% stop share). Stop-start systems shut down the engine during vehicle stop phases and—in an ideal case—reduce idle emissions to zero. In the WLTP, this technology will result in lower CO_2 savings than is currently the case in the NEDC.

For quantifying the influence of the driving cycle on the CO_2 emission level in NEDC versus WLTC, we draw upon three independent and public data sources:

1. The engineering service provider Ricardo Inc. developed a sophisticated vehicle emission simulation model to quantify the test cycle dependencies for a wide range of current and future vehicle technologies. [1,2]
2. The engineering service provider AVL applied a similar vehicle emission simulation model and published its own independent model results. [3]
3. Europe's largest car club, the German ADAC, tested a large number of vehicles both in NEDC and WLTC and included the results in its ADAC EcoTest program. [4]

For all three sources we calculate the quotients of distance-based CO_2 emissions in WLTC and NEDC to arrive at the WNQ, the *WLTC-NEDC Quotient*:

$$WNQ = \frac{CO_2 \text{ WLTC } [\frac{g}{km}]}{CO_2 \text{ NEDC } [\frac{g}{km}]}$$

3.1.1 Ricardo DVT vehicle simulation runs

A complete, physics-based vehicle and drivetrain system model was developed by Ricardo, Inc., and implemented in MSC.Easy5. Ricardo parameterized the CO_2 model for the predefined driving cycles and vehicle technologies and developed a user friendly application tool, called the Data Visualization Tool (DVT) [1]. For this study, this tool was used to perform vehicle simulation runs on the NEDC and WLTC. Fuel consumption and CO_2 emissions for a number of current vehicle technologies as well as for advanced 2020/2025 technologies were determined. This analysis covers mostly automatic transmission vehicles and includes all key European car segments: B-segment (small cars), C-segment (medium cars), D-segment (large cars) and J-segment (sport utility cars)[20]. The DVT allows for modifications of important model input parameters, like vehicle mass, rolling resistance, aerodynamic drag, and others. Starting from current baseline technologies, the total driving resistances have been reduced for the model runs by 10% for more advanced conventional technology packages and by 20% for more innovative propulsion systems to be expected in the 2020/2021 time frame[21].

Table 3 and Figure 6 summarize the simulation results and the corresponding NEDC-WLTC conversion factors (WNQ) for various vehicles and technology packages.

Table 3. Ricardo DVT vehicle simulation runs with cold start correction and resulting NEDC-WLTC conversion factors (WNQ)

Segment	Fuel	Engine	DI	AT	SS+	ADV	HEV	WNQ
small (B)	petrol	1.5l, 82 kW		X				**0.95**
small (B)	petrol	1.5l, 82 kW		X	X			**1.04**
small (B)	petrol	0.7l, 72 kW	X	X	X	X		**1.14**
small (B)	petrol	0.6l, 59 kW	X	X		X	X	**1.16**
small (B)	diesel	1.2l, 59 kW	X	X				**0.95**
small (B)	diesel	1.2l, 59 kW	X	X	X			**1.04**
small (B)	diesel	1.1l, 69 kW	X	X	X	X		**1.04**
medium (C)	petrol	2.0l, 88 kW		X				**0.93**
medium (C)	petrol	2.0l, 86 kW		X	X			**0.96**
medium (C)	petrol	0.8l, 76 kW	X	X	X			**1.12**
medium (C)	petrol	0.6l, 62 kW	X	X		X	X	**1.12**
medium (C)	diesel	1.6l, 97 kW	X	X				**0.98**
medium (C)	diesel	1.6l, 75 kW	X	X	X			**1.01**
medium (C)	diesel	1.3l, 77 kW	X	X	X	X		**1.00**
large (D)	petrol	2.4l, 118 kW		X				**0.90**
large (D)	petrol	2.4l, 118 kW		X	X			**0.98**
large (D)	petrol	1.0l, 101 kW	X	X	X	X		**1.10**
large (D)	petrol	0.8l, 83 kW	X	X		X	X	**1.11**
large (D)	diesel	2.0l, 122 kW	X	X				**0.89**
large (D)	diesel	2.0l, 122 kW	X	X	X			**1.03**
large (D)	diesel	1.7l, 105 kW	X	X	X	X		**0.99**
SUV (J)	petrol	2.4l, 128 kW		X				**0.94**
SUV (J)	petrol	2.4l, 128 kW		X	X			**1.00**
SUV (J)	petrol	1.1l, 110 kW	X	X	X	X		**1.13**
SUV (J)	petrol	0.9l, 90 kW	X	X		X	X	**1.13**
SUV (J)	diesel	2.2l, 131 kW	X	X				**0.90**
SUV (J)	diesel	2.2l, 131 kW	X	X	X			**1.02**
SUV (J)	diesel	1.8l, 109 kW	X	X	X	X		**1.02**

DI = direct injection; SS+ = stop-start + improved alternator + regenerative braking; AT = automatic transmission; ADV = advanced 2020/2025 technology package; HEV = hybrid electric vehicle;

20 Details on the definitions of the vehicle technology packages can be found in: [2]

21 Additional corrections for cold start emissions have been applied to the DVT model outputs, which reduced the WNQ values by 4%.

