WHITE PAPER

MAY 2020

ON THE WAY TO "REAL-WORLD" CO_2 VALUES: THE EUROPEAN PASSENGER CAR MARKET IN ITS FIRST YEAR AFTER INTRODUCING THE WLTP

Jan Dornoff, Uwe Tietge, Peter Mock

www.theicct.org

communications@theicct.org

twitter @theicct

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BEIJING | BERLIN | SAN FRANCISCO | SÃO PAULO | WASHINGTON

ACKNOWLEDGMENTS

The authors thank all internal and external reviewers of this report for their guidance and constructive comments, with special thanks to Anup Bandivadekar, Georg Bieker, Georgios Fontaras, John German, Peter Kasten, Jelica Pavlovic, Dino Silvestro, Zifei Yang, as well as two additional anonymous reviewers. Their review does not imply an endorsement, and any errors are the authors' own.

For additional information:

ICCT - International Council on Clean Transportation Europe
Neue Promenade 6, 10178 Berlin
+49 (30) 847129-102

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

Funding for this work was generously provided by Stiftung Mercator and the European Climate Foundation

EXECUTIVE SUMMARY

Since September 2017, all new passenger car models in the European Union (EU) are required to be type-approved following the Worldwide Harmonized Light Vehicles Test Procedure (WLTP). For a smooth transition, existing vehicle models that were type-approved under the New European Driving Cycle (NEDC) procedure could still be registered until August 31, 2018. The complete transition from NEDC to WLTP for all vehicle categories stretched over a period of four years and new vehicles coming to the market in 2018 were a mix of vehicles type-approved according to the NEDC or the WLTP.

The preliminary 2018 CO_2 monitoring dataset from the European Environmental Agency (EEA) contains both WLTP and NEDC CO_2 values for about one-quarter of new car registrations in 2018. Based on these data, the WLTP CO_2 emission levels of 2018 vehicles are, on average, about 21% higher than the respective NEDC values. A similar analysis of a dataset from the German car drivers' association ADAC EcoTest using CO_2 data for 158 passenger cars shows the same result, indicating that WLTP CO_2 levels are on average about 21% higher than NEDC CO_2 levels.

As a consequence, when analyzing fueling records for WLTP type-approved vehicles from the consumer website Spritmonitor.de, we observe a strong drop in the real-world CO_2 gap for 2018, to approximately 14%. This is compared to a high of around 40% for NEDC type-approved vehicles. In other words, WLTP type-approved vehicles from the year 2018, on average, emit about 14% more CO_2 under real-world driving conditions than suggested by the official WLTP figures and therefore come with a significantly more realistic indication of their behavior than NEDC type-approved vehicles of the same year (Figure ES-1).

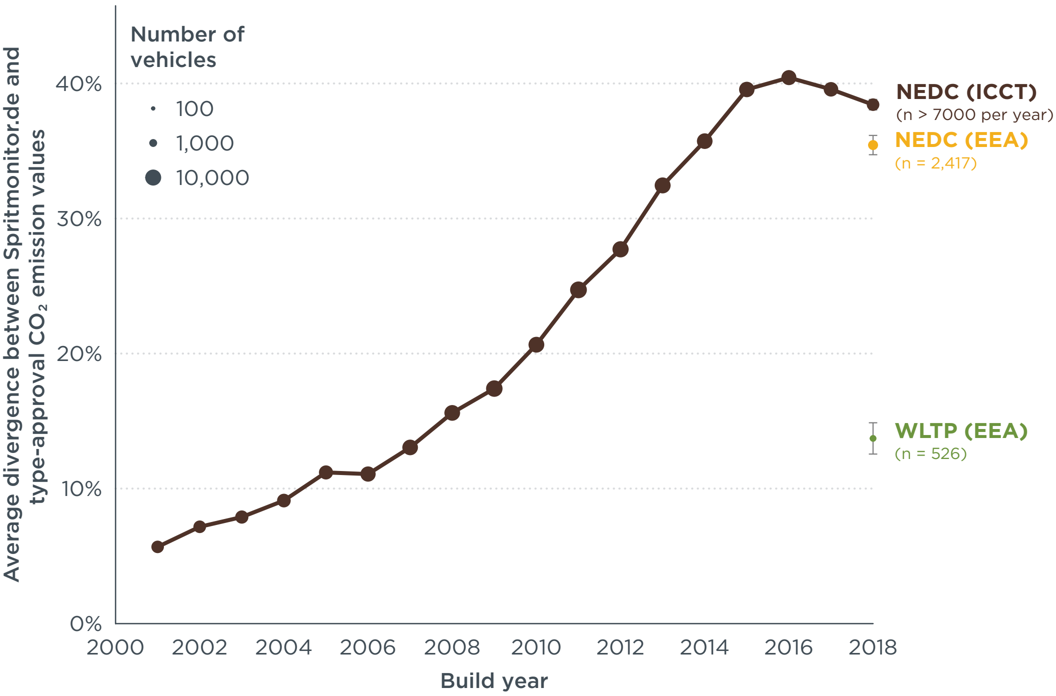

Figure ES-1. Divergence between Spritmonitor.de and type-approval CO_2 emission values over time, including a differentiation of the divergence for those vehicles that were registered in 2018 and were type-approved to the WLTP.

However, these results for 2018 vehicles should be regarded only as preliminary findings and should not be extrapolated to future years. For one, the amount of data for WLTP vehicles was still relatively low in 2018. It also is likely that the observed average WLTP-NEDC CO_2 ratio and the average real-world gap will notably change for vehicles type-approved from 2019 onward.

This is due to a revision of the WLTP-NEDC correlation procedure, implemented by the European Commission in December 2018, as well as provisions in the post-2020 CO_2 standards, aiming to close earlier regulatory loopholes that allowed and may have incentivized manufacturers to artificially increase the WLTP-NEDC CO_2 ratio.

