European Commission

Scientific Advice Mechanism (SAM)

Closing the gap

between light-duty vehicle real-world CO_2 emissions and laboratory testing

High Level Group of Scientific Advisors

Scientific Opinion No. 1/2016

Research and Innovation

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Scientific Opinion 01

Brussels, 11 November 2016

2016 Directorate-General for Research and Innovation

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The High Level Group Members Elvira Fortunato, Dame Julia Slingo and Henrik C. Wegener were in charge of developing this Scientific Opinion which has been endorsed by the full Group.

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EXECUTIVE SUMMARY

The CO_2 emission standards for light-duty vehicles represent a key element of EU policies for the decarbonisation of transport. Under the current New European Driving Cycle (NEDC) laboratory-based test regime there has been a significant and growing gap between the CO_2 emissions of light-duty vehicles certified at type approval and their average real-world emissions. This may undermine the effectiveness of EU regulations designed to lower CO_2 emissions, affect national taxation and mislead consumers. The World-wide harmonized Light vehicles Test Procedure (WLTP) is based on a more realistic laboratory test cycle and will be introduced in the EU in September 2017. It is expected to substantially reduce, but not eliminate this gap.

The European Commission intends to present in 2017 a proposal for post-2020 emission performance standards for light-duty vehicles based on the WLTP. In order to underpin this policy initiative, the High Level Group of Scientific Advisors has been asked to provide scientific advice for improving the measurement of light-duty vehicle CO_2 emissions by addressing two separate questions:

- *What is the European and worldwide scientific basis for improving the measurement of light vehicle CO_2 emissions and fuel consumption in order to produce values closer to average real-world data?*
- *Which approaches might be considered, what are their strengths and weaknesses, also in terms of reliability and transparency, and what additional scientific and analytical work would be needed?*

This Scientific Opinion provides evidence-based answers drawn from a detailed literature review, a visit to a vehicle emissions laboratory, a scientific expert workshop and a stakeholders meeting. It concludes that:

- In order to ensure the representativeness of the type approval test, a framework for the monitoring of real driving CO_2 emissions is required. This should consist of an exploitation of CO_2 data obtained from real driving emissions testing for pollutants using Portable Emissions Measurement Systems (PEMS), the development of a targeted *ex-post* Real Driving Emissions (RDE) methodology for CO_2, and the introduction of a formal reporting of fuel consumption from on-board vehicle diagnostic systems.

- In order to grow the trust of the consumer in the regulatory system and the car industry, and to guarantee a level playing field for car manufacturers, a number of framework conditions must be met. These include in particular the strengthening of regulatory oversight and technical capacity in Europe, and increased transparency of the whole process.
- Legislation on CO_2 emissions from road transport should be designed in a way that stimulates innovation and is able to adapt to the increasing take-up of new technologies such as plug-in hybrid and electric vehicles.
- The assumption that CO_2 emissions measured with the WLTP will be closer to real-world emissions is reasonable. However, while the WLTP has the potential to become a common reference globally, its further development is recommended with a formal review every five years to ensure that the gap between laboratory and real-world emissions is not growing.

Implementation of all these recommendations will enable the EU and its citizens to have a more complete understanding of the contribution of light-duty vehicles to the EU's carbon emissions and provide incentives to move as quickly as possible to a low carbon future.

Additional scientific and analytical work is particularly needed in the following areas:

- Assessment of the extent to which CO_2 emission data obtained from the RDE procedure for pollutants can be used to monitor the gap;
- Development of a targeted *ex-post* RDE methodology for CO_2 complementary to the WLTP in order to monitor the gap;

- Development of standardised and accurate on-board diagnostic systems for fuel consumption monitoring, data management and data analytics;
- Development of additional methods to capture the full life cycle of carbon emissions related to new types of vehicles powered by energy sources other than diesel and petrol.

1 – INTRODUCTION

Within the EU, transport is responsible for around 20% of greenhouse gas emissions, rendering it the second largest emitting sector after the energy industry. Within the transport sector, 94% of those emissions come from road transport and in particular light-duty vehicles[1]. The need to reduce greenhouse gas emissions to avoid dangerous climate change was emphasized again at the COP21 climate conference in Paris where an intenational agreement to limit global temperature rise since pre-industrial times to below 2°C and preferably nearer 1.5°C was agreed, placing stringent limitations on carbon emissions. The EU has set its own emissions targets and as part of those it seeks to reduce emissions from the road transport sector.

In 2009 mandatory reductions were introduced by regulation, setting emission performance standards for new passenger cars. In 2014, these were extended to 2021 and made more stringent. Car manufacturers are thus obliged to ensure that the new passenger car fleet of the EU will emit on average not more than 95 g CO_2/km as of 2021. Adherence to these regulations is verified through laboratory testing of new vehicles following an agreed driving cycle, which seeks to determine the CO_2 emissions under standardised average driving conditions. However, over time it has become clear that the flexibilities within the laboratory test have been increasingly exploited to genrate the best possible emission values, with the result that the gap between declared CO_2 emission rates and those under real driving conditions has widened substantially.

The effect of this increasing gap is (i) undermining EU commitments to reducing carbon emissions, (ii) misleading the consumer in terms of vehicle performance, (iii) compromising legislation on vehicle taxation designed to incentivise the uptake of low carbon, fuel efficient vehicles; and (iv)

[1] See http://ec.europa.eu/eurostat/statistics-explained/index.php/Sustainable_development_-_transport#Greenhouse_gas_emissions_from_transport

potentially slowing down the pace of technological innovation necessary for the transition to a low carbon transport system.

Consequently, there is an urgent need to find more robust methods for setting standards and monitoring carbon emissions from light-duty vehicles to underpin future policies and legislation designed to reduce the EU's overall carbon emissions and to incentivise the uptake of low carbon technologies.

2 – AIM AND SCOPE OF THE SCIENTIFIC OPINION

The carbon dioxide (CO_2) emission standards for light-duty vehicles represent a key element of EU policies for the decarbonisation of transport. However, under the current test regime there is a significant and growing gap between the CO_2 emissions of light-duty vehicles certified at type approval (which are measured by laboratory testing) and their average real-world emissions. This may undermine the effectiveness of EU regulations designed to lower CO_2 emissions, as well as affecting national taxation and misleading consumers.

Contrary to the legislation for pollutants, such as particles or nitrogen oxides (NO_x), which applies to every single vehicle, under the current legislation CO_2 emission limits are set for each manufacturer - more precisely for the average emission performance (according to type approval values) of each manufacturer's fleet of new vehicles sold in a given year. In addition, to help drivers choose new vehicles with low fuel consumption, EU Member States are required to ensure that relevant information is provided to consumers, including a label showing a vehicle's fuel efficiency and CO_2 emissions. Again, those values are based on type approval laboratory measurements.

With the adoption of Regulation 333/2014, the EU sent a signal towards basing the subsequent post-2020 targets on the new World-wide harmonized Light vehicles Test Procedure (WLTP), a laboratory test procedure which is expected to be much closer to real-world CO_2 emissions than the current New European Driving Cycle (NEDC) laboratory test. The WLTP will be progressively applied from September 2017. However, while the new legislation for pollutants foresees verification of laboratory-based measurements of pollutants through Real Driving Emissions (RDE) testing, this is not the case for CO_2 emissions.

The High Level Group of Scientific Advisors, established under the European Commission's Scientific Advice Mechanism (SAM), has therefore been asked to provide scientific advice for improving the measurement of light-duty vehicle CO_2 emissions in terms of accuracy, reliability and transparency. Specifically, the European Commission has asked the SAM High Level Group to answer the following two questions in its Scientific Opinion:

- *What is the European and worldwide scientific basis for improving the measurement of light vehicle CO2 emissions and fuel consumption in order to produce values closer to average real-world data?*
- *Which approaches might be considered, what are their strengths and weaknesses, also in terms of reliability and transparency, and what additional scientific and analytical work would be needed?*

This Scientific Opinion provides answers to the two questions as follows: Following an executive summary, an introduction to the topic (chapter 1) and an outline of the aim and scope of the Scientific Opinion (chapter 2), the text describes first the methodology used (chapter 3) and explains the EU policy framework and regulatory environment (chapter 4). This is needed to understand the context in which this Scientific Opinion has been prepared. Chapter 5 analyses the problem and the state of the art by explaining the current and future test cycles used at type approval (NEDC and WLTP), by comparing the situation in the EU with the one in the United States of America (US), and by describing the origin, characteristics and evolution of the gap between laboratory measurements and real-life emissions, which triggered the request of the European Commission to the SAM High Level Group. Chapter 6 assesses the different options to close the gap, in particular RDE testing, the monitoring of fuel consumption using on-board diagnostics, the use of data reported by consumers, as well as modelling and correction algorithms. Chapter 7 offers a set of conclusions for the policy-maker. A glossary, a list of the experts consulted, a list of the references quoted in this Scientific Opinion as well as of all other written evidence used, and suggestions of websites for further reading can be found in chapter 8.