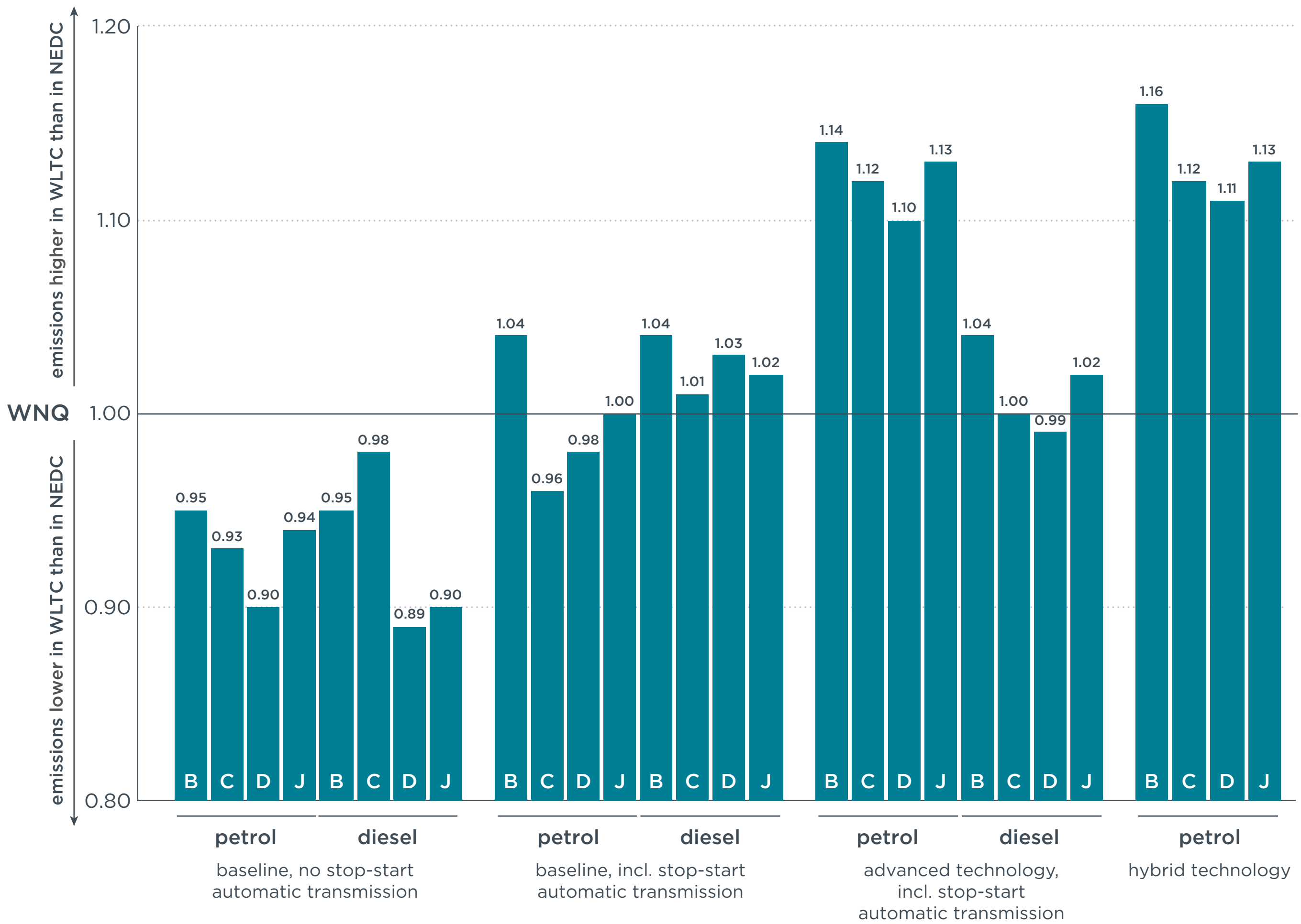

Figure 6. Ricardo vehicle simulations runs and resulting NEDC-WLTC conversion factors

As can be seen from the Ricardo results, non-hybrid vehicles with conventional technologies have a WNQ ratio of less than 1, that is, those vehicles have lower CO_2 emissions in the WLTC than in the NEDC. There are some variations for individual vehicle segments and fuel types, but generally the WNQ ratio is between 0.90 and 0.95. Vehicles that make use of a stop-start system, a basic braking energy recuperation system and an advanced alternator show a significantly higher WNQ, around 1.00. This means those vehicles show about the same CO_2 emission levels in both cycles. The difference between these two cases is explained by the higher share of vehicle stop time on the NEDC. More advanced vehicles, including those with downsized engines and those with hybrid power trains, generally show a WNQ of around 1.10, that is, they have CO_2 emissions that are about 10% higher in the WLTC than in NEDC. It is important to note that all Ricardo vehicle runs are for automatic transmission cars, which tend to have a higher WNQ than manual transmission vehicles (see also AVL results in next paragraph)[22].

3.1.2. AVL vehicle simulation runs

AVL, making use of a different model, carried out vehicle simulation runs similar to those done by Ricardo. The analysis covers only the C-segment (medium cars), Europe's most popular vehicle segment, accounting for about 30% of all sales today. The vehicle specifications for the simulation runs were defined in cooperation between AVL and the European Council for Automotive R&D (EUCAR), representing the 15 major European manufacturers of cars, trucks and buses. The AVL analysis focuses on manual transmission conventional power train systems but also includes petrol and diesel powered hybrid systems [3].

Table 4 and Figure 7 summarize the simulation runs and the corresponding NEDC-WLTC conversion factors (WNQ) for the AVL power train architectures.

22 Ricardo vehicle simulation runs with a manual transmission are available for one baseline configuration of one vehicle segment. Since these runs were not based on the most recent WLTC gear shift protocol, the data is not comparable to the AVL vehicle simulation runs (see 3.1.2.) and was therefore not taken into account for the analysis in this paper.

Table 4. AVL vehicle simulation runs and resulting NEDC-WLTC conversion factors (WNQ)

Segment	Fuel	Engine	DI	AT	SS	HEV	WNQ
medium (C)	petrol	1.4l, 75 kW, 4 cyl.					**0.91**
medium (C)	petrol	1.4l, 75 kW, 4 cyl.			X		**0.94**
medium (C)	petrol	1.2l, 85 kW, 3 cyl.	X				**0.90**
medium (C)	petrol	1.2l, 85 kW, 3 cyl.	X		X		**0.93**
medium (C)	petrol	1.0l, 70 kW, 3 cyl.	X	X	X	X	**1.08**
medium (C)	diesel	1.6l, 85 kW, 4 cyl.	X				**0.93**
medium (C)	diesel	1.6l, 85 kW, 4 cyl.	X		X		**0.95**
medium (C)	diesel	1.6l, 85 kW, 4 cyl.	X	X	X	X	**1.07**

HEV = hybrid electric vehicle; DI = direct injection; SS = stop-start; AT = automatic transmission

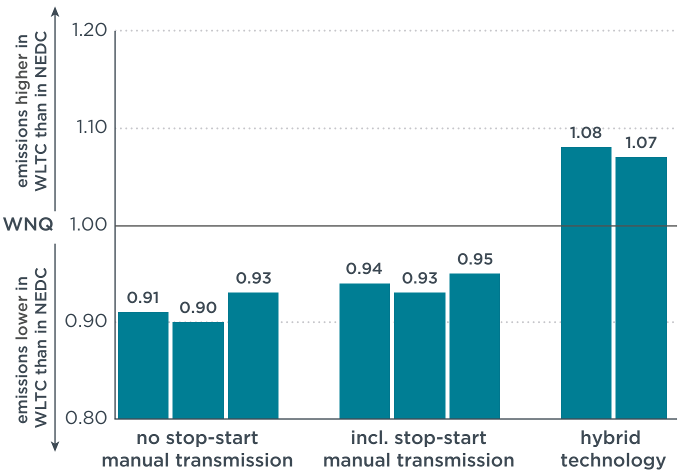

Figure 7. AVL vehicle simulations runs and resulting NEDC-WLTC conversion factors

Based on the AVL results, CO_2 emissions of conventional power train vehicles have a WNQ of lower than 1, that is, the emission level is about 5%–10% lower in the WLTC than in the NEDC. As previously explained, a stop-start system is more effective in the NEDC and, according to the AVL results, raises the WNQ by about 2.5%. In general, hybridization in combination with a downsized combustion engine (only petrol in this case) is more effective in the NEDC. This leads to a WNQ of >1 for the hybrid vehicles, that is, those vehicles tend to emit about 7%–8% more CO_2 in the WLTC. Between petrol- and diesel-fueled systems there are no observable large discrepancies. The WNQs vary only slightly, that is, +2% for ICE and -1% for HEV for the diesels.