Based on our analyses, we derive the following recommendations for policymakers:

» **Increase transparency**. Currently it is not possible to differentiate between measured and declared CO_2 values in the EEA CO_2 monitoring database and in publicly accessible member state datasets. To monitor manufacturers' performance and to understand the underlying reasons for the observed WLTP-NEDC CO_2 ratio, it is important to have access to both values. They should be reported to the general public by the European Commission and member states.

» **Continue monitoring**. The 2018 cohort of vehicles is the first one for which a significant amount of WLTP CO_2 data is available. Type-approval NEDC and WLTP values should be closely monitored and the underlying reasons for the observed WLTP-NEDC CO_2 ratio should be scrutinized. If CO_2-based vehicle taxation schemes at the EU member state level are transposed to WLTP, it is important to take into account that the observed WLTP-NEDC CO_2 ratio for 2018 is likely not representative of future years.

» **Implement correction mechanisms**. With its revision of the WLTP-NEDC correlation procedure at the end of 2018, the European Commission strengthened the procedure and made it more difficult for manufacturers to exploit regulatory loopholes. However, manufacturers still can declare unreasonably high WLTP CO_2 emission values to arrive at less stringent target levels for 2021–2024. We therefore recommend implementing a correction mechanism that would lower a manufacturer target value from 2021 onward in case an intentional inflation of the WLTP-NEDC CO_2 ratio is observed.

» **Ensure real-word CO_2 reduction.** As part of the CO_2 standards regulation, the European Commission is required to assess how data from fuel consumption meters may be used to prevent the real-world gap from growing, by June 2023 at the latest. In 2027, the European Commission must furthermore assess the feasibility of adjusting each manufacturer's average CO_2 emissions to its real-world performance, beginning in 2030. With respect to the tremendous importance of realistic CO_2 emission values for the success of the European Green Deal, this timeline should be expedited.

TABLE OF CONTENTS

ABBREVIATIONS

ADAC	Allgemeiner Deutscher Automobil-Club
CO_2	Carbon dioxide
CO_2MPAS	CO_2 Model for PAssenger and commercial vehicles Simulation
EEA	European Environmental Agency
EU	European Union
JRC	Joint Research Centre
LAT	Laboratory of Applied Thermodynamics, University of Thessaloniki
NEDC	New European Driving Cycle
RDE	Real Driving Emissions
UK	United Kingdom
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

INTRODUCTION

Since the 1990s, fuel consumption and CO_2 emission levels of new passenger car models in Europe have been determined using the New European Driving Cycle (NEDC). The NEDC defined a speed trace that all new vehicle models need to follow during laboratory testing. In addition, it specified allowed ranges for a number of factors influencing the test procedure, such as the tire pressure or the ambient temperature of the laboratory test cell (Mock et al., 2014). As a result, the NEDC ensured a high level of reproducibility of fuel consumption and CO_2 emission test results.

Nevertheless, analyses by ICCT and other research organizations demonstrate that the discrepancy between official NEDC CO_2 emission[1] values and fuel consumption figures experienced by the average customer during real-world driving have increased dramatically over time. In 2001, this real-world gap was about 8%, meaning the average real-world CO_2 emission level of new cars was about 8% higher than the official NEDC level. By 2017, the gap had reached about 39% (Tietge et al., 2019). Between 2009 and 2015, the rate at which the gap increased was particularly high. This indicates that, at a time when the first mandatory CO_2 standards for new cars came into effect, manufacturers optimized vehicles for NEDC test conditions and increasingly exploited flexibilities in the NEDC test procedure (Stewart, Hope-Morley, Mock, & Tietge, 2015).

As a consequence, NEDC CO_2 emission values over time became less representative of real-world driving and less comparable between individual vehicle models and production years. This development had negative consequences for consumers who were spending more on fuel than advertised, governments due to foregoing tax revenue and misaligned tax incentives, vehicle manufacturers by creating a tilted playing field and a loss of credibility, and society as a whole due to not achieving expected emission reductions and facing accelerating climate change.

In 2007, a United Nations subcommittee decided to develop a new test procedure for passenger car emissions that would better reflect driving conditions in the real world and globally harmonize testing conditions as much as possible, thereby making it easier and cheaper for manufacturers to offer vehicles in different markets (Mock et al., 2014). In 2014, the first version of this new test procedure, the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), was adopted at the United Nations level (Mock, 2013).

In the European Union (EU), the WLTP was transposed into the applicable type-approval regulation by June 1, 2017. Starting in September 2017, all new vehicle models[2] are type-approved following the WLTP instead of the NEDC test procedure (Commission Regulation [EU] 2017/1151, 2017). To encourage a smooth transition, existing vehicle models that were type-approved under the NEDC could still be registered in the EU until August 31, 2019.

The ratio between NEDC and WLTP CO_2 values is a cornerstone of EU vehicle efficiency policies because it affects new-vehicle CO_2 targets from 2021 onward. Due to a one-year phase-in period and special derogations for the sale of end-of-series vehicles, the transition from NEDC to WLTP stretches over a period of four calendar years. The new passenger car fleet coming to the market between 2017 and 2019 is a mix of vehicles that are type-approved according to the NEDC or the WLTP.[3] For the 2020 fleet, it was decided to keep the CO_2 target based on the NEDC and to determine vehicle-specific NEDC values for those vehicles type-approved under WLTP, using a WLTP-NEDC

1 Fuel consumption and CO_2 emissions of a vehicle are directly linked. In the following, for better readability, we refer only to CO_2 emission levels.

2 For passenger cars of category M1 and light commercial vehicles of category N1 class I. For light commercial vehicles of category N1 class II and III and of category N2, the WLTP introduction dates are delayed by one year.