3 – METHODOLOGY

Following the request for a Scientific Opinion submitted on 04/12/2015 by the EU Commissioner for Climate Action and Energy Miguel Arias Cañete to the EU Commissioner for Research, Science and Innovation Carlos Moedas, a scoping paper was prepared under the leadership of the European Commission's Directorate-General for Climate Action (DG CLIMA) in close cooperation with the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) and the Secretariat of the European Commission's Scientific Advice Mechanism. The purpose of the scoping paper[2] was to describe the issue under consideration together with its regulatory context and to formulate the precise questions to be answered by the SAM High Level Group. At its meeting on 29/01/2016, the SAM High Level Group accepted the task following a presentation by the Director-General for Climate Action Jos Delbeke, subject to some minor clarifications which were subsequently answered by DG CLIMA. The SAM High Level Group endorsed the scoping paper, which was published on 11/02/2016 on the SAM website, and entrusted the High Level Group members Henrik Wegener, Elvira Fortunato and Dame Julia Slingo to lead the development of the Scientific Opinion.

The evidence gathering process consisted of four different elements:

Review of the scientific literature

An extensive review of the scientific literature on the matter was carried out by staff of the SAM Secretariat during the period February to May 2016. The exercise included a review of the peer-reviewed scientific literature in the field of CO_2 emissions from light-duty vehicles using the Web of Science and Scopus databases. In addition, the SAM Secretariat gathered and reviewed relevant policy reports and studies published by the European Commission's Joint Research Centre (JRC), other Commission services, non-governmental organisations (such as the International Council on Clean Transportation

[2] See https://ec.europa.eu/research/sam/pdf/meetings/hlg_sam_012016_scoping_paper.pdf#view=fit&pagemode=none

ICCT or the European Federation for Transport and Environment T&E) and industry, on condition that these were publicly accessible. The literature review enabled the SAM High Level Group to break down the Commission's request into more detailed questions and to identify the most relevant experts in the field. An overview of the consulted literature can be found in chapter 8.4.

Laboratory visit

The Chair of the SAM High Level Group Henrik Wegener visited on 04/03/2016 the Vehicle Emissions Laboratory (VELA) at the European Commission's Joint Research Centre (JRC) in Ispra, Italy, which is one of the world-leading laboratories in the field. This was followed by presentations by JRC experts, with Dame Julia Slingo participating via video link. The visit helped the SAM High Level Group to understand the JRC's role in the development of EU legislation on vehicle emissions, and gave it a hands-on introduction to the technical challenges of measuring CO_2 emissions from cars.

Scientific expert workshop

The SAM High Level Group organised a scientific expert workshop at the Nova University of Lisbon, on 7-8/06/2016, which was attended by 17 European experts, the three High Level Group members tasked with the Scientific Opinion and four members of the SAM Secretariat. The experts were selected by: a) identifying the ten most-cited European researchers in the field; b) inviting the European Council of Applied Sciences, Technologies and Engineering (Euro-CASE), the European Academies Science Advisory Council (EASAC) as well as All European Academies (ALLEA) to nominate additional experts, thus enhancing the breadth of expertise and the geographic coverage of workshop participants; and c) identifying relevant experts from industry and non-governmental organisations – not however as representatives of their organisations, but in their personal capacity based on scientific-technical merit (*e.g.* relevant publications, patents). In addition, a leading expert from the US Environmental Protection Agency provided a presentation via video link, thus enriching the discussions with a view from outside Europe. Two representatives of DG CLIMA and DG GROW participated as observers. The agenda, participant list and minutes of the workshop as well as all the presentations given by the experts have been published on the SAM website[3].

Stakeholder meeting

As the last step in evidence gathering, a stakeholder meeting was organised in Brussels on 15/09/2016, which was attended by 19 stakeholder organisations. These included policy stakeholders (different services of the European Commission, the European Parliamentary Research Service and OECD), associations representing business stakeholders (associations of car manufacturers, automotive suppliers and certification bodies), civil society stakeholders (consumer associations, automobile clubs, as well as non-governmental organisations active in the field of climate and transport), and scientific stakeholders (academy networks). A full list of participating stakeholders can be found on the SAM website[4]. The stakeholder meeting was organised to gather comments on the issues that were identified during the scientific discussions at the Lisbon workshop. The stakeholder meeting was held in a very constructive atmosphere and provided the opportunity to fill some remaining knowledge gaps, especially related to the political process as well as the technical feasibility of potential solutions, such as using fuel consumption meters and other on-board diagnostics.

Upon conclusion of the evidence gathering process, the three High Level Group members tasked with leading the work reviewed the evidence and developed the Scientific Opinion with the support of the SAM Secretariat. Initial findings were presented to the EU Commissioner for Climate Action and Energy Miguel Arias Cañete at a meeting of the SAM High Level Group on 28/09/2016. The Scientific Opinion was subsequently finalised, adopted by the SAM High Level Group and submitted to the European Commission on 11/11/2016, as requested.

[3] See https://ec.europa.eu/research/sam/index.cfm?pg=co2emissions
[4] See https://ec.europa.eu/research/sam/index.cfm?pg=co2emissions

4 – EU POLICY FRAMEWORK AND REGULATORY CONTEXT

This section describes the EU policy framework currently in place regarding the CO_2 emissions of light-duty vehicles. It presents the main approved pieces of EU legislation for both passenger cars and light commercial vehicles (together known as light-duty vehicles). It also describes some key elements of ongoing legislative initiatives which are considered relevant for this Scientific Opinion.

The NEDC laboratory test is presently used at type approval to certify emission and fuel consumption values of light-duty vehicles. As of 2017, the NEDC laboratory test will be replaced by the WLTP, which is also laboratory based.

The WLTP, supported by the EU and Japan, was developed by a dedicated working group under the umbrella of the United Nations Economic Commission for Europe (UNECE)[5] and was adopted by the UNECE in March 2014. It aims to reflect more accurately real-world driving and to harmonise emissions testing across the globe. The new WLTP is expected to start being applied in the EU for new type approval tests in September 2017. As of 2018 all new vehicle types, apart from the end-of-series, will be type approved under the WLTP.

The European Commission intends to present in 2017 a proposal for post-2020 CO_2 emission performance standards for light-duty vehicles, based on the WLTP. The European Commission's stated aim is to set an emission reduction trajectory up to 2030, while taking into account the competitiveness of car manufacturers and suppliers to the automotive industries.

The introduction of the WLTP for light-duty vehicles affects two Regulations - Regulation (EC) 443/2009 for passenger cars, amended by Regulation

[5] See https://www2.unece.org/wiki/pages/viewpage.action?pageId=2523179

333/2014, and Regulation (EU) 510/2011 for light commercial vehicles, amended by Regulation 253/2014. These two regulations define the average pan-European CO_2 fleet emission targets for all vehicles sold, which have to be reached by 2015 and 2020 (light commercial vehicles) and 2021 (passenger cars). These fleet average targets are 130 g CO_2/km and 95 g CO_2/km for passenger cars, and 175 g CO_2/km and 147 g CO_2/km for light commercial vehicles, respectively.

In order to reach these pan-European targets, emission limits are set for each manufacturer according to the average mass of their vehicles, using a limit value curve. The limit value curve means that fleets composed of heavier cars are allowed higher emissions than fleets composed of lighter cars. As only the fleet average is regulated, a manufacturer is permitted to sell vehicles with CO_2 emissions above the individual limit provided these are balanced by vehicles with emissions below this value. Taking into account that the agreed targets under the current legislation refer to the NEDC test procedures, until 2020 all WLTP measured values will need to be converted into NEDC values.

The Regulations (EC) No 443/2009 for passenger cars and (EU) No 510/2011 for light commercial vehicles require each Member State to record information for each new vehicle registered in its territory. Every year, each Member State has to submit to the Commission all the information related to new registrations. The European Environment Agency (EEA) collects data on all new vehicles registered in Europe and makes these available online[6]. In particular, the following details are required for each new passenger car registered: manufacturer name, type approval number, type, variant, version, make and commercial name, specific emissions of CO_2, mass of the vehicle, wheel base, track width, engine capacity, fuel type and fuel mode. Additional information such as engine power is also submitted.