It is important to note that all non-hybrid vehicles simulated by AVL have manual transmissions. It is well established that this transmission type has higher benefits than automatic transmission types when shifting from the NEDC to the WLTC. This is because fixed gear shift points are applied in the NEDC for manual transmissions, which results in relatively high average engine speeds and thereby is disadvantageous for manual transmissions. This disadvantage will be eliminated in the WLTC, where a more flexible gear shift model will be applied that leads to lower average engine speeds. From additional AVL examinations reported in their paper [3], it can be concluded that the CO_2 saving effect for the transition from an existing manual transmission to an automatic transmission is about 4.5% higher for the NEDC (mean saving effect: 7.7%) than for the WLTC (mean saving effect: 3.3%). This is equivalent to a 0.045 higher WNQ for automatic transmissions compared to manual ones. Having these transmission-related effects in mind, the AVL simulation results are well in line with those from the Ricardo simulation exercise.

3.1.3. ADAC EcoTest laboratory tests

Since October 2011 the ADAC *EcoTest* procedure includes by default a NEDC, a WLTC and a special ADAC motorway cycle [4]. In total 378 passenger cars (diesel, petrol and HEV) were tested between October 2011 and July 2014. This data set represents a good mix of vehicles on the European market and allows for a separate analysis of diesel, petrol and hybrid cars. Because of the large number of available measurements, the calculated averages for these three technology categories are of especially high quality with low ranges of uncertainty.

ADAC is measuring the WLTC under hot starting conditions right after the (cold) NEDC test. Moreover, the mobile air conditioning (MAC) system is activated during the WLTC. Hence, the WLTC measurement results cannot be directly compared with those of the NEDC. Instead, a correction algorithm was developed to translate the two effects into a cold start WLTC test without MAC. For that, an average cold start effect of 12% higher CO_2 emissions was assumed over the whole NEDC[23] and downscaled to

23 ICCT internal analyses based on [5]. In fact, there is a possibility that future engines will warm up faster and that the cold start effect could therefore potentially decrease.

the WLTC taking into account the relation of the driven distances, resulting in a 5.7% cold start effect over the WLTC. This value is confirmed by direct comparisons of measured WLTC emissions under cold and hot starting conditions, included in the ERMES database (a data pooling of independent European labs) [6].

The over-consumption effect of the MAC system was determined by applying older ADAC measurement data of Euro 5 and Euro 6 cars, where NEDC results with and without active MAC can be directly compared (after a cold start correction). The derived MAC correction factors were transferred to the WLTC taking into account the relation of the mean velocities and simplistically assuming that the MAC's additional fuel consumption is constant over time and independent from the current driving situation. In this context it is helpful that the two effects (cold start and MAC) have opposing effects and almost neutralize each other, allowing for a sound correction method. Overall, the simplified assumptions result in slightly overestimated WNQs[24].

Table 5 summarizes the results based on the ADAC EcoTest data. CO_2 emission values on average are slightly higher in NEDC compared to the WLTC (1.4% for diesel cars, 2.7% for petrol cars). Both arithmetic means are highly significant because of the high number of measured cars and the relatively low scatter among individual vehicle types (uncertainty with 95% confidence: 1.0%). For the hybrid vehicles, CO_2 emissions are on average 1.5% higher than during NEDC testing. For the ADAC EcoTest data it is not possible to distinguish between vehicles with and without stop-start technology and also not between vehicles with manual or automatic transmission systems. Hybrid vehicles include both stop-start and automatic transmission functionality and it should be noted that the difference between the WNQ values presented in Table 5 could be largely driven by the fact that many of the non-hybrid vehicles tested by ADAC were manual transmission vehicles without stop-start system.

Table 5. ADAC EcoTest measurement data and resulting NEDC-WLTC conversion factors (WNQ)

Technology category	Measured vehicles	Mean WNQ	Uncertainty of the mean WNQ (95% confidence)*
Diesel—Current combustion vehicle	188	**0.986**	0.010
Petrol—Current combustion vehicle	164	**0.973**	0.010
Petrol—Current hybrid vehicle	26	**1.015**	0.052

* Twice the standard deviation of the arithmetic mean

Figure 8 includes additional results differentiated by car segments as classified by the ADAC, ranging from A (Mini cars) to F (Luxury cars). SUVs, often representing another car segment (J), are not handled separately by ADAC but are spread over the higher car segments. Mid-sized cars from segments C, D and E show significantly lower WNQs than the smaller classes A and B. For example, the averaged B segment WNQ is 6%–7% higher compared to the D segment. Larger engines benefit more from higher engine efficiencies at high-load operating points, while the operation of smaller engines already reaches relatively high efficiencies even during low load NEDC driving. This effect even overcompensates the higher percentage of manual transmissions in the lower vehicle segments, which normally would be reflected by lower WNQs.

Diesel-fueled cars tend to show slightly higher WNQs than the petrol-fueled ones for all segments, except the F segment with its high-powered engines. The diesel-petrol WNQ_E differences range from 0% to 6.5% for individual segments and amount to 1.4% for the total car fleet. However, these differences are not highly significant. Hybrid cars have the highest averaged WNQ, but the uncertainties for the hybrid results are clearly higher than for the vehicles with conventional power trains. This is because of the larger scatter among individual vehicle types (manufacturers apply very specific strategies for hybrid technologies) and the relative low number of measured hybrid vehicles.

The ADAC measurements cover only state-of-the-art vehicles and represent a mix of technologies on the market today, that is, different car segments, manual and automatic gearboxes, with and without stop-start systems, direct and port-injection petrol engines. Technically speaking these results do not allow precise projections for the targeted 2020 fleet mix, but they confirm the Ricardo and AVL simulation results for current vehicle technologies.

24 The over-consumption effect of the MAC operation under WLTC driving might be a bit lower in reality than assessed by this simplified approach because of higher engine efficiencies compared to the NEDC.