3 Light-commercial vehicles of category N1 class II/III newly registered in 2020 can still be type-approved according to NEDC due to end-of-series provisions.

correlation procedure (Commission Regulation [EU] 2017/1153, 2017). From 2021 onward, the fleet targets will be WLTP based. For the time period between 2021 and 2024, the 2020 NEDC target value will be adjusted to WLTP, applying manufacturer-specific correlation factors that are derived from the ratio of declared WLTP and NEDC values of new vehicle registrations in 2020. For the years 2025 to 2030, instead of absolute target values, percentage CO_2 reduction targets apply. The baseline for those percentage reductions will be determined by converting the 2020 NEDC target value of 95 g/km to a 2021 WLTP target, using the marketwide fleet average ratio of measured WLTP to declared NEDC CO_2 values of the year 2020.

The strong dependency of future CO_2 targets on the WLTP-NEDC CO_2 ratio in 2020 may incentivize manufacturers to exploit the WLTP-NEDC correlation procedure by simultaneously understating NEDC and overstating WLTP CO_2 values. To prevent manufacturers from doing so and to reduce the testing burden, the European Commission introduced a simulation-based methodology, based on the CO_2MPAS (CO_2 Model for PAssenger and commercial vehicles Simulation), along with additional regulatory guidance to convert measured WLTP values into calculated NEDC CO_2 values (Fontaras et al., 2018).

The preliminary 2018 European Environmental Agency (EEA) CO_2 monitoring dataset presents the first opportunity to analyze the WLTP-NEDC CO_2 ratio based on a larger set of empirical data. The dataset includes declared NEDC and WLTP CO_2 type-approval values for about 26% of the passenger cars newly registered in that year (Tietge, 2019). Using this dataset, we can calculate WLTP-NEDC correlation factors and analyze potential patterns, for instance by fuel type or by manufacturer. In addition, we can compare these type-approval CO_2 values with real-world CO_2 values reported by vehicle owners, measured during their daily on-road driving. Our analysis in this paper builds on previous work carried out by TNO (Ligterink, Cuelenaere, & Stelwagen, 2019) and the Joint Research Centre of the European Commission (JRC) (Chatzipanagi, Pavlovic, Komnos, Ciuffo, & Fontaras, 2019), and updates previous analyses carried out by ICCT as part of its “From Laboratory to Road” series (Tietge et al., 2019).

The rest of this study is structured as follows. In section 2 of the paper, we explain how CO_2 emission levels of new vehicles are determined during the WLTP-NEDC transition phase. In section 3, we analyze available NEDC and WLTP type-approval and measured data to identify potential preliminary patterns. In section 4, we add real-world data to the analysis to quantify the gap between NEDC, WLTP, and real-world fleet CO_2 values. Section 5 is a summary of our findings and concludes with a set of recommendations to regulators.

This study focuses solely on passenger cars. Light-commercial vehicles are outside the scope but should be studied in future analyses because they are similarly affected by the WLTP-NEDC transition.

DETERMINING VEHICLE CO_2 EMISSION VALUES DURING THE TRANSITION PHASE

With the introduction of the WLTP in 2017, an increasing number of new vehicles were type-approved to the WLTP instead of the NEDC. The regulatory CO_2 target for 2020, however, remains based on NEDC. As a result, in order to monitor and enforce the 2020 NEDC target, and to determine the equivalent 2021 WLTP target, every new vehicle needs to receive not only a WLTP CO_2 value but also an NEDC CO_2 value.

The most straightforward solution would have been to require manufacturers to double test, which is to say requiring them to determine type-approval NEDC and WLTP CO_2 values by measuring a test vehicle in the laboratory using both the NEDC and WLTP. However, this approach would have placed a high burden on vehicle manufacturers and type-approval authorities, as every type-approval test procedure would have had to be performed twice. In addition, this approach would have provided ample potential for gaming by allowing manufacturers to optimize a vehicle for the NEDC but not the WLTP and thereby artificially increasing the WLTP-NEDC correlation factor.

To prevent mandatory double testing of vehicle CO_2 emissions, the European Commission developed the CO_2MPAS tool, which is used to simulate the NEDC CO_2 emissions of conventional combustion engine vehicles. Due to the complexity and relatively small number of hybrid electric vehicle models, these are not covered by CO_2MPAS and double testing for determining NEDC CO_2 values remains necessary (Commission Implementing Regulation [EU] 2017/1153, 2017).

HOW THE CORRELATION TOOL CO_2MPAS WAS DEVELOPED

The basis for CO_2MPAS consist of vehicle tests carried out in 2014. In total, 12 manual transmission and 8 automatic transmission vehicles were tested under NEDC and WLTP conditions by the Laboratory of Applied Thermodynamics (LAT) of the Aristotle University of Thessaloniki and other contributors (Tsokolis, Dimaratos, & Samaras, 2014). Researchers at LAT and the JRC then fed the test results for those 20 vehicles into commercial vehicle simulation software. Using the software, it was possible to simulate CO_2 emissions over 150–200 operating conditions per vehicle. CO_2MPAS was developed from the resulting pool of about 8,000 NEDC and WLTP tests.

The principal objective was to create a computer simulation software that, upon input of the vehicle characteristics and its measured WLTP CO_2 emission level, would calculate the corresponding NEDC CO_2 emission level with sufficient accuracy. In the next step, the CO_2MPAS tool was calibrated, updated, and validated using another set of 48 tested vehicles. In 2017, CO_2MPAS was released and manufacturers were required to use it when determining NEDC CO_2 values of their WLTP type-approved vehicles (Fontaras et al., 2018). The CO_2MPAS tool has been improved and extended continuously since then. The JRC maintains a growing database of vehicles that is used to verify the stability of the model and the accuracy of its results. The regulation requiring the use of CO_2MPAS also introduced the concept of random sampling and testing to ensure that no tampering of CO_2MPAS occurs. Ten percent of the vehicles type-approved are randomly subjected to testing for this purpose.