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[6] See http://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-10

The Car Labelling Directive (Directive 1999/94/EC) aims to raise consumer awareness of the fuel consumption and CO_2 emissions of new passenger cars. As a demand-side policy, this Directive is considered to be an important complementary measure to help car manufacturers meet their specific CO_2 emission targets as set under Regulation (EC) 443/2009. *Inter alia*, this Directive requires: i) a label showing fuel economy and CO_2 emissions to be attached to all new cars or displayed nearby at the point of sale; ii) a guide on fuel economy and CO_2 emissions from new cars to be produced in consultation with manufacturers at least annually; and iii) that all promotional literature contain the official fuel consumption and specific CO_2 emissions data for the passenger car model to which it refers.

5 – IDENTIFICATION OF THE PROBLEM AND STATE OF THE ART

This section gives the scientific and technical background to the first question asked: "What is the European and worldwide scientific basis for improving the measurement of light-duty vehicle CO_2 emissions and fuel consumption in order to produce values closer to average real-world data?”

5.1 Comparison of the NEDC and WLTP test cycles

The type approval of any light-duty vehicle in the EU requires a regulatory CO_2 emission test cycle which consists of two parts:

i. Determination of the vehicle's road load

Road load is defined by the International Organization for Standardization as the "force or torque, which opposes the movement of a vehicle"[7]. The total road load of a vehicle depends on aerodynamic drag, rolling resistance and road grade (the incline or slope of a road) and varies as a function of the vehicle speed.

The road load parameters to be used in a laboratory emissions test are typically established by the manufacturer, under the supervision of the type approval authorities, according to one of the following methods:

- Coast down test on a test track (most common);
- Driving at constant speeds with torque meters mounted on the wheel hubs;
- Measurement of aerodynamic resistance in a wind tunnel and rolling resistance on a flat belt.

In the determination process of road loads, in particular using the most common coast down method, many parameters can influence the test

[7] See https://www.iso.org/obp/ui/#iso:std:iso:10521:-1:ed-1:v1:en

results. Such parameters include, for instance, the type of tyres or lubricants used, the mass of the test vehicle, or the presence of aerodynamically relevant parts like exterior mirrors. This set of parameters is the single most important source of uncertainties in the measured CO_2 emission values of a vehicle.

ii. **Testing the vehicle on a chassis dynamometer**

Using the road loads obtained as described above, the vehicle is tested in the laboratory following a prescribed driving curve on a chassis dynamometer. Flexibilities in the procedure for setting the road loads on the chassis dynamometer and deviations from the driving curves (within the tolerances allowed by the regulatory procedure) constitute two other relevant sources of uncertainty in the final CO_2 emission values of a vehicle.

The test cycle currently used for the type approval of vehicles in the EU is the New European Driving Cycle (NEDC), which will be replaced by the World-wide harmonized Light vehicles Test Procedure (WLTP) as of September 2017.

Many academic publications have compared the NEDC and the WLTP cycles (see for example Duarte *et al* 2016; Pavlovic *et al* 2016; Tutuianu *et al* 2015 ; Marotta *et al* 2015; Alves *et al* 2015; Bielacyc *et al* 2015; Sileghem *et al* 2014). In particular, the work of Marotta *et al* 2016 provides a good synthesis of the main differences between the NEDC and the WLTP.

The WLTP presents two fundamental improvements with respect to the previous procedure: on the one hand, it uses a more realistic driving cycle derived from a database of 800,000 km of in-use vehicle data (thus ensuring a more realistic coverage of the engine operation range), and on the other hand, it uses a more realistic and more robust test procedure which provides a better characterisation of the vehicle, leaving less space for interpretation. In particular, existing shortcomings of the NEDC test cycle are resolved by the WLTP, notably by providing more realistic test definitions, and by allowing less flexibility in carrying out the tests.

Category	Item	In NEDC	In WLTP	Impact on CO_2
Road Load Determination	Vehicle test mass	Present	Modified	↑
	Tire selection	Present	Modified	↑
	Tire pressure	Present	Modified	↑
	Tire tread depth	Present	Modified	↑
	Calculation of resistance forces	Present	Corrected	↑
	Inertia of rotating parts	Absent	Introduced	↑
	Default road load coefficients	Present	Modified	**?**
Laboratory test	Driving cycle	Present	Modified	**±**
	Test temperature	Present	Modified	↑
	Vehicle inertia	Present	Modified	↑
	Preconditioning	Present	Modified	↑
	Gear Shift strategy	Present	Modified	↓
Processing test results	Battery state of charge correction	Absent	Introduced	↑
	Correction of cycle flexibilities	Absent	Under discussion	**±**
Certificate of Conformity	CO_2 type approval extension / vehicle family	Present	Modified	↑

Table 1 : Comparison of the NEDC and WLTP test cycles

Source: adapted from Zacharof et al 2016

↑	*The WLTP will lead to higher CO_2 emission values*
?	*The expected impact of the WLTP on CO_2 emission values is unclear (e.g. the NEDC uses a table with default road load coefficients, whereas the WLTP will use formulae for calculating default road load coefficients based on relevant vehicle characteristics)*
±	*The WLTP will lead to CO_2 emission values that can be either higher or lower, depending on each vehicle*
↓	*The WLTP will lead to lower CO_2 emission values*

As far as CO_2 emissions are concerned, table 1 below presents a summary of the main procedural differences between the NEDC and the WLTP and the related impact on CO_2 emission values. This table will be analysed in detail in the following.

Some new provisions, which were absent in the NEDC, have been added to the WLTP to make it more robust and representative of real-life emissions and fuel consumption ("Introduced" in Table 1). Some provisions of the NEDC that today are considered inappropriate have been corrected ("Corrected"), others have been made stricter while respecting the need for some flexibility in the test procedure ("Modified"). Finally, a European Task Force is dealing with the corrections of WLTP flexibilities – their integration into European legislation is still in progress ("Under discussion").

The differences between the NEDC and WLTP test procedures have either a direct or indirect impact on CO_2 emissions and a qualitative estimation of such impact is presented in the table using the symbols in the final column.

Several experts have indicated that although WLTP is much more realistic than the NEDC, it is not perfect and will require further development in the future. This is, in fact, already foreseen by the UNECE. For instance, Ligterink *et al* 2015 have investigated a series of corrections that could be applied to variations of the parameters within the tolerance ranges allowed by the WLTP. However, as a general approach, there was a clear consensus among the experts consulted that test cycles need to be kept simple and reproducible.

One of the major advantages of the WLTP is the fact that the procedure has been developed together with non-European partners and therefore has the potential to become a common reference globally. Europe and Japan have already committed to introduce the new procedure in the years to come. India and Korea are expected to follow closely. Other countries, like China and Australia, which currently also use the NEDC as type approval cycle, will presumably also move to a more realistic procedure, but at the moment it is unclear whether the WLTP will be their choice.

5.2 Comparison of the EU and US approaches

The type approval process in the United States is different from the one in the European Union. In the US a new 5-cycle approach has been adopted for type approval testing in 2006 and is used for consumer information, complementing the original 2-cycle approach which is used for fuel economy standards. The original two cycles covered only city and highway driving conditions and were considered to be unrepresentative; the three new ones reflect in addition "high speed aggressive", "hot with maximum air conditioning" and "cold city driving", thus adding realistic driving scenarios resulting in quite high real driving emissions. Remaining gaps between laboratory measurements and real-world emissions (*e.g.* due to road conditions) are addressed by applying a mathematical adjustment factor. The current US standards are under evaluation for the period 2022-2025.