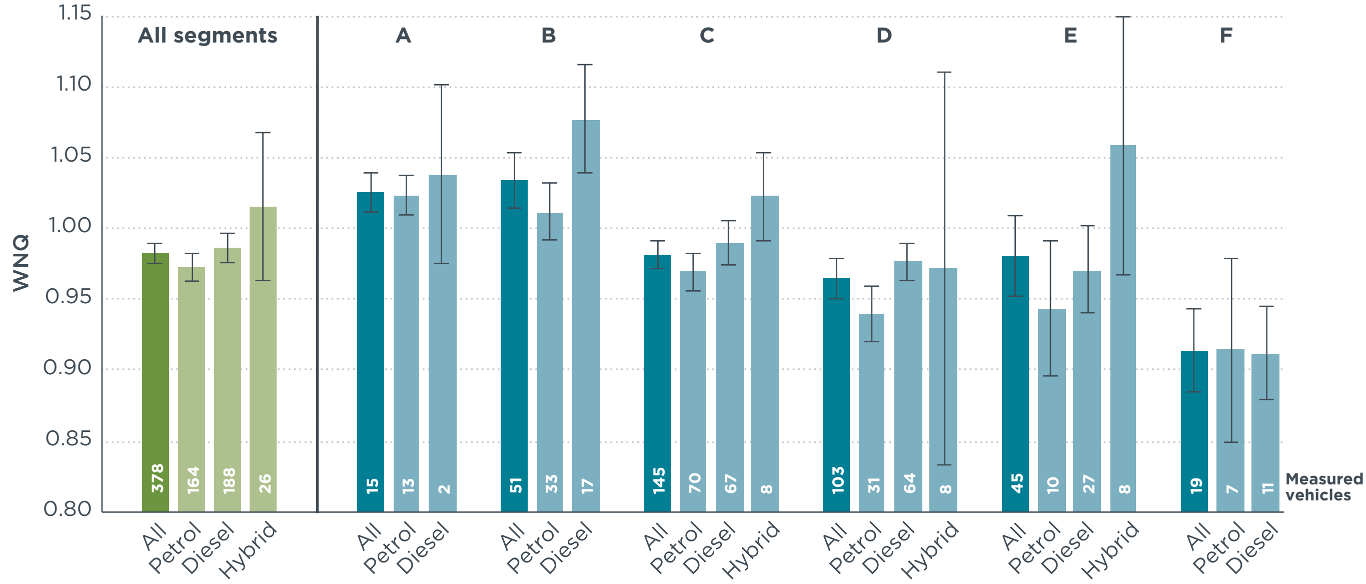

Figure 8. ADAC measurements and derived mean NEDC-WLTC correction factors, broken down by engine technologies and car segments A-F. Error bars represent 95% confidence intervals of the mean WNQs (2x StdDev of the arithmetic mean)

3.1.4. 2020 projection of driving cycle impacts

In order to allow for a translation of the 2020 EU cars' 95 g/km NEDC-based CO_2 target into one based on the WLTP, an assessment of the technical fleet composition in 2020 is necessary. From the different data sources described above, it is evident that different vehicle power train technologies and other innovative technical features (like stop-start systems) impact the conversion factors. The estimated shares of these technologies are applied for a weighted combination of the technology-separated WNQs in order to determine a unique fleet-averaged translation factor being valid for 2020. Table 6 and Table 7 summarize the underlying assumed fleet composition in 2020, based on [8,9] for the technology mix in 2013 as the reference year.

In addition to the tabulated data, it should be noted that 90% of new cars in 2020 are assumed to be equipped with stop-start technology, and 80% of diesel cars will be "advanced diesels" as defined in the Ricardo simulation analysis.

Table 6. Market shares of automotive power train technologies in EU 2020

Power train category*	Total EU market share		DI/Turbo technology penetration thereof	
	2013	2020	2013	2020
Petrol/LPG/ CNG—ICE	43%	37%	33%	80%
Petrol/LPG/ CNG—HEV	2%	8%	10%	60%
Diesel—ICE	55%	53%	100%	100%
Diesel—HEV	<< 1%	2%	100%	100%

* ICE: Internal Combustion Engine; HEV: Hybrid-electric vehicle; LPG: Liquified Petrol Gas; CNG: Compressed Natural Gas; DI: Direct Injection

Table 7. Market shares of car segments, diesel shares and automatic transmission (AT) shares in EU 2020

Car segment	Market share 2013 = 2020	Diesel share 2013 = 2020	AT share (without HEV)	
			2013	2020
A-Mini cars	10%	6%	23%	30%
B-Small cars	23%	34%	8%	15%
C-Medium cars	22%	63%	17%	25%
D-Large cars	9%	63%	39%	50%
E-Executive cars	3%	85%	80%	80%
F-Luxury cars	<1%	68%	100%	100%
J-Sport utility cars	17%	75%	24%	35%
M-Multi purpose cars	14%	81%	21%	30%
S-Sports coupés	1%	26%	50%	50%
Total	**100%**	**55%**	**22%**	**30%**

The vehicle simulation results of the Ricardo DVT, as described in Section 3.1.1, were used as the data source for the 2020 projection, as they cover a large spectrum of current and future advanced technologies for the key car segments. Technology gaps in this database, such as manual transmissions or diesel hybrid technologies, were filled by including the vehicle simulation results of the AVL study. For example, the higher benefit of manual transmissions under the WLTC in comparison to the NEDC were incorporated by deriving a correction factor for converting the WNQs from automatic to manual transmissions. The ADAC measurement results were used to validate the fleet-averaged WNQ model results of current technologies and for verification of the differences among the different car segments. Table 8 includes as an example some of the derived WNQs and the assumed 2020 technology market penetrations for the main technology classes of the C segment.

Table 8. Derived WNQs and 2020 market penetrations for the C segment

Technology class (C segment)	Manual transmissions		Automatic transmissions	
	WNQ	2020 SHARE	WNQ	2020 SHARE
Petrol, port injection, conventional	0.89	2%	0.93	1%
Petrol, port injection, stop-start	0.91	2%	0.96	1%
Petrol, direct injection, advanced turbo	1.07	18%	1.12	6%
Petrol hybrids	-	0%	1.12	7%
Diesel, conventional	0.93	5%	0.98	2%
Diesel, conventional, stop-start	0.96	4%	1.01	1%
Diesel, advanced	0.95	37%	1.00	12%
Diesel hybrids	-	0%	0.99	2%

Overall result:

The combination of the technology market shares projected to 2020 (Table 6 and Table 7) with the modelled and measured CO_2 WLTC/NEDC quotients (WNQ) results in a total passenger car fleet average WNQ for 2020 of 1.021. In other words, the technology fleet mix in 2020 will provide on average 2.1% higher levels of fuel consumption and CO_2 emissions under the WLTC driving schedule than it would have using the NEDC driving schedule.

3.2 IMPACT OF REVISIONS IN VEHICLE TEST MASS DETERMINATION

3.2.1 Influence of the vehicle test mass

The mass of a vehicle has a direct impact on its fuel consumption and CO_2 emissions. As shown in previous analyses, reducing the mass of a vehicle by 10% results in a reduction in CO_2 emissions of around 4%[25] if the engine size is not adjusted to maintain constant performance[26]. This estimate was confirmed for the Ricardo vehicle simulation model mentioned earlier in this paper. Table 9 summarizes the averaged results for current state-of-the-art petrol and diesel conventional internal combustion engine vehicles, advanced combustion type vehicles anticipated for the 2020 horizon and advanced hybrid technologies if engine size is not adjusted to maintain constant performance. In relation to a predicted average passenger car fleet in 2020, a general 10% mass reduction would result in a 4% decrease of fuel consumption and CO_2 emissions in the WLTC. Of that 4% reduction, 1.5% comes from reduced rolling resistances and 2.5% from reduced vehicle acceleration forces.