Although the development of the CO_2MPAS tool itself was based on technical input derived from vehicle testing, not all loopholes of the NEDC procedure were closed. Some of the test parameters used in the CO_2MPAS tool are the result of political decisions. For example, in the NEDC procedure, manufacturers were allowed to fully charge the battery of a vehicle before carrying out the type-approval test. This practice helped reduce the use of the alternator and thereby obtained a more favorable CO_2 value (Mock et al., 2014). With the introduction of the WLTP, this loophole was closed. Charging the vehicle's battery before the type-approval test and correcting for changes in battery charge levels are now forbidden. For the WLTP-NEDC correlation procedure, however, the European Commission and EU member states decided to treat the battery as fully charged at test start, regardless of whether or not a CO_2MPAS simulation or a physical test is performed (Regulation [EU] 2017/1153, 2017). This manufacturer gaming practice under the NEDC is thus granted full credit.

HOW THE NEDC TYPE-APPROVAL CO_2 VALUE IS DETERMINED

Figure 1 illustrates how the CO_2MPAS tool is applied in the correlation procedure to verify the declared NEDC CO_2 emissions. The scheme differentiates between steps that take place at the manufacturer's testing facilities under supervision of a technical service and/or a member state type-approval authority, and steps that are encoded in the CO_2MPAS software tool and accompanying regulatory procedures.

Step 1: WLTP testing and declaring NEDC and WLTP CO_2 values

Before running the CO_2MPAS tool, the first step during type approval is for a manufacturer to declare the WLTP CO_2 emission value $WLTP_{declared}$ and the NEDC CO_2 emission value $NEDC_{declared}$ for the respective vehicle. The manufacturer declares these values for a "vehicle H" of an interpolation family, which is a vehicle with preferably the highest cycle energy demand (the energy required to perform a drive cycle) of a vehicle family. If the manufacturer decides to apply the interpolation method for determining CO_2 emissions of individual vehicles within an interpolation family (see Step 5), WLTP and NEDC CO_2 values for a "vehicle L", a vehicle with preferably the lowest cycle energy demand, must also be declared. A technical service then carries out physical WLTP vehicle testing of vehicle H and, where applicable, vehicle L, on behalf of the manufacturer and with the vehicles provided by the manufacturer, on a chassis dynamometer in a laboratory.

The test results include CO_2 emission values for each of the four WLTP speed phases (low, medium, high, extra-high), plus an average CO_2 emission value measured over the entire WLTP speed trace ($WLTP_{measured}$). For $WLTP_{declared}$ to be accepted as the official CO_2 value, the respective $WLTP_{measured}$ value must be lower. It can be necessary to perform up to three confirmatory WLTP laboratory tests, depending on the results of the preceding tests.

Step 2: Generating a vehicle-specific CO_2MPAS model

In the second step, the manufacturer generates CO_2MPAS input files for vehicles H and L (if applicable) containing:

» Vehicle, engine, and gearbox parameters;

» WLTP and NEDC road-load parameters;

» CO_2 emission levels measured during laboratory testing for each of the WLTP cycle phases (low, medium, high, extra-high) respectively;

» The declared WLTP CO_2 values ($WLTP_{declared}$); and

» The declared NEDC CO_2 values ($NEDC_{declared}$).

The input files are submitted to the type-approval authority or a technical service where the data are verified and then used as input parameters for CO_2MPAS. The tool generates simulation models that are specific for the respective vehicles H and L. These models are then automatically calibrated to meet the measured CO_2 emission levels for each of the WLTP cycle phases.

The procedural differences between WLTP and NEDC that impact the driving resistance during testing, like vehicle mass or tire pressure and thread depth, are taken into account through differences in the respective road load parameters. Considering these differences, NEDC road load parameters are calculated from the WLTP road load parameters and used for both the simulation and physical testing, if applicable (Commission Implementing Regulation [EU] 2017/1153, 2017).

Step 3: Simulating CO_2MPAS NEDC values

In the third step, the CO_2MPAS models are used to simulate the corresponding NEDC CO_2 values ($NEDC_{CO2MPAS}$). In addition, CO_2MPAS selects at random whether a vehicle must undergo physical verification testing, and if applicable, whether vehicle H or L must be tested. On average, 10% of the vehicle interpolation families for which CO_2MPAS is used are verified by physical testing. Independent of a vehicle being selected for double testing, data on the performance and accuracy of all official CO_2MPAS simulations are communicated to the JRC for monitoring the stability and accuracy of the model.

Step 4.1: Determination of official CO_2 type-approval value

In a fourth step, the CO_2 emission values to be accepted as the official type-approval value of vehicle H and, if applicable, L are determined.

If the respective simulated $NEDC_{CO2MPAS}$ value does not exceed the manufacturer declared value $NEDC_{declared}$ by more than 4%, the declared value is accepted as the official type-approval value of vehicle H or L respectively. Otherwise, the manufacturer can decide either to accept the $NEDC_{CO2MPAS}$ result as official type-approval value or perform a physical NEDC test.

In the latter case, a physical NEDC test is conducted by a technical service or the type-approval authority. To ensure results comparable to CO_2MPAS, the conditions and calculated road load parameters from the simulation are used. Deviations are allowed only where the physics of chassis dynamometer testing necessitate them. The measured CO_2 emissions $NEDC_{measured}$ value must not exceed the $NEDC_{declared}$ value by more than 4% for a declared $NEDC_{declared}$ value to be accepted as the official type-approval NEDC value. Otherwise, the physical NEDC test must be repeated. If the average $NEDC_{measured}$ of both tests also exceeds the 4% threshold, a third test is performed and the average $NEDC_{measured}$ of all three tests becomes the type-approval value.