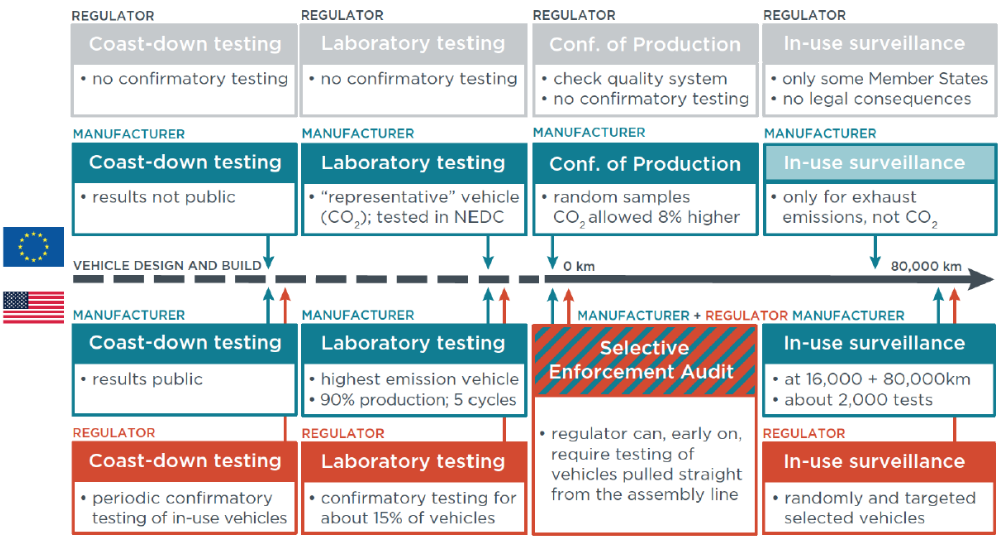

Figure 1: Comparison of the EU and US schemes for vehicle emissions testing

Source: Presentation given by Peter Mock (International Council on Clean Transportation) at the SAM Scientific Expert Workshop, 7-8 June 2016[8]

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[8] See https://ec.europa.eu/research/sam/pdf/topics/co2_scientific_workshop-session_2_impulse_peter_mock.pdf#view=fit&pagemode=none

A summary of the cycles and emission standards that apply in the US can be found in Delphi 2015 (pages 19-22 for the cycles and 64-67 for CO_2). The recent work of Ligterink *et al* (2016) presents a detailed comparison of the EU and US vehicles testing schemes. Figure 1 provides a very useful overview of the different approaches.

A fundamental difference between the EU and US is the strong focus on independent conformity testing in the US. In fact, the EPA has a multi-faceted oversight and enforcement programme. The EPA greatly increases oversight by random on-road testing and by testing vehicles directly from the assembly lines. The EPA can impose fines and order vehicle recalls. The EU currently does not have such an independent and effective vehicle conformity testing scheme.

Data transparency is central to the EPA's policies. The US regulator puts strong emphasis on information, communication and post-certification practices. An official fuel consumption website is maintained for this purpose (https://www.fueleconomy.gov/) under the responsibility of the EPA in cooperation with the US Department of Energy. This website gives consumers access to information about the fuel efficiency and emissions of current and historic vehicle models. The website offers the possibility for users to record their own real-world fuel efficiency experience. It is similar to the German website www.spritmonitor.de, except for the fact that www.fueleconomy.gov is hosted by a governmental agency. The real-world values for "miles per gallon" are converted into CO_2 emission equivalents and linked to the type approval CO_2 data for each vehicle model. More detailed information can be found in the references EPA (2014a), EPA (2014b) and EPA (2015).

5.3 Origin, characteristics and evolution of the gap between real-world emissions and laboratory testing

Under the current test regime (NEDC) there has been a significant and growing gap between the measured emissions of light-duty vehicles certified at type approval and their average real-world emissions.

The gap between the declared CO_2 emissions at type approval and the real emissions was identified as early as 2005 in the International Energy Agency Report (2005) "Making cars more fuel flexible – Technology for real improvements on the road". This document reported a gap for light-duty vehicle CO_2 emissions between the values measured by official certification tests in OECD countries and the actual on-road fuel economy of 10 to 15 %.

Since then several researchers have tried to quantify the gap using various approaches (*e.g.* emission inventories, vehicle simulations, fuel sales based estimations). A very detailed literature review on this subject is presented by Zacharof *et al* 2016, indicating two main reasons for the gap:

a) The certification tests with their characteristics and limitations, which in essence include:

- Boundary conditions, assumptions and limitations that were introduced in order to make the test procedure more robust and reproducible, which however may not reflect real-world conditions (*e.g.* fixed temperature, low average power driving cycle, no use of auxiliary appliances);
- The built-in flexibilities of the NEDC-based type approval procedure (*e.g.* lack of precise definition for certain parameters influencing CO_2 emissions, *e.g.* charging level of battery, quality and type of tyres, presence of exterior mirrors). In particular, a significant part of the gap can be explained by the coast down testing, *i.e.* the measurement of how a car decelerates with gearshift in neutral position, typically from around 100 km/h to standstill. This can be influenced, for example, by preparing tyres for the test environment or by using ultra-low friction oils. The coast down procedure is important because

the road load figures calculated from it provide the reference for other measurements. Zacharof *et al* therefore conclude that the road load figures and coast down coefficients must be representative and should be made public to enable their independent monitoring, as is the case in the US.

b) The intrinsic variability of vehicle use in real life of which there are three types:

- Vehicle configuration (*e.g.* passenger and cargo load, tyres, fuel quality, maintenance);
- Driver behaviour (*e.g.* driving style, use of vehicle in urban versus motorway conditions, use of auxiliaries such as air conditioning);
- External conditions (*e.g.* environmental, road, and traffic conditions).

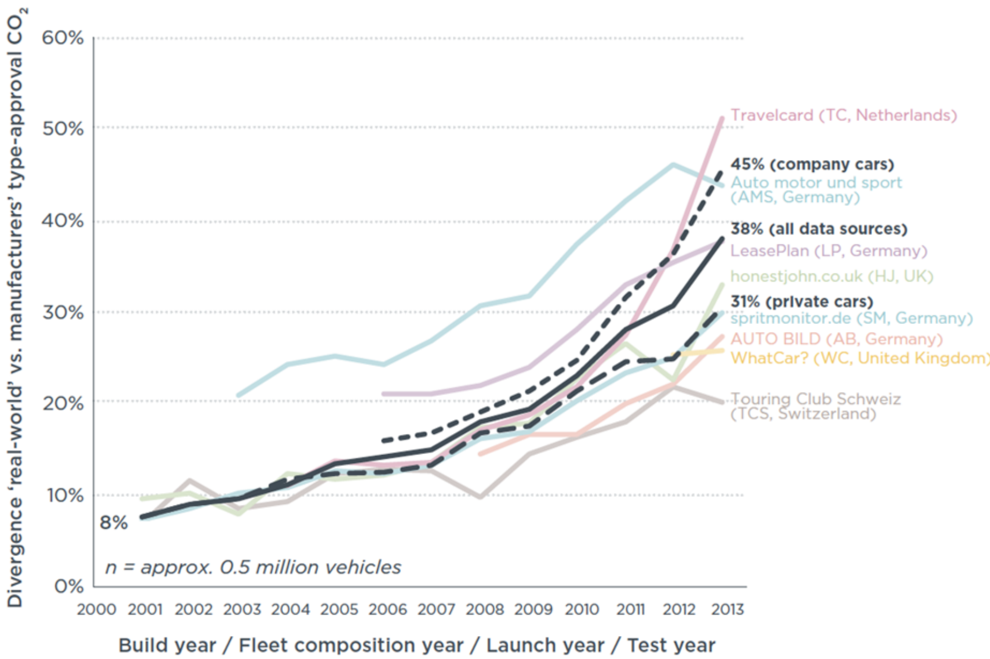

Figure 2: Divergence between real-world and manufacturers' type approval CO_2 emissions for various real-world data sources, including average estimates for private cars, company cars, and all data sources

Source: Tietge et al 2015, P. ii)

A multitude of studies has shown that the gap has increased over time during the last 15 years, with an acceleration following the introduction of Regulation (EC) 443/2009 setting binding CO_2 targets (for 2015 and 2021) for car manufacturers. This is clearly demonstrated by Tietge *et al* 2015 (see Figure 2) who compare different studies to demonstrate that the gap between laboratory and real-world CO_2 emissions has increased 2-5 times, from 8-10% in 2001 to 20-50% in 2013, depending on the source.

This suggests that the increase in the gap is connected to a) the possibilities for manufacturers to exploit the peculiarities and flexibilities (or "elasticities") offered by the NEDC test procedure, and b) the introduction of technologies offering CO_2 reduction benefits in the NEDC cycle (*e.g.* start-stop system), but which provide fewer benefits under real driving conditions. Details are provided in Zacharof *et al* 2016.

Deviations between real-world emissions and NEDC values vary strongly between car models. In December 2015, the German car magazine *Auto, Motor und Sport* published an analysis of 600 cars tested in the years 2014 and 2015. As part of its car tests, each car was submitted to an "eco-drive", *i.e.* it was driven in a very economical way on a 275km long route encompassing city, country and motorway driving, which should yield results close to the NEDC cycle. It was possible with cars from five car manufacturers to achieve consumptions that were even lower (up to 11.4%) than the average NEDC consumption, whereas for 7 other brands the consumption was between 10% and 14.4% higher than the NEDC values. These differences between manufacturers might well be due to the fact that the NEDC cycle is particularly favourable to small engines and certain technologies (*e.g.* start-stop system). No scientific analysis has been found which looks into the question of whether these differences are also attributable to some manufacturers exploiting "elasticities" more than others. These deviations between real-world emissions and NEDC values for different car models are also evident in the work of Ligterink *et al* 2016 and Ntziachristos *et al* 2014.