In addition, reducing rolling resistance of the tyres by 10% results in an additional 1.5% reduction in average CO_2 emissions. A 10% reduction in acceleration forces from reduced aerodynamic drag results in an additional 3% reduction in average CO_2 emissions[27].

Table 9. Impact of variations in mass, aerodynamic drag and rolling resistance on fuel consumption and CO_2 emissions in WLTC.

Technology category	-10% mass*	-10% rolling resistance	-10% aero drag
Petrol—Current combustion engine	-3.0%	-1.2%	-2.5%
Petrol—Advanced combustion (2020)	-4.3%	-1.7%	-3.3%
Petrol—Advanced hybrid (2020)	-3.6%	-2.3%	-4.1%
Diesel—Current combustion engine	-3.6%	-1.4%	-2.6%
Diesel—Advanced combustion (2020)	-3.9%	-1.4%	-2.8%
Assumed fleet average 2020	**-4%**	**-1.5%**	**-3%**

* including impact of mass reduction on rolling resistance

3.2.2 Revisions in vehicle test mass determination from NEDC to WLTP

The NEDC test procedure allows the mass of the lightest vehicle model version to be used for CO_2 compliance testing, that is, the vehicle version that does not have any optional equipment on board. To that mass 75 kg is added for the weight of the driver and luggage, plus another 25 kg. The resulting mass, called the reference mass, is used for NEDC testing to determine the CO_2 emissions of the vehicle and all vehicles of the same family.

25 http://www.theicct.org/sites/default/files/publications/WLTP_inertia_workingpaper_2011.pdf

26 Reducing mass also allows the vehicle to accelerate faster. Downsizing the engine to maintain constant performance results in additional efficiency and CO_2 reductions, which are not included in this analysis.

27 For the sake of completeness, Table 9 also includes the fuel consumption effect of reduced tyre rolling resistance and aerodynamic drags, which are used along with the vehicle mass to calculate the cycle energy demand. As there was no intent to change aerodynamic drag and tyre rolling resistance coefficients for the WLTP compared with the NEDC, only the change in how vehicle mass is calculated is considered in this paper.

In contrast to the NEDC, the WLTP procedure takes into account optional equipment and the vehicle payload when determining the actual mass of the vehicle. For practical reasons it was decided by the UNECE working group to test only two vehicle versions: (1) One vehicle that requires the least amount of energy to drive the test (i.e., in most cases the one with no optional equipment, lowest rolling resistance and least aerodynamic drag), and (2) one which has the highest energy demand of a vehicle model family (i.e., in most cases the one that has all optional equipment available on board, highest rolling resistance and greatest aerodynamic drag). For these two vehicles the actual CO_2 emissions are determined in the WLTP test. For all other vehicle model versions in between, CO_2 emissions are based on a regression line that connects the two tested model versions. Figure 9 illustrates the procedure[28]. Furthermore, instead of adding 100 kg (as in the NEDC), the WLTP requires adding 100 kg plus 15% of the maximum vehicle load within a vehicle family.

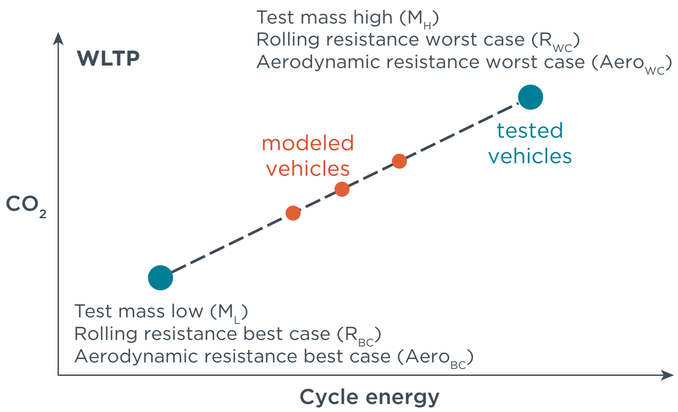

Figure 9. The influence of the vehicle test mass on cycle energy in the WLTP

As a result of this changed procedure, vehicle mass and CO_2 emissions will be more realistic in the WLTP compared to the NEDC. This is because instead of assuming the same mass (usually that of the lightest vehicle) for all vehicle variants of the same family, the actual mass (and aerodynamic drag and rolling resistance) will be determined for each vehicle version, and the actual CO_2 emission level will be calculated.

3.2.3 Impact on CO_2 of the change in mass determination

As the new procedure will increase the average vehicle weight, it will also create higher average CO_2 emissions for manufacturers when switching from NEDC to WLTP.

To quantify this effect, it is important to know the average additional mass for optional vehicle equipment (extras). Based on a previous assessment of data for the Volkswagen passenger car fleet[29], we estimate the European average maximum additional mass for optional equipment at 175 kg. Of course, not all customers order the full spectrum of available optional equipment for their vehicle. Taking vehicle price as a proxy and analyzing detailed fleet data from the commercial data provider IHS-Polk [9], we find that on average about 40% of available optional equipment is ordered by the customers. Combining these two estimates, we arrive at an expected increase in vehicle weight due to taking into account optional equipment of around 70 kg in the WLTP.

In addition, 15% of the maximum vehicle load is taken into account in the WLTP, representing the *mass representative of the vehicle load* (L):

$$L = 0.15 * (\text{Max. laden mass} - (\text{Mass in running order} + 25\text{ kg} + \text{Average mass of extras}))$$

The average *technically permissible maximum laden mass* in 2012 was 1,860 kg, while the average *mass in running order* amounted to 1,400 kg[30]. This then results in an average maximum payload of 460 kg (in addition to the driver but without considering extras), from which 25 kg and 70 kg (average mass of extras) are subtracted for a useable payload of 365 kg and a *mass representative of the vehicle load* of around 55 kg.

Adding both weight increases (optional equipment and additional payload), we expect an increase in vehicle weight in the WLTP of around 125 kg (test mass of 1550 kg compared to 1425 kg), an overall increase of 8.8% compared to the NEDC. Considering a 4% CO_2 sensitivity for a 10% mass change, the impact on fuel consumption and CO_2 emissions therefore is 3.5%.

3.3 THE INFLUENCE OF AMBIENT TEMPERATURE ON CO_2 EMISSIONS DURING A COLD START

Typical temperatures for engine coolants and lubricants during the regular operation of a vehicle range between 90 °C and 110 °C. After some hours of parking, engine temperature will slowly decrease toward the (lower) ambient temperature, and after restarting it will take some time for the engine to heat up again. During this heat-up period—usually the first few kilometres driven—friction losses are higher than during normal operation and therefore fuel consumption and CO_2 emissions also

28 For more details, see also http://www.theicct.org/sites/default/files/publications/WLTP4_2011.pdf

29 For details see http://www.theicct.org/sites/default/files/publications/WLTP3_2011.pdf

30 Mock, P.: European vehicle market statistics. Pocketbook 2013. The International Council on Clean Transportation (ICCT) Europe. 2013. http://eupocketbook.theicct.org

are higher. This cold start effect is also part of the type-approval regulations. The testing vehicle is preconditioned in a soak area at constant ambient temperature before the actual measurements take place.