Step 4.2: Random verification testing

The random number generated by CO_2MPAS determines if and which vehicle of an interpolation family must undergo a physical NEDC test for verification. If the selected vehicle was already physically tested in step 4.1 to determine the official type-approval NEDC CO_2 value, the other vehicle defining the interpolation family is physically tested instead. If both vehicles were already physically tested or if the interpolation vehicle is defined by only one vehicle H, no physical verification test is performed.

A deviation factor (“De” factor) is calculated for random verification tests. The factor is based on the random test results, reflecting the relative deviation between measured $NEDC_{measured,RT}$ and declared CO_2 emissions $NEDC_{declared}$ (see Figure 1).

Step 5: Determining CO_2 values for individual vehicles

Under the NEDC regulation, all vehicles belonging to a vehicle type[4] were assigned the same CO_2 emission value. However, even for vehicles of the same type, the CO_2 emissions can vary substantially depending on their individual, customer-selected configuration. Optional equipment, for example, increases vehicle mass. Wider or less efficient tires increase the rolling resistance and rims or other body parts lead to differences in aerodynamic drag. These variations have a direct effect on the cycle

4 Under NEDC, a vehicle type is a group of vehicles which are part of the same inertia class and do not differ in engine and vehicle characteristics. They can, however, differ in parameters like wheel size, tire dimensions, and optional equipment.

energy demand but are not taken into account in the NEDC. In most cases, the NEDC approach therefore furnishes unrepresentatively low CO_2 emission values.

With the introduction of the WLTP, every vehicle is assigned an individual CO_2 emission value. In principle, this would require testing every possible vehicle configuration. To reduce the testing burden, the CO_2 interpolation family concept was introduced.

This concept allows a manufacturer to group vehicles in interpolation families if their CO_2 emissions are only linearly dependent on the cycle energy demand.[5] The manufacturer can then choose between two options to determine the CO_2 emissions of individual vehicles.

The first option is defining both a vehicle H and L, representing the vehicles with the highest and lowest cycle energy demand of all vehicles in the interpolation family. After the NEDC type-approval values are determined for vehicles H and L, the manufacturer derives the WLTP and NEDC CO_2 value for an individual vehicle using linear interpolation based on the respective cycle energy demand of the individual vehicle as input.

Alternatively, the manufacturer could choose not to apply the CO_2 interpolation method and define only a vehicle H, the vehicle with the highest cycle energy demand. In that case, all individual vehicles in the interpolation family share the vehicle H WLTP and NEDC CO_2 type- approval values.

Step 6: Adjusting manufacturer CO_2 emission performance

To prevent manufacturers from gaming the correlation procedure, a correction mechanism was defined that takes effect if either the deviation factor determined in step 4.2 exceeds 4% for any interpolation family or if the manufacturer has provided inaccurate correlation procedure input data. In these cases, a correction factor is calculated as the sales weighted deviation factor for all vehicles in an interpolation family for which a deviation factor exists. The fleet average NEDC CO_2 emission value of that manufacturer is then increased by the correction factor.

5 The cycle energy demand of an individual vehicle is calculated based on its road load parameters. Similar to the CO_2 interpolation concept, the road load parameters of an individual vehicle are determined by linear interpolation of the respective parameters of a vehicle L and H of a road load family.