There was consensus among the experts consulted by the SAM High Level Group that the WLTP is a clear step forward and will substantially reduce the gap between laboratory-based values and real-world CO_2 emissions since it is more representative of real driving conditions and allows less flexibilities compared to the NEDC. Pavlovic *et al* 2016 estimate that the WLTP will potentially halve the current gap between type approval and real-world fuel consumption. However, as the WLTP is not implemented yet, it is too early to assess the exact impact it will have.

For the estimation of real driving CO_2 emissions of car fleets, the existence of a gap as such is not a problem as long as it is known and does not increase over time. If the gap remains constant, a correction factor can be applied to reflect real driving emissions, as is done in the US. Therefore, a key question is how avoid the gap increasing again once the WLTP is introduced. In principle, it is expected that the higher robustness of the WLTP procedure will limit the possibility for a future significant increase of the gap. However, this statement is based on the current understanding of the problem and the assumptions made when developing the WLTP. The impact of the WLTP on the development of the gap will have to be monitored, in order to inform future enhancements of the test cycle. This will require more robust methods for measuring real driving CO_2 emissions. In addition, applying correction factors to car fleets will not solve the problem for consumers as the gap between individual car models varies strongly.

6 – OPTIONS FOR MEASURING REAL DRIVING EMISSIONS OF CO_2

This section addresses the second question asked: "Which approaches might be considered, what are their strengths and weaknesses, also in terms of reliability and transparency, and what additional scientific and analytical work would be needed?" It notably discusses whether and how Real Driving Emissions (RDE) for CO_2 can be measured in a reliable and reproducible way. A number of options available to policy-makers are analysed.

First of all it is important to understand the context in which these options should be considered. Here, it is important to be reminded of the concept of "Not-to-Exceed" (NTE) limit, which means that an emission value used or determined at type approval must not be exceeded by more than a certain permitted tolerance factor defined in the legislation when repeated in another test, regardless of the parameters and conditions applied as long as they are within the validity range of the regulatory test procedure.

The NTE concept is well approved for regulated pollutants such as NO_x. In the case of CO_2, however, it is more complicated to define such a "Not-to-Exceed" value that could cater for every single situation of a car across Europe. Indeed, considerable work addressing technical, statistical and administrative rules for the application of the NTE concept to CO_2 emission testing would be necessary before any decision can be made on the use of such a concept in a regulatory framework, as this would need to be in line with the requirement of having simple, and most importantly, reproducible tests.

However, for CO_2 emissions, such an approach should be explored. It would mean that where the WLTP test is repeated *ex-post* by an independent party, the WLTP type approval values must not be exceeded by more than a certain margin (to be defined on the basis of technical criteria). This could apply at two levels:

- Either only to the road loads: Such an approach would require that car manufacturers have to publish the road loads used for the different car models and the way these road loads are established. In the context of UNECE, South Korea is interested in developing this concept further as part of future developments of the WLTP (see KATRI 2015);
- Or directly to the type approval CO_2 emissions of the vehicle.

6.1 Portable Emissions Measurement Systems (PEMS)

Real driving emissions methodologies are already under development for NO_x and other pollutants, using Portable Emissions Measurement Systems (PEMS). The basic concept is to put the laboratory into the vehicle rather than putting the vehicle into the laboratory. PEMS measure emissions from combustion engines on the road, thus allowing real-world in-use testing. PEMS integrate advanced gas analysers, exhaust mass flow meters, a weather station, a link to a satellite navigation system and a connection to the on-board diagnostics of the vehicle. Therefore, PEMS provide a complete and reliable real-time monitoring of emissions (HC, CO, CO_2, NO, NO_2, particulate matter) and link these measurements to the vehicle, engine and environmental parameters. A good overview of the technology can be found on http://iet.jrc.ec.europa.eu/pems/portable-emissions-measurement-systems-pems. Details are also presented by Fontaras *et al* 2016. Detailed information on RDE tests can be found in Andersson *et al* 2014, May *et al* 2014, Favre *et al* 2013, Kousoulidou *et al* 2013, and Weiss *et al* 2011.

Measuring real-world emissions on the road offers a number of advantages, such as:

- CO_2 emissions data can be collected from actual on-road driving, with the potential to generate a large data pool;
- CO_2 emissions are already measured and recorded for every RDE PEMS test as a parameter needed to calculate the RDE NO_x value;

- A wide range of conditions (weather, driving behaviour, vehicle parameters) can be covered;
- Emission anomalies may be detected and linked to specific events, thus offering resilience against defeat strategies.

CO_2 emissions data gathered with PEMS from the RDE procedure for pollutants will become available for the whole European car fleet as of 2019. The RDE procedures currently approved for air pollutants are designed to represent real driving conditions. Verification is required of whether RDE procedures currently approved for air pollutants would allow the extraction of CO_2 emission sequences that could be considered representative for European average driving conditions. If this is the case then the use of these data could be envisaged.

Due to their very nature, individual PEMS trips on the road show a high degree of variation, leading to correspondingly high variations in CO_2 emissions, even for trips that are considered identical. Each PEMS trip reflects a specific combination of driving behaviour and external conditions. Using PEMS for measuring CO_2 is thus not straightforward in terms of reproducibility. It is also important to recall that the ultimate goals of the different pieces of legislation are different for NO_x and CO_2. For NO_x the main objective is to verify that the values measured do not exceed a certain threshold defined in the legislation (+ a tolerance factor allowing for measurement uncertainties).

It should be kept in mind that emissions of CO_2 depend also on factors that cannot be controlled by car manufacturers. These factors include among others:

- The driving behaviour and style, including the extent to which fuel saving features provided by the vehicle are used (for example, a plug-in hybrid vehicle which is not necessarily recharged regularly by the owner);
- Ambient conditions: temperature, humidity, atmospheric pressure;
- The characteristics of the road: road conditions, topography;
- The traffic conditions: fluidity, speed limits, traffic management.

Given this large variability, it is a challenging task to capture the "average European consumer" and the "average European trip", *i.e.* "the representative European PEMS run", taking into account vehicle specifications (*e.g.* mass), vehicle use (*e.g.* urban/road/motorway usage), driving behaviour, and external conditions (*e.g.* weather, temperature, road grade), which vary considerably across Europe and its variety of climate zones and topography.

One methodology for measuring real driving emissions using PEMS has been developed by the car manufacturer PSA in collaboration with the non-governmental organisations *Transport & Environment* and *France Nature Environnement* as well as the certification body *Bureau Veritas* (see Rimaux and Swoboda 2016). The aim is to propose a protocol that could be used for standardising the use of PEMS.

In this protocol, the same driving corridor reflecting different types of traffic situations is used for all tests (92 km), the auxiliaries are switched on as needed and the only instruction to drivers is to follow the traffic code, *e.g.* obeying speed limits. The same methodology is used for both NO_x and CO_2. Using the same trip, variations will appear even with the same driver (*e.g.* because of weather conditions) – these different trips are then used to calculate an average. Afterwards the results are correlated with results obtained from a test bench. The result is an average value that comes as close as possible to the average real-world emissions monitored on a set of PSA vehicles.

The PSA approach is very valuable and it constitutes a very interesting case on which further studies and research can be based. However, it is premature to consider this approach as a regulation-ready option for the same reasons indicated above, namely that it would take considerable standardisation work to identify what would be a driving cycle representative for Europe as a whole. In particular, transforming the process from one which was to date tested only in PSA vehicles into a sound and robust method which can be used for different vehicle models, segments, brands and different driving circumstances may be a task for future research and/or technical development.

A sound assessment of the variability of the CO_2 data measured with PEMS is required. As there is only a limited amount of data for CO_2 measurements using PEMS published, there is not enough information on the variability, distribution and upper limits of PEMS CO_2 data for vehicle types of the European car fleet.

6.2 Monitoring fuel consumption using on-board diagnostics

Fuel consumption is a reliable indicator of the tank-to-wheel CO_2 emissions of a car because there is a direct correlation between the two. The use of fuel consumption data as a proxy for CO_2 emissions has been analysed in several publications (see for example Zhang *et al* 2014, Ntziachristos *et al* 2014 and Alessandrini *et al* 2012).