The effect of the cold start in terms of additional g/km CO_2 depends on the starting temperature of the engine and the overall driven distance in the test cycle. A lower temperature at engine start means higher emission levels, but the longer the test cycle the more of these additional emissions are levelled by operating the engine at normal, higher temperatures. The relative effect of a cold start will therefore be lower for a test cycle with a longer driving distance.

As discussed in Section 3.1, above, the WLTP is more than twice as long as the NEDC and, thus, the cold start impacts are much lower on the WLTP. The impact of this different cycle length on CO_2 emissions from the cold start was included in the computer simulations presented in Section 3.1. However, these computer simulations assumed that the same ambient temperature would be used for the NEDC and the WLTP. If different ambient temperatures are used, then an additional adjustment is needed.

For the NEDC, studies are available quantifying the effect of temperature on emission levels [5,6,7]. Figure 10 summarizes the results to depict the influence of the engine start temperature on the relative changes of distance based CO_2 emissions (in g/km) over the NEDC driving cycle. A starting temperature of 23 °C is set as the baseline, as this represents typical testing conditions during NEDC type-approval measurements. From this baseline, the CO_2 emissions for cold start increase by 19% (i.e., higher CO_2 emissions) as the starting temperature drops to -7 °C and CO_2 emissions decrease by up to 12% (i.e., lower CO_2 emissions) for starting the vehicle with a hot engine.

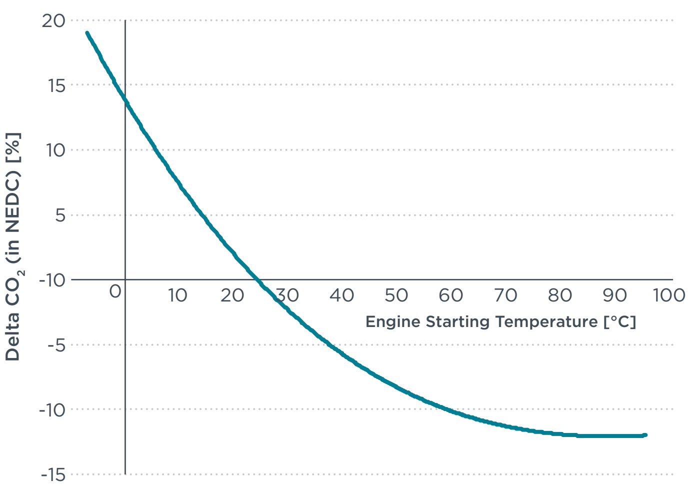

Figure 10. Impact of engine starting temperature on CO_2 emissions. Delta percentage is related to 23°C and to distance-based NEDC results (11.03 km). [5,6,7]

In the NEDC, the test temperature is set to range between 20 °C and 30 °C. The WLTP is somewhat more precise in its definition, setting the test temperature at 23 ±5 °C[31]. In the extreme case that a manufacturer tested its vehicle at a temperature of 29 °C in NEDC but is forced to lower the test temperature now to 23 °C in the WLTP, the result would be somewhat higher CO_2 emission levels for those vehicles. However, there is wide agreement among experts that testing a vehicle at these high temperatures in the NEDC is, and always has been, clearly against the original intention of the regulator and that this behaviour should therefore not be rewarded when switching from NEDC to WLTP.

If the reference temperature is lowered below the new WLTP set point of 23 °C this would be a new testing condition that should be accounted for. The EU has announced it is planning to introduce a temperature correction at the European level, thereby adapting the test temperature to 14 °C, which is much more representative of the average temperature in Europe. It is not clear at the moment if this regional temperature correction will come into effect at the same time as the introduction of WLTP in the EU.

To estimate the effect of lowering the test temperature from 23 °C to 14 °C, the first step is to assess the impact in the NEDC, based on the relationship shown in Figure 10. The additional emission level at 14 °C is 4.5%.

The second step is to take into account that the driven distance of the WLTC is longer than the NEDC and the cold start effect therefore is lower. To convert the NEDC distance-based cold start effect into a WLTC-based one, apply a factor consisting of the ratio of the driven distances of both cycles:

$$\text{Delta } CO_{2\ \text{WLTC}}\ [\%] = \text{Delta } CO_{2\ \text{NEDC}}\ [\%] * \frac{11.03\ \text{km}}{23.27\ \text{km}}$$

The temperature correction applied to the WLTC would therefore amount to 2.1%, taking into account the ratio of the driven distances of both cycles.

Finally, it is important to note that heat storage devices (like engine compartment encapsulations or active heat

31 The WLTP GTR in its current version (14.09.2014) is rather precise concerning the 23 °C set point at the soak area, where no systematic deviations of the ambient temperature over time are allowed. However, the conditions for the dynamometer test cell are much less precise. Here, a tolerance of ±5 °C is allowed (reduced to ±3 °C only at the start of test), no minimum duration of the vehicle's retention time in the test cell before test start is defined, and no control measurements of engine coolant and lubricant temperatures before the test start are foreseen. Altogether, these tolerances and definitions could allow for an "after-soak" conditioning phase in the test cell to heat up the engine again to 28 °C before testing.

storage systems) delay the cool-down behaviour of engines after shutdown. Therefore, the engine temperature at restart will be higher compared to conventional (uninsulated) engines. The engine heating-up during the next trip will be faster, and CO_2 emissions will be lower. Any use of heat storage devices should be properly credited during vehicle testing as currently planned by the EU when adopting the WLTP. Such a new regulation will acknowledge the positive environmental effect of such devices and will allow testing at higher temperatures. However, these rather new technologies are not expected to reach a significant market penetration within the next few years. For the 2020 fleet mix we assume a 10% penetration for passenger cars, allowing for an increased starting temperature of 10 °C on average[32].

These vehicles were not taken into account for the calculation of the temperature correction effect. Altogether, a total 2020 fleet average temperature correction effect of 1.9% (= 0.9 * 2.1%) therefore seems most appropriate should the EU go ahead with changing the ambient temperature for the WLTP to 14 °C.

3.4 TOTAL IMPACT OF SWITCHING FROM NEDC TO WLTP FOR A 2020 VEHICLE FLEET

Table 10 summarizes the estimated average effect of switching from NEDC to WLTP, following the assessment as described in the sections above. The relative impacts of the three different regulatory issues are connected multiplicatively, which adds up to a total of 5.7% if a temperature correction is not taken into account (i.e., if the test temperature remains at 23 °C) and 7.7% if the test temperature is lowered to 14 °C. As explained earlier, this estimate is based on the expected technology fleet mix in the EU in 2020. Figure 11 illustrates the estimated effect both in percentage terms and if applied to an absolute target of 95 g/km in the NEDC. The resulting target value in WLTP would then be 100 g/km (without temperature correction) and 102 g/km (including temperature correction).