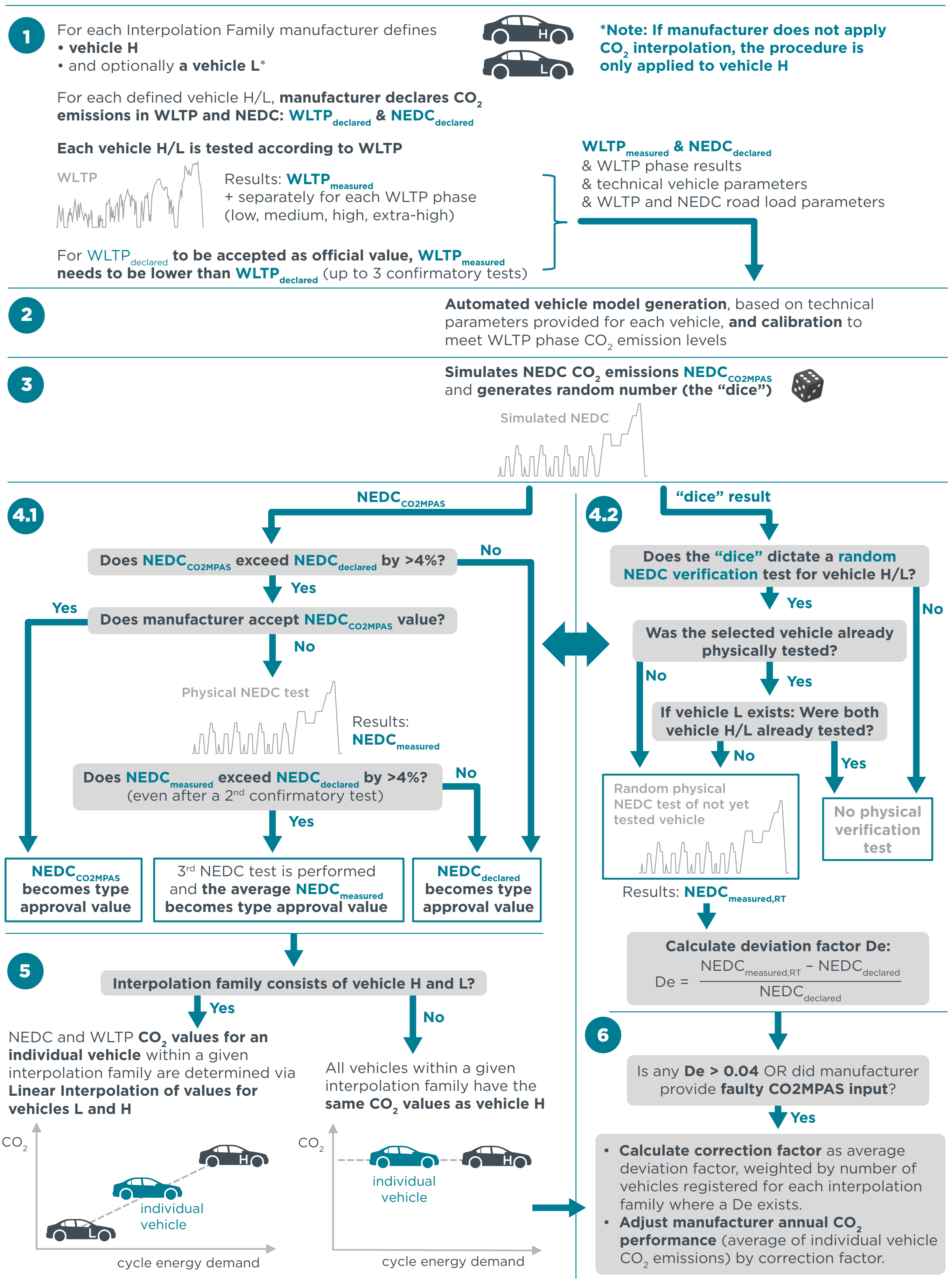

Figure 1. Schematic illustration of the correlation procedure used to determine the official type-approval NEDC CO_2 value of a vehicle type-approved according to the WLTP.

HOW THE CORRELATION PROCEDURE CAN BE GAMED

As explained above, the CO_2 targets for 2021 and beyond are directly linked to the ratio of WLTP to NEDC CO_2 emissions in 2020. This provides an incentive for manufacturers to inflate the WLTP-NEDC CO_2 ratio using the following strategies.

The WLTP-NEDC correlation procedure provides manufactures with the opportunity to declare NEDC CO_2 values up to 4% lower than a vehicle is expected to emit. Originally, the 4% margin was intended to cover uncertainties of the simulation tool. However, the same margin is applied to physical NEDC testing whereas the repeatability of NEDC CO_2 emissions is reported to be within 1% (Pavlovic, Ciuffo, Fontaras, Valverde, & Marotta, 2018). It can be assumed that manufacturers regularly perform physical NEDC testing during product development and therefore know precisely about a vehicle's CO_2 emissions level. Because an exceedance of the 4% margin between the calculated CO_2MPAS and declared NEDC CO_2 value would only trigger physical testing, the manufacturer can understate the NEDC value virtually without risk.

Manufacturers could also declare higher WLTP CO_2 emissions than necessary. This is possible because manufacturers need only to demonstrate during type approval that a vehicle emits less CO_2 emissions than declared. No upper limit for the declared value was defined, as overstating CO_2 values usually is not considered to be in the interest of the manufacturer—manufacturers typically aim for low CO_2 values in order to meet CO_2 regulations and to advertise vehicle efficiency. However, for several reasons, inflating declared WLTP CO_2 values is less critical for the manufacturers. First, the WLTP CO_2 emissions are not relevant for meeting the current, NEDC-based, CO_2 targets. Second, advertised CO_2 emissions were until recently, and partly still are, NEDC values. And lastly, customers do not have experience with and hence have no expectations about the level of WLTP CO_2 values.

The European Commission published a study in July 2018 that found manufacturers' declared WLTP CO_2 values were as much as 13% higher than measured WLTP CO_2 values. On average, the difference was found to be around 4.5% (European Commission, 2018).

To minimize the long-term effect of gaming declared WLTP CO_2 values, post-2020 CO_2 standards specify that CO_2 targets for 2025 and beyond will not be based on the declared but instead on the measured WLTP CO_2 emissions in 2020 (Regulation [EU] 2019/631, 2019). However, correcting the target calculation for the years 2021 to 2024 is not possible because it has already been passed into law. Consequently, manufacturers could still exploit this loophole. As a response, the European Commission created an amendment, requiring manufacturers to report both the declared and measured WLTP CO_2 emissions through the CO_2MPAS input file, enabling the European Commission to monitor inflated declared values (Regulation (EU) 2018/2043, 2018). However, no corrective measures are defined and the data are not made publicly available to date.

Another approach taken by some manufacturers, at least initially, was to apply different engine and vehicle operating strategies in WLTP and NEDC. The European Commission published the results from detailed test data of two vehicles in the aforementioned study (European Commission, 2018). The WLTP tests of the two vehicles were found to have been manipulated in such a way as to inflate the WLTP CO_2 value. Specifically, the WLTP tests were carried out starting with a discharged battery, with the start-stop system turned off, and using higher engine speeds than foreseen by the gearshift provisions. The European Commission estimated that these measures increased WLTP CO_2 values of the vehicles by about 5%. In the case of another vehicle, the European Commission found that different gearshift strategies were applied during WLTP and NEDC testing in order to inflate the WLTP CO_2 value.

To prevent manufacturers from applying different strategies for WLTP and NEDC testing, in December 2018, the European Commission issued an amendment to the WLTP-NEDC correlation procedure, requiring manufacturers to operate all CO_2 saving devices in a vehicle during WLTP as well as NEDC testing. Similarly, manufacturers are now required to apply the same gearshift strategy for both tests (Regulation [EU] 2018/2043, 2018).

Another possibility for inflating the WLTP-NEDC CO_2 ratio is grouping vehicles in an interpolation family while not applying the CO_2 interpolation method for individual vehicles. As described in Step 5 of Figure 1 and illustrated in Figure 2, in this case the official WLTP and NEDC CO_2 values of vehicle H are applied to all vehicles within the family. The left side of Figure 2 shows the effect of differences in cycle energy determination between WLTP and NEDC. Whereas differences in aerodynamic drag and rolling resistance are taken into account in both procedures when defining vehicle H and L, only the WLTP procedure takes into account the actual mass of the vehicle, including the additional mass of optional equipment. The NEDC procedure, by contrast, takes into account only the mass of the base vehicle, excluding any optional equipment. The difference in mass between vehicle H and L therefore is substantially higher in WLTP than in NEDC, resulting in a larger difference in cycle energy and subsequently a larger spread in CO_2 emissions.