In terms of measuring CO_2 emissions, fuel consumption meters could be used in three ways:

i. Measuring fuel consumption of a vehicle over a longer period of time (or its lifetime) in a non-erasable manner. Information on the fuel consumption of individual vehicle types, together with the distance driven, could be regularly and systematically read out for the entire fleet, for instance on a yearly basis or at the mandatory periodic vehicle inspection.
ii. Measuring average fuel consumption over a relatively short time (as is already available in many vehicles) and indicating it on a display in the car, thus informing the driver. This is especially important to support fuel efficient driving, but its accuracy for total fuel consumption needs to be verified.
iii. In principle, the monitoring of fuel consumption in real-time along with environmental conditions and other factors should be feasible, considering that many vehicles are now digitally connected. Such

automatic monitoring data, combined with information on the vehicle type but otherwise anonymised, could be used for public information on a European or national level and to estimate CO_2 emissions from transport. Such an approach would raise privacy-related questions, however.

The large amount of data that can be derived from the approaches outlined above will allow a proper statistical analysis and the attribution of significant correlations between the real fuel consumption values and the different factors influencing them. In the case of the correlations with vehicle dependent factors (*e.g.* mass, engine, aerodynamics, *etc.*), this information will be very relevant for the monitoring of the gap with respect to the *ex-ante* measurements of CO_2 using WLTP. It will also allow very useful insights to be derived on the correlations between real consumption values with other factors that are not under the control or responsibility of car manufacturers (*e.g.* driving behaviour, environmental conditions, topography, *etc.*).

The fuel consumption data will be highly valuable to car manufacturers, consumers and policy-makers including local, regional and national authorities responsible for the design of adequate emission abatement strategies.

Currently the so-called "potpourri" legislation which is being negotiated in the Council and the European Parliament aims at transposing the Euro 6 Regulation (Regulation (EC) 715/2007) into the Lisbon Treaty legislative format. The Parliament has proposed to add to the "potpourri" legislation the mandatory installation of a fuel consumption meter, in conjunction with the necessary test procedure for assessing its accuracy at the moment of type approval. The data obtained in such a manner could be used to assess the real-life CO_2 emissions by using the average fuel consumption for a vehicle type considering all driving events.

While type approval figures would not be corrected retroactively, such comprehensive fuel consumption data from on-the-road trips would be valuable consumer information and might put pressure on vehicle manufacturers to get the fuel consumption figures closer to real-world values in the first place. It would also provide useful feedback for future improvements of the regulatory test cycle. In this context, for a future revision of the Car Labelling Directive, it could be considered that fuel consumption and CO_2 emission labels would have to show not only type approval values but also real driving values as soon as these become available.

6.3 Monitoring fuel consumption based on reporting

There is already a number of interactive fuel consumption monitoring websites mostly run by private initiatives, such as www.spritmonitor.de, where users can enter their fuel consumption and distance driven. These inputs are then statistically evaluated and can be publicly consulted. For example, *Travelcard Nederland BV* gathers fuel consumption data from business car fleets with the fuel paid by the employer, consisting of kilometre reading, date and type and amount of fuel[9]. While the kilometre reading is recorded manually by the driver at each fuelling event, the remaining information is automatically logged by the card-based system.

Ligterink *et al* 2016 have used the data to monitor the gap between the type approval value and the real-world fuel consumption over time for these particular consumers. Figure 3 represents the average (per fortnight) of the additional fuel consumption per fuelling as a percentage of the vehicles' type approval fuel consumption. It clearly shows the substantial and growing gap between type approval and real-world fuel consumption for both petrol and diesel cars in this specific case. According to the data, in

[9] The database concerns mainly company cars, which are a common employment benefit in the Netherlands for employees. The cars span most of the vehicle sales segment, and are used generally on a daily basis. Company cars are typically at most four years old, and the employees are allowed to select a new car in a given market segment, every couple of years. The usage pattern does not change much over time, and the group of drivers is rather constant. The average age of the car in the fuel consumption monitoring is about two years.

2008 an average vehicle used approximately 12% more fuel than in the type approval test, whereas in 2014 the average additional fuel consumption increased to approximately 40%.

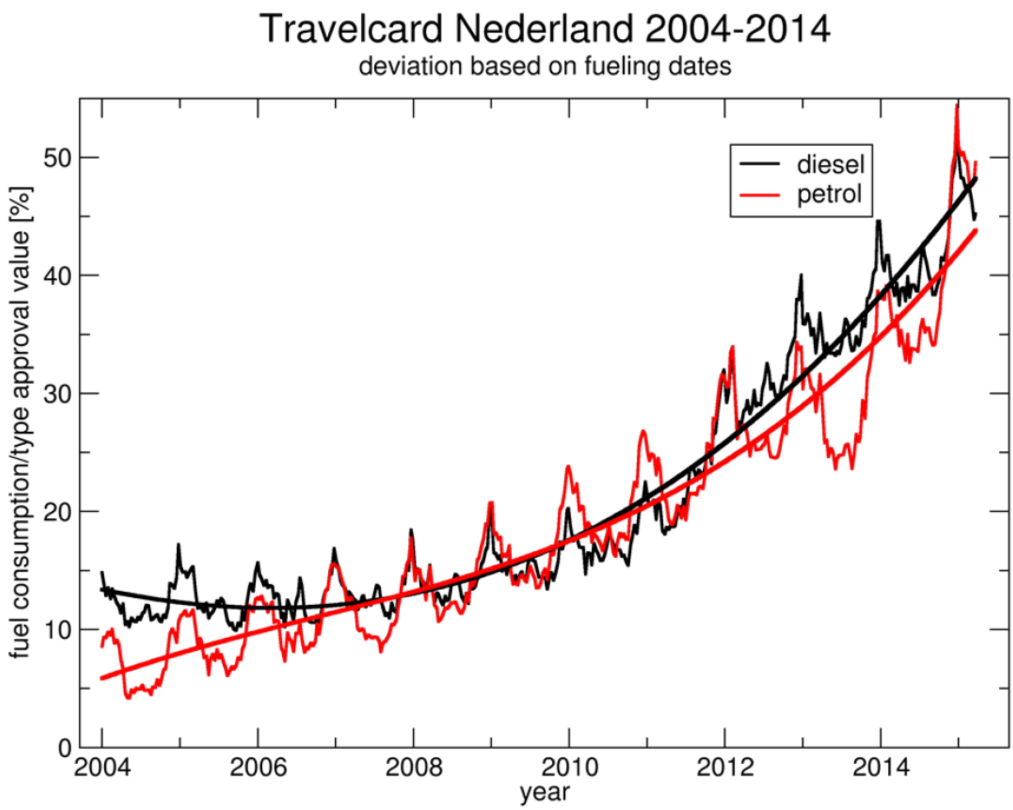

Figure 3: Development of real-world fuel consumption versus type approval values according to Travelcard Nederland

Source: Ligterink et al 2016 p. 8

Several scientific papers have dealt with in-use fuel consumption data obtained from scientific, commercial, and public databases. For example, Ntziachristos *et al* 2014 have collected in-use fuel consumption data of 924 passenger cars from various European sources and have evaluated the data in comparison to their corresponding type approval values. From the analysis of the literature, it may be concluded that there is scope for improvement in the quality of the data on fuel consumption monitoring websites mainly in terms of standardisation and reducing the risk of input errors.

6.4 Modelling and correction algorithms

A model is a mathematical approximation to reality. Its accuracy largely depends on a good understanding of the processes and the correlation between different factors as well as on the quality of the data that go into the model. Modelling can indeed play an important role in estimating the gap between laboratory measurements and real driving emissions. As models are always an approximation of reality, they can never be as accurate as real measurements. However, modelling can be a very useful and fast tool to complement these measurements (*e.g.* by using real measurement data to draw more generic conclusions with respect to the type approval value), for example to model the likely impact of future legislation.

An example is the CO_2MPAS model that has been developed by the European Commission's Joint Research Centre (JRC). It correlates CO_2 emissions and fuel consumption values obtained following the WLTP with those that would have been expected using the NEDC and vice versa. This enabled the JRC to perform a first assessment of the gap between laboratory measurements and real driving emissions that can be expected under the WLTP (for more information see Zacharof *et al* 2016).