32 See also Daimler Eco-innovation on engine compartment encapsulation approved by the European Commission: http://ec.europa.eu/clima/policies/transport/vehicles/cars/documentation_en.htm

Table 10. Total estimated impact of switching from NEDC to WLTP for a 2020 vehicle fleet

Regulatory issue	NEDC	WLTP	Impact on CO_2 emissions
Driving cycle	Operation at low loads with low engine efficiency, higher cold start effect (shorter distance), higher engine speeds (manual transmissions)	Higher speeds and acceleration forces, lower vehicle stop share (stop-start systems)	+ 2.1%
Vehicle mass	No optional equipment No additional payload	Optional equipment: 70 kg Additional payload: 55 kg	+ 3.5%
Temperature	Engine start temperature: 23 °C	Engine start temperature: 14 °C	+ 1.9%
Total impact 14 °C			**+ 7.7%**
Total impact 23 °C			**+ 5.7%**

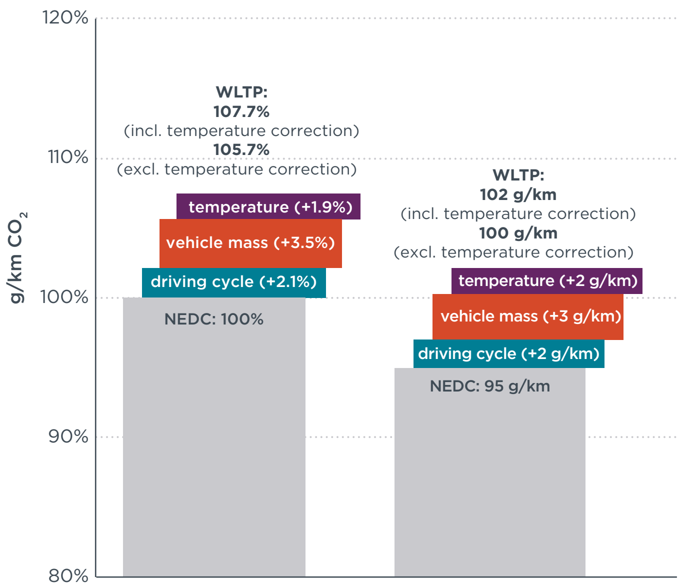

Figure 11. Graphical illustration of estimated impact from switching from NEDC to WLTP

It should be noted that from a customers' perspective, the effect of the transition from NEDC to WLTP will likely be higher than expressed by the estimate above. This is because manufacturers today, to some extent, make use of the additional flexibilities provided in the NEDC regulation. Even though this is not illegal, strictly speaking, it contradicts the intentions of the original NEDC regulations. When switching from NEDC to WLTP, which limits these flexibilities and closes “loopholes” in the NEDC procedure, CO_2 emission values will become more representative of real-world driving and customers will benefit from these improved values. It is not the intention of the regulator to reward manufacturers for making use of unintended NEDC flexibilities, which is why it would be inappropriate to take this effect into account for determining the NEDC-WLTP conversion factor.

Test temperature is a good example of such a flexibility. In the NEDC, the test temperature is set to range between 20 °C and 30 °C. If manufacturer A exploits the given tolerance and tests its vehicles at temperatures close to 30 °C and manufacturer B tests at temperatures around 25 °C, then manufacturer A would have a competitive advantage over manufacturer B, as the resulting CO_2 emissions for higher temperatures are lower. Although not illegal, the behaviour of manufacturer A is not in line with the original intention of the legislator who could not foresee that temperature control in the labs would be so advanced that reliable testing at temperatures close to 30 °C would be possible. For a NEDC-WLTP conversion factor the original intention of the NEDC regulation should be considered, not what is made possible by the current state-of-the-art technology.

Other examples include tyre and aerodynamic resistance for vehicles. In both cases it is possible to interpret the NEDC regulation in such a way that an unrepresentative special coast-down vehicle with especially low tyre rolling resistance and optimized aerodynamics is tested, although in-production vehicles are sold with a different set of tyres and different aerodynamic characteristics and therefore have clearly higher driving resistances. In the WLTP, these flexibilities will be eliminated to some extent and CO_2 emission values will increase. Nevertheless, as for the temperature example, these aspects should not be taken into account for the NEDC-WLTP conversion factor, as it would mean rewarding manufacturers for taking advantage of regulatory “loopholes”.

Similarly, the NEDC does not include any balancing of the state of charge (SOC) of the vehicle battery between end and start of a chassis dynamometer test. The technical capabilities for measuring the SOC were not given, and the legislator was not aware of the consequences at that time. Although not illegal in NEDC, it is clearly against the intention of the regulator to fully charge the battery before the test takes place, and therefore it should not be taken into account when switching to WLTP, where more precise definitions for the balancing of the SOC are included.

It should also be noted that when testing current vehicles designed for the NEDC on the WLTP, the differences observed are likely to be higher than the conversion factors derived here. The reason is that current vehicles are optimized for the NEDC, while their performance is comparably bad when applying WLTP testing conditions. For a valid comparison, it would be necessary to test a vehicle that is optimized (in terms of engine strategy, etc.) for NEDC and the same vehicle after reoptimizing it for the WLTP. Note that such a comparison based on vehicle testing is illusive, given that a manufactured vehicle will always be optimized to one test cycle only. This is why the approach favoured by the European Commission and technical experts is vehicle computer simulations, such as the Ricardo-AEA and AVL simulations, referred to in this paper, where equivalent optimization is easier to ensure.

4. Next steps for the practical implementation of the WLTP in the EU

As explained in Section 1, the WLTP was adopted at the U.N. level in March 2014 and is currently being prepared for conversion into a UNECE regulation. In parallel, the European Commission is preparing for the implementation of the WLTP in the EU, aiming for introducing the WLTP for type approval of new vehicles from 2017 on. In Section 3 it was estimated that the effect of the WLTP on the EU CO_2 target value will be an increase of around 5%–8% (5.7% without temperature correction and 7.7% with).

While the WLTP needs to be introduced in the EU as quickly as possible, in order to replace the technically outdated NEDC testing scheme, it is important to allow for sufficient lead time for manufacturers to adapt to the new testing conditions. Therefore, testing should continue to use the NEDC until 2017, allowing the 2015 CO_2 target of 130 g/km to remain unchanged. This seems especially sensible, given that the 2015 target was already exceeded in 2013, when the new vehicle fleet average dropped to 127 g/km.