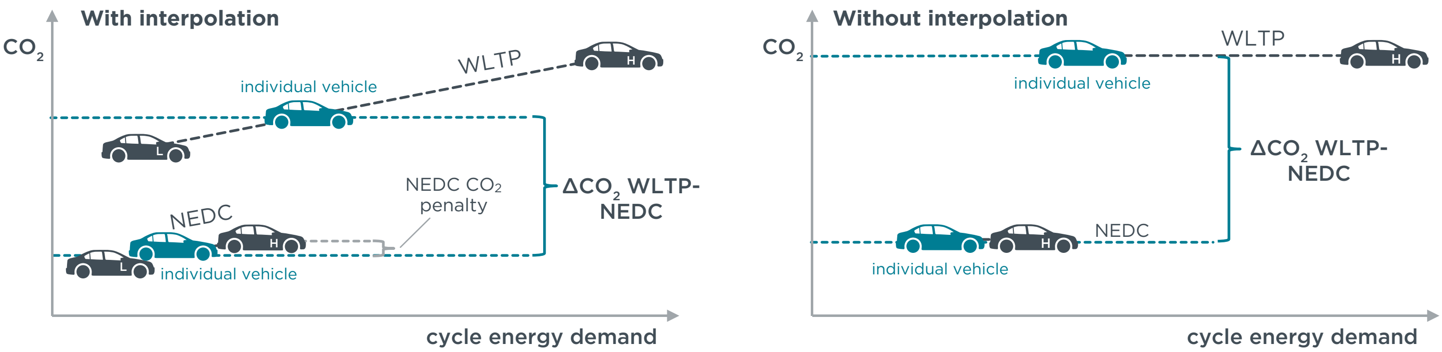

Figure 2. Inflating WLTP-NEDC CO_2 ratio by defining only a vehicle H and not using the CO_2 interpolation method for individual vehicles in a family.

As a consequence, when not applying the interpolation method, the difference between WLTP and NEDC CO_2 emissions for an individual vehicle (right side of Figure 2) is considerably higher than if determined using CO_2 interpolation (left side of Figure 2). The main drawback for a manufacturer not applying the CO_2 interpolation method is higher official NEDC CO_2 values for individual vehicles. However, considering the long-term effect with respect to future WLTP-based CO_2 targets, the potential benefits for a manufacturer are likely to outweigh this shorter-term drawback. For this reason, the European Commission introduced the possibility of excluding suspicious vehicle families from the calculation of a manufacturer's WLTP-NEDC CO_2 ratio in 2020 (Commission Implementing Regulation [EU] 2018/2043, 2018). However, detailed data on manufacturers applying or not applying the CO_2 interpolation method for vehicle families are not publicly available to date.

ANALYZING AVAILABLE LABORATORY DATA

Using the EU monitoring data for 2018, it is possible to obtain a first glimpse of the WLTP-NEDC CO_2 ratio (EEA, 2019).[6] The data that the EEA publishes are the WLTP and NEDC CO_2 values as reported in the certificate of conformity of the vehicles and submitted by Member States. Complementing the EEA data with data provided by the Allgemeine Deutsche Automobil-Club (ADAC) allows for a more in-depth analysis: As part of its EcoTest, ADAC provides not only the type-approval WLTP and NEDC CO_2 values for 183 new passenger cars, but also its own WLTP measurement results for comparison. By using both datasets, it is possible to derive preliminary conclusions about the WLTP-NEDC CO_2 ratio and possible explanations for noteworthy patterns.

EEA DATA

The preliminary EEA dataset covers about 15 million new passenger car registrations for the year 2018, of which about four million, or 26%, have both a WLTP and an NEDC CO_2 value. The majority of vehicles, 71%, have only an NEDC value. The remaining 3% of vehicles have only a WLTP value, a case not foreseen by the regulation. The NEDC type-approval CO_2 values for those vehicles type-approved according to the WLTP are derived following the correlation procedure illustrated in Figure 1.

The mean WLTP-NEDC CO_2 ratio of the raw dataset is 1.21, but values range from 0 to 18. Figure 3 plots the distribution of the WLTP-NEDC CO_2 ratio in the raw data. The 43,000 vehicles with a WLTP-NEDC CO_2 ratio of 1—vehicles that allegedly have the same WLTP and NEDC CO_2 value—stand out in the distribution. This subset represents 1% of all vehicles that have both WLTP and NEDC CO_2 values. Almost two-thirds of the vehicles with a WLTP-NEDC CO_2 ratio of 1 were registered in Germany, and almost one third were registered in the United Kingdom (UK). Of the UK vehicles, the vast majority with a WLTP-NEDC CO_2 ratio of 1 were of the Opel/Vauxhall brand. Various brands were affected in Germany. Because these vehicles stand out in the distribution, and because there is no plausible explanation for this pattern other than data entry or transmission errors, we remove these vehicles from further analysis. A portion of the records were likely valid, but the number of valid records with a WLTP-NEDC CO_2 ratio of 1 would likely be minute.