During the Scientific Expert Workshop organised by the SAM High Level Group in Lisbon, several experts pointed out that the WLTP should be complemented by a methodology for monitoring real driving CO_2 emissions, possibly based on PEMS data gathered during the RDE tests for pollutants and/or on the use of real fuel consumption as an indicator of real CO_2 emissions. In all these options, modelling will play a central role and it should thus be regarded as complementing the other options rather than replacing them.

Another way to close the gap between laboratory measurements and real driving emissions by using mathematical approaches is to apply correction algorithms. The purpose of such algorithms is to correct for flexibilities allowed by the test cycles. As outlined earlier, the US Environmental Protection Agency has a long-standing experience in developing and applying such correction figures. These are, however, not transferrable to the WLTP because of the significant differences compared to the US test cycles.

Ligterink *et al* 2015 have presented an in-depth analysis of possible correction algorithms for the WLTP, some of which are more relevant than others depending on the impact of the flexibilities on the CO_2 emission values. This applies, for instance, to deviations from the target speed in the test cycle, the charging status of the battery, the inaccuracy of the road load setting on the chassis dynamometer, as well as the vehicle conditioning and the condition of the test track for the coast down procedure, to name but a few. It is not the purpose of this Scientific Opinion to present these correction methods in detail, but to flag the contribution they can make to close the gap.

The main advantage of correction algorithms is that they offer a "quick fix" to deal with the flexibilities allowed by the test cycles and help to inform future improvements of the WLTP. At the same time, it is clear that they cannot replace the need for tackling the problems that are at the source of the gap. Correction algorithms are perfectly valid and useful when the gap is reasonably constant, but require revision when there are signs that the gap increases.

7 – CONCLUSIONS

Given the urgency and ambition of the Paris commitments, legislation should be designed in a way that incentivises manufacturers to optimise technology in order to lower CO_2 emissions in reality rather than adapting to the test cycles. Consequently, the introduction of the WLTP as test cycle for the type approval of light-duty vehicles should be complemented by a number of measures that allow the monitoring of real driving emissions as well as actions that help build the trust of consumers in the regulatory system.

The SAM High Level Group proposes a system which is as representative as possible of the average real world emissions, and which takes into consideration the best available technologies, the stage of development of the different technologies and the balance between simplicity of the process and the benefits. Figure 4 summarises the main elements of the proposal.

Type approval

- The WLTP is a clear step forward in terms of reducing the gap between laboratory measurements and real-world CO_2 emissions. It should be implemented in the type approval system without further delay.
- The WLTP needs to be developed further in the future. This is needed to keep up with technological developments (e.g. hybrids), alongside taking into consideration auxiliary devices like air conditioning and accounting for a wider range of environmental conditions.
- A new widening of the gap needs to be prevented. From analysis of the data on the evolution of the gap over time, it may be concluded that a review of the test cycle every five years seems to be an appropriate time frame. At the same time, regulatory certainty and appropriate planning horizons need to be ensured for car manufacturers.

- For the type approval process, all compliance data and details on the procedures should be public including the road load figures and coast down procedures used at type approval.
- There is consensus that a mechanism needs to be developed in order to monitor continuously the representativeness of the current type approval tests *vis-à-vis* real-world CO_2 emissions. *Ex-post* data can permit regulators to monitor the evolution of type approval legislation and to adapt it accordingly, as well as to trigger a re-testing of certified vehicles.

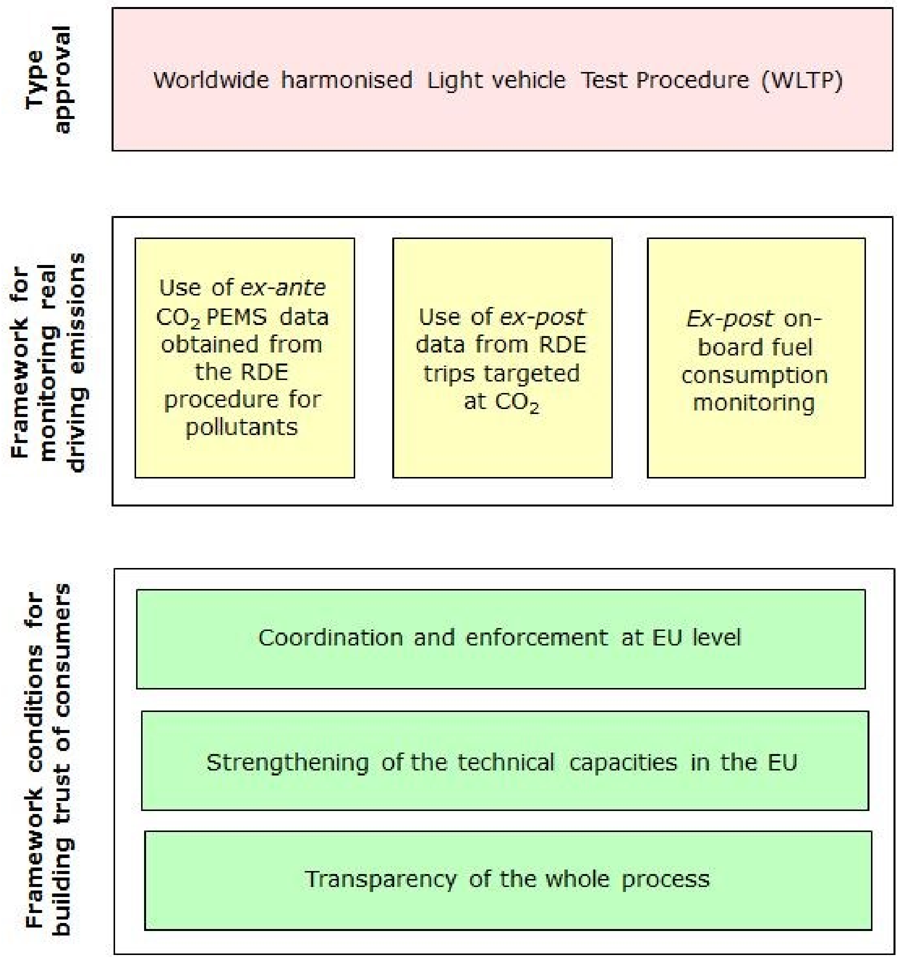

Figure 4: Necessary elements to close the gap between laboratory measurements and real driving emissions

Source: Authors' elaboration

Framework for monitoring real driving emissions

A framework for monitoring the development of the gap between type approval testing and real driving emissions should be envisaged.

- Real Driving Emissions (RDE) methodologies are already under development for NO_x and particle measurements, using Portable Emissions Measurement Systems (PEMS), which include the measurement of CO_2. These data will be fully available as of 2019, thus providing a complete data set for the whole European car fleet (new registrations). An assessment should be made of the extent to which these data can be used to monitor the gap.
- In addition to the CO_2 emissions data already obtained from the RDE procedure for pollutants, a targeted ex-post RDE methodology for CO_2 should be developed, complementary to the WLTP. This methodology could be based on measuring devices existing in the vehicle, e.g. fuel consumption meters, or on other technological options such as PEMS.
- Fuel consumption is a reliable and cost-effective indicator of the tank-to-wheel CO_2 emissions of a car and could be an alternative to PEMS for CO_2 emission measurements in the longer term, provided that fuel consumption data are accurate, accessible and formally reported. To this end, a standard approach to collect, store, use and communicate fuel consumption values needs to be developed, making maximum use of sensors already present in cars. However, it will be necessary to define minimum quality standards for fuel consumption meters to obtain reliable data. Fuel consumption data need to be made accessible to relevant stakeholders (including vehicle users, manufacturers, public authorities, *etc*.), while respecting privacy. Consumer reporting of fuel consumption is recognised as a valuable source of information and should be encouraged.

Framework conditions for building trust of consumers

In order to grow the trust of the consumer in the regulatory system and the car industry a number of framework conditions must be met. This includes in particular:

- Regulatory oversight should be strengthened across Europe with more coordination as well as reliable standardised and empowered type approval and monitoring systems. This would facilitate the implementation of EU legislation in all EU Member States.
- Authorities at EU and Member State levels should retain and reinforce deep in-house expertise and state-of-the-art laboratories. This would enable proper enforcement by independent evaluations of test cycles, *ex-post* market surveillance and random audits, and would support consumer trust in the car industry.
- Transparency of the whole process is essential to allow a level playing field, to enable well-informed choices by consumers and to provide all stakeholders with confidence in the outcomes. All compliance data and details of the test cycle procedures and RDE data should be public. Exchange of equivalent data and best practices with international partners is encouraged.

Finally, with respect to reaching a level playing field between all technologies and the increasing market importance of plug-in hybrid, electric and other alternative fuel vehicles, it will be necessary in the future to develop additional methods to capture the full life cycle of carbon emissions.