The next step would be to add the WLTP for type approval testing of new vehicles in 2017, such that new vehicles would be tested both in NEDC and WLTP. The legally binding values for the CO_2 monitoring would remain the NEDC results. At the same time, the WLTP test results would be the basis for customer information (sales brochures and CO_2 labelling) and eventually national tax regulations, thereby creating a strong incentive for manufacturers to optimize their vehicles for the WLTP. This would allow regulators and manufacturers to collect more experience with the effects of the WLTP and to prepare for the full switch to WLTP without revising the binding CO_2 target of 130 g/km for 2015-2019. Given that this target was already met on average in 2013, it seems highly unlikely that any manufacturer will not meet it in the 2015-2019 time range, be it in NEDC or WLTP testing conditions. Therefore, translating this target from NEDC in WLTP for the 2015-2019 time range does not seem necessary (Figure 12).

From 2020 on, new vehicles would be tested in the WLTP only, and CO_2 emission targets would have to be met in the WLTP. For this, it is necessary to translate the existing 95 g/km NEDC-based target into an equivalent WLTP-based target. As shown in Section 3 of this paper, the resulting WLTP-based target value for the fleet average is estimated to be 100 g/km (without temperature correction). The EU CO_2 regulation includes a one-year phase-in period, requiring that only 95% of new car sales in 2020 comply with the CO_2 target, that is, the 5% of vehicles with highest CO_2 emission levels will not be counted in 2020 when determining whether a manufacturer met its target or not. This flexibility, together with the 2017-2019 double-testing period, and also the time frame between adoption of the EU-WLTP and its introduction for type-approval in 2017 will allow manufacturers a six-year lead time before fully switching to WLTP from 2021 on.

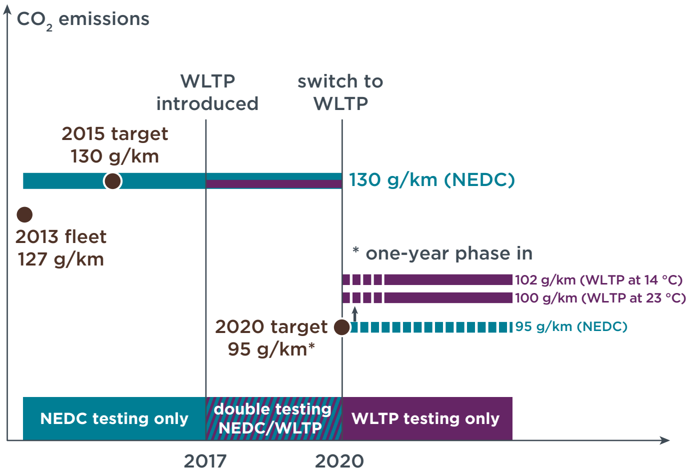

Figure 12. Schematic illustration of timeline for implementation of the WLTP in the EU

Abbreviations

acc	Vehicle acceleration
ADV	Advanced 2020/25 technology package
$Aero_{BC}$	Aerodynamic resistance Best Case within a vehicle family
$Aero_{WC}$	Aerodynamic resistance Worst Case within a vehicle family
AT	Automatic transmission (with x gears)
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
DI	Direct Injection
DVT	Data Visualization Tool
EPA	United States Environmental Protection Agency
ERMES	European Research on Mobile Emission Sources
EU	European Union
EUCAR	European Council for Automotive R&D
EUDC	Extra Urban Driving Cycle (subcycle of NEDC)
FTP	Federal Test Procedure
GRPE	Working Party on Pollution and Energy (UNECE)
GTR	Global Technical Regulation
HEV	Hybrid Electric Vehicle
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
ITF	International Transport Forum
JC08	Japanese test Cycle (2008)
LPG	Liquified Petrol Gas
MAC	Mobile Air Conditioning
M_H	Highest test mass within a vehicle family
M_L	Lowest test mass within a vehicle family
NEDC	New European Driving Cycle
NGO	Non-governmental organization
PFI	Port Fuel Injection
R_{BC}	Rolling resistance Best Case within a vehicle family
RLD	Road Load Determination
RRC	Rolling Resistance Coefficient
R_{wc}	Rolling resistance Worst Case within a vehicle family
SOC	State Of Charge of the vehicle battery
SS	Stop/start system
SS+	Stop/start system + improved alternator + regenerative braking
TCMV	Technical Committee on Motor Vehicles
UDC	Urban Driving Cycle (subcycle of NEDC)
UNECE	United Nations Economic Commission for Europe
U.S.	United States of America
vel	Vehicle velocity
WLTC	Worldwide harmonized Light-duty Test Cycle
WLTP	Worldwide harmonized Light vehicles Test Procedure
WNQ	WLTC-NEDC quotient of CO_2 emissions

References

[1] Kasab, J., Shepard, D. & Velliyiur, S. (25 January 2013). *User guide for Data Visualization Tool*. Washington DC: Report of Ricardo Inc. on behalf of the International Council on Clean Transportation.

[2] Kasab, J. (30 January 2013). *Analysis of greenhouse gas emission reduction potential of light duty vehicle technologies in the European Union for 2020-2025*. Washington DC: Supplemental project report of Ricardo Inc. on behalf of the International Council on Clean Transportation.

[3] Morra, E., Ellinger, R., Jones, S., Huss, A. & Albrecht, R. *Tank-to-Wheel CO_2 emissions of future C-segment vehicles*. AVL, Graz, Austria. Lecture given at "Der Antrieb von morgen 2014, 9. MTZ-Fachtagung", 28-29 January 2014, in Wolfsburg, Germany.

[4] ADAC, Munich, Germany: *EcoTest chassis dynamometer measurements of passenger cars*. Charged data provided to ICCT on 11 July 2014.

[5] *The Handbook Emission Factors for Road Transport (HBEFA)*. (July 2014). Database issued by INFRAS, Bern, Switzerland. Version 3.2. http://www.hbefa.net/e/index.html.

[6] Ligterink, N., van Mensch, P., Cuelenaere, R., Hausberger, S., Leitner, D. & Silberholz, G. (5 August 2014). *Correction algorithms for WLTP chassis dynamometer and coast-down testing*. TNO-rapport—concept. https://circabc.europa.eu/w/browse/4f56a84c-6a9f-4be7-978f-c0881e769be1.

[7] Willner, K. & Taylor, G. (2 March 2011). *Swedish In-Service Testing Programme 2011 on emissions from passenger cars and light duty trucks*. Emissions from Light Duty Diesel Vehicles tested at low ambient temperature Test report by AVL MTC AB Certification & Regulation Compliance. On behalf of the Swedish Transport Agency. http://www.transportstyrelsen.se/Global/Vag/Miljo/Kalltemperatur2011.pdf

[8] Monitoring of CO_2 emissions from passenger cars—Regulation 443/2009. EU data base 2013 (provisional data). Issued by European Environment Agency (EEA), Copenhagen, Denmark. http://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-6

[9] IHS-Polk data as a basis for ICCT *European Vehicle Market Statistics Pocketbook 2013*. http://www.theicct.org/european-vehicle-market-statistics-2013