Implementation of all these recommendations will enable the EU and its citizens to have a more complete understanding of the contribution of light-duty vehicles to its carbon emissions and provide the incentives to move as quickly as possible to a low carbon future.

8 – ANNEXES

8.1 Glossary

2-cycle / 5-cycle method	Test cycles used in the United States of America during type approval to assess the emission levels of engines and the fuel economy of vehicles in the laboratory. The 2-cycle test is used for compliance checks whereas the more realistic 5-cycle test is used for determining labels and calculating greenhouse gas emissions.
Auxiliary appliances/devices	Devices mounted on a car which are related to other functions than propulsion, such as air conditioning, navigation systems or equipment for entertainment.
Car fleet	All new cars of a particular type that have been registered (*i.e.* put in circulation) across the EU during one calendar year. The totality of all cars in operation at a given time in a specific region is usually denoted as "car stock".
Chassis dynamometer	An experimental setup enabling vehicles to be operated indoors on a stationary platform to simulate real-world vehicle operation. The level of resistance on the dynamometer simulates the level of resistance that the vehicle would encounter if operated on the road.
Coast down test	A test performed on a flat surface to calculate the resistance levels (or "road loads") offered to a moving vehicle. The test measures how a car decelerates with gearshift in neutral position, typically from around 100 km/h to standstill. The procedure serves to calibrate the measurements taken in the laboratory during a test cycle.
Cold phase	The time elapsing between the starting of the motor of a vehicle at ambient temperature and the motor reaching normal operational temperature.
Correction algorithm	A mathematical formula allowing to correct uncertainties or inaccuracies inherent to measurements.
Decarbonisation	The reduction or removal of CO_2 emissions from human activities, in this case transport, with the aim of mitigating global warming.

Fuel consumption meter	A device installed in the vehicle measuring its fuel consumption. Combined with an information about the distance travelled it gives an indication of the fuel economy of a vehicle.
Fuel economy	The fuel efficiency relationship between the distance travelled and the amount of fuel consumed by a vehicle.
High Level Group of Scientific Advisors	A scientific advisory board established by the European Commission within the Scientific Advice Mechanism (SAM), consisting of seven high-level experts from across Member States and scientific disciplines.
Hybrids / Plug-in hybrids	A vehicle that draws energy from both, a consumable fuel and an electrical energy/power storage device (*e.g.* a battery). A plug-in hybrid can be recharged by plugging it into an external source of electric power.
Light commercial vehicle (LCV)	A vehicle with a gross weight of not more than 3.5 tonnes, which is designed and constructed for the carriage of goods (commonly denoted as "vans").
Light-duty vehicle (LDV)	A vehicle with a gross weight of not more than 3.5 tonnes, which is designed and constructed for the carriage of up to 9 persons or the carriage of goods (commonly denoted as "cars and vans").
Modelling	The mathematical representation of a process, concept, or operation of a system.
New European Driving Cycle (NEDC)	A European test cycle used during type approval to assess the emission levels of car engines and the fuel economy of passenger cars in the laboratory. It will be replaced as of 2017 by the Worldwide harmonized Light vehicles Test Procedure (WLTP).
Not-to-Exceed concept (NTE)	Use of an emissions value defined in the legislation which must not be exceeded during the operation of the vehicle in a particular test procedure.
On-board diagnostics (OBDs)	Instruments that inform the driver or technician about the status of a vehicle and its subsystems, using sensors and displays.
Particulate filter	A device designed to remove particulate matter or soot from the exhaust of a diesel engine.

Portable Emissions Measurement System (PEMS)	An experimental setup that can be mounted on a vehicle in order to test its emissions on the road for the purpose of assessing the real driving emissions of that vehicle. It is necessary in particular to measure the flow of pollutant emissions.
Real Driving Emissions (RDE)	The emissions of a vehicle measured during real-world driving trips of certain specifications. The measurement of these emissions may allow drawing conclusions on the representativeness of the emissions measurements taken in a laboratory.
Road load	The force or torque which opposes the movement of a vehicle, such as rolling resistance, gradient resistance, and aerodynamic resistance.
Scientific Advice Mechanism (SAM)	A mechanism established by the European Commission in 2015 with the aim of ensuring that the College of European Commissioners has access to high quality, independent, timely and transparent scientific advice. It consists of a High Level Group of Scientific Advisors and a structured relationship with academies in Europe. It is supported by a secretariat in the Commission's Directorate-General for Research and Innovation.
Type approval	The procedure whereby a public approval authority certifies that a type of vehicle satisfies the relevant administrative provisions and technical requirements. This follows an extensive testing of the vehicle in a laboratory according to a test cycle defined in the legislation.
Worldwide harmonized Light vehicles Test Procedure (WLTP)	A test cycle which has been developed under the auspices of the United Nations Economic Commission for Europe (UNECE) with the aim of developing a global standard for the testing of vehicles in a laboratory as part of the type approval procedure. It is expected to be applied for new type approval tests in the EU as of September 2017, replacing the former New European Driving Cycle (NEDC). Other countries such as Japan intend to adopt the standard as well.

8.2 List of experts and stakeholder representatives

The following persons (in alphabetical order) contributed to the development of this Scientific Opinion, either by being consulted by the SAM High Level Group or by representing their organisations at fact-finding meetings:

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Jens Badur (International Confederation of Inspection and Certification Organisations CEOC)
Gianmarco Baldini (Joint Research Centre, European Commission)
Patrícia Baptista (Instituto Superior Técnico, Portugal)
Pierre Bonnel (Joint Research Centre, European Commission)
Dirk Bosteels (Association for Emissions Control by Catalyst AECC)
Ellen Bulander (European Association of Automotive Suppliers CLEPA)
Chris Carroll (Bureau Européen des Unions de Consommateurs BEUC)
Michalis Christou (Joint Research Centre, European Commission)
Biagio Ciuffo (Joint Research Centre, European Commission)
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8.4 List of written evidence used

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World Energy Council (2016): "E-mobility: closing the emissions gap", https://www.worldenergy.org/publications/2016/e-mobility-closing-the-emissions-gap/

8.5 Websites for further reading

The following websites provide further information for the interested reader. This list is not meant to be exhaustive and serves for information purposes only.

DG Climate Action, European Commission:

http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

http://ec.europa.eu/clima/policies/transport/vehicles/labelling/index_en.htm

Joint Research Centre, European Commission:

https://green-driving.jrc.ec.europa.eu/#/

http://iet.jrc.ec.europa.eu/pems/portable-emissions-measurement-systems-pems

European Environment Agency:

http://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-10

United Nations Economic Commission for Europe (UNECE):

https://www2.unece.org/wiki/pages/viewpage.action?pageId=2523179

US Environmental Protection Agency:

https://www3.epa.gov/otaq/ld-hwy.htm

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European Automobile Manufacturers Organisation (ACEA):

http://www.caremissionstestingfacts.eu/difference-between-lab-tests-real-world-emissions/#

International Council on Clean Transportation (ICCT):

http://www.theicct.org/passenger-vehicles

European Federation for Transport and Environment (T&E):

https://www.transportenvironment.org/what-we-do/cars-and-co2

TNO:

https://www.tno.nl/en/about-tno/dossiers-in-the-news/real-world-vehicle-emissions/

Others:

www.spritmonitor.de

Responding to a request submitted by the European Commission, the High Level Group of Scientific Advisors is analysing possible ways to close the growing gap between the CO_2 emissions of passenger cars certified at type approval in the laboratory and their average real-world emissions.

In its Scientific Opinion the High Level Group recommends complementing the laboratory-based World-wide harmonized Light vehicles Test Procedure (WLTP) test cycle with a framework for the monitoring of real driving CO_2 emissions. This should consist of an assessment as to whether data obtained with Portable Emissions Measurement Systems (PEMS) from the future real driving emissions testing for pollutants can be used to monitor the gap, the development of a specific real driving emissions test procedure for CO_2, and the introduction of a formal reporting of the fuel consumption of passenger cars, taking advantage of on-board vehicle diagnostic systems. In order to grow the trust of the consumer in the regulatory system and the car industry, and to guarantee a level playing field for car manufacturers, the High Level Group also recommends enhancing coordination and enforcement at EU and Member State level, strengthening the technical oversight capacities in the EU, and ensuring transparency of the whole process.

This Scientific Opinion is aimed at providing an evidence-based underpinning of a policy proposal for post-2020 emission performance standards for light-duty vehicles.

Studies and reports

Publications Office