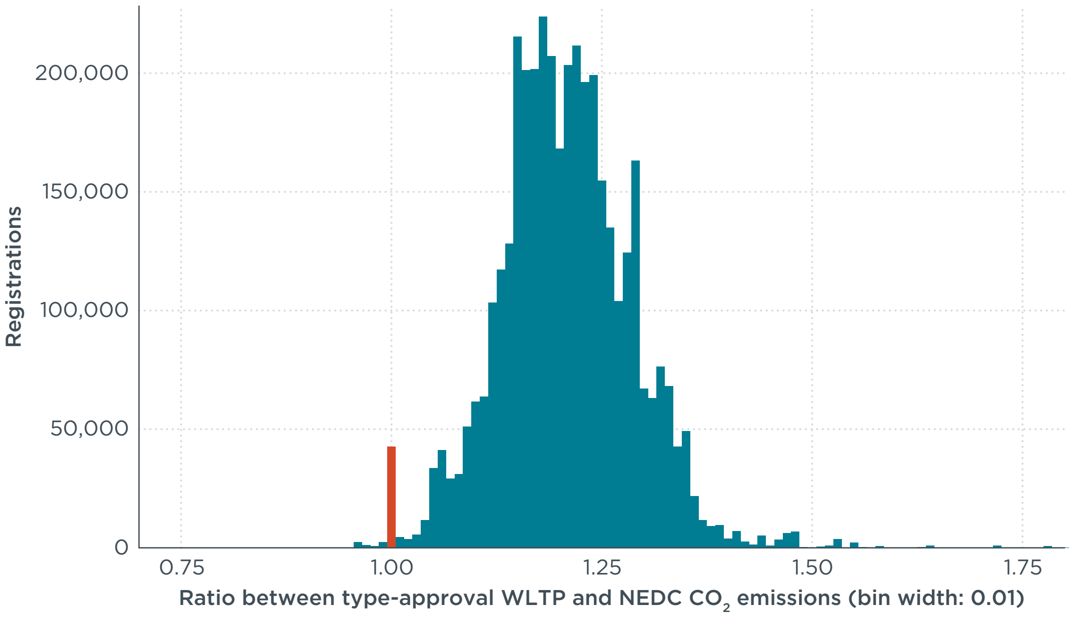

Figure 3. Distribution of 2018 new car registrations in the EEA dataset, by WLTP-NEDC CO_2 ratio.

6 For the analysis within this paper, we used the preliminary dataset published by EEA in mid-2019 (EEA, 2019). Since its publication, the preliminary EEA data underwent further scrutiny, and vehicle manufacturers had the possibility to request a change of their data in case of inconsistencies.

To simplify the analysis, we further remove NEDC or WLTP type-approved vehicles with no tailpipe emissions (battery and fuel cell electric vehicles), vehicles with NEDC CO_2 emissions below 50 g/km (plug-in hybrid electric vehicles), and bi-fuel vehicles (vehicles using both gasoline and natural gas or liquified petroleum gas). The remaining vehicles represent 98% of the vehicles with both NEDC and WLTP CO_2 values.

Lastly, we remove all vehicles with a WLTP-NEDC CO_2 ratio lower than the 0.05th percentile and above the 99.95th percentile in order to obtain a plausible range of WLTP-NEDC CO_2 ratios (see Figure 4). The vast majority of the 0.1% (2,037) of vehicles that are removed were registered in Germany.

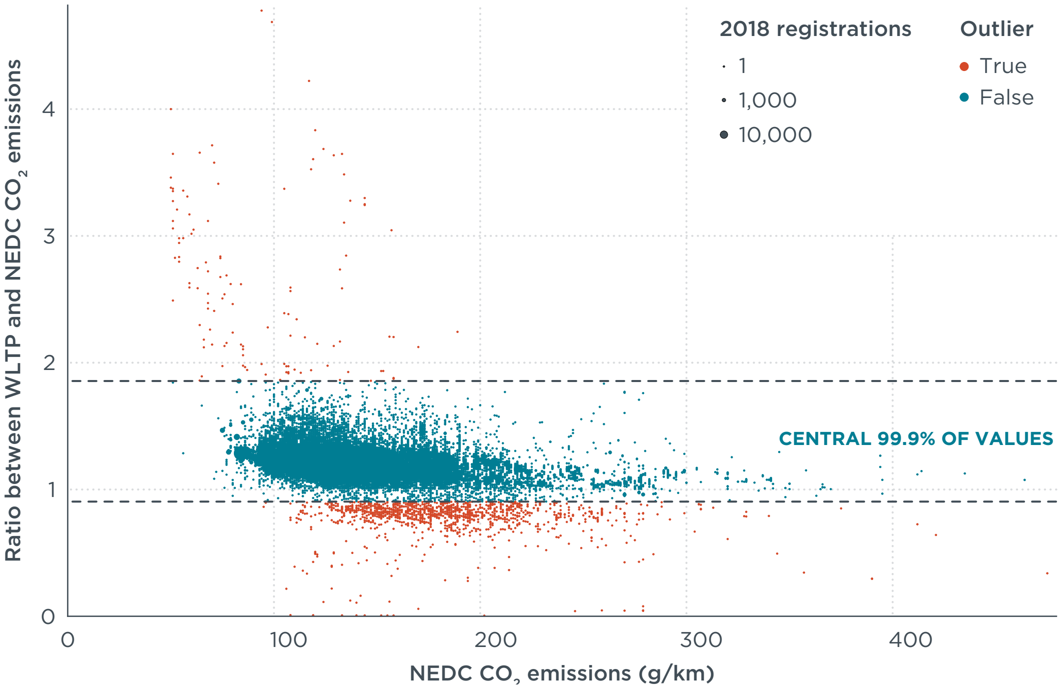

Figure 4. WLTP-NEDC CO_2 ratio of 2018 new car registrations in the EEA dataset, plotted over their respective NEDC CO_2 emission levels, also indicating which data points are removed as outliers from further analysis.

Figure 5 summarizes the steps undertaken to filter the preliminary 2018 EEA dataset for further analysis. Starting originally with 15.2 million new passenger car registrations, after removing duplicates, filtering for vehicles with both WLTP and NEDC CO_2 values, and applying a set of additional filters, about 3.8 million vehicles remain for further analysis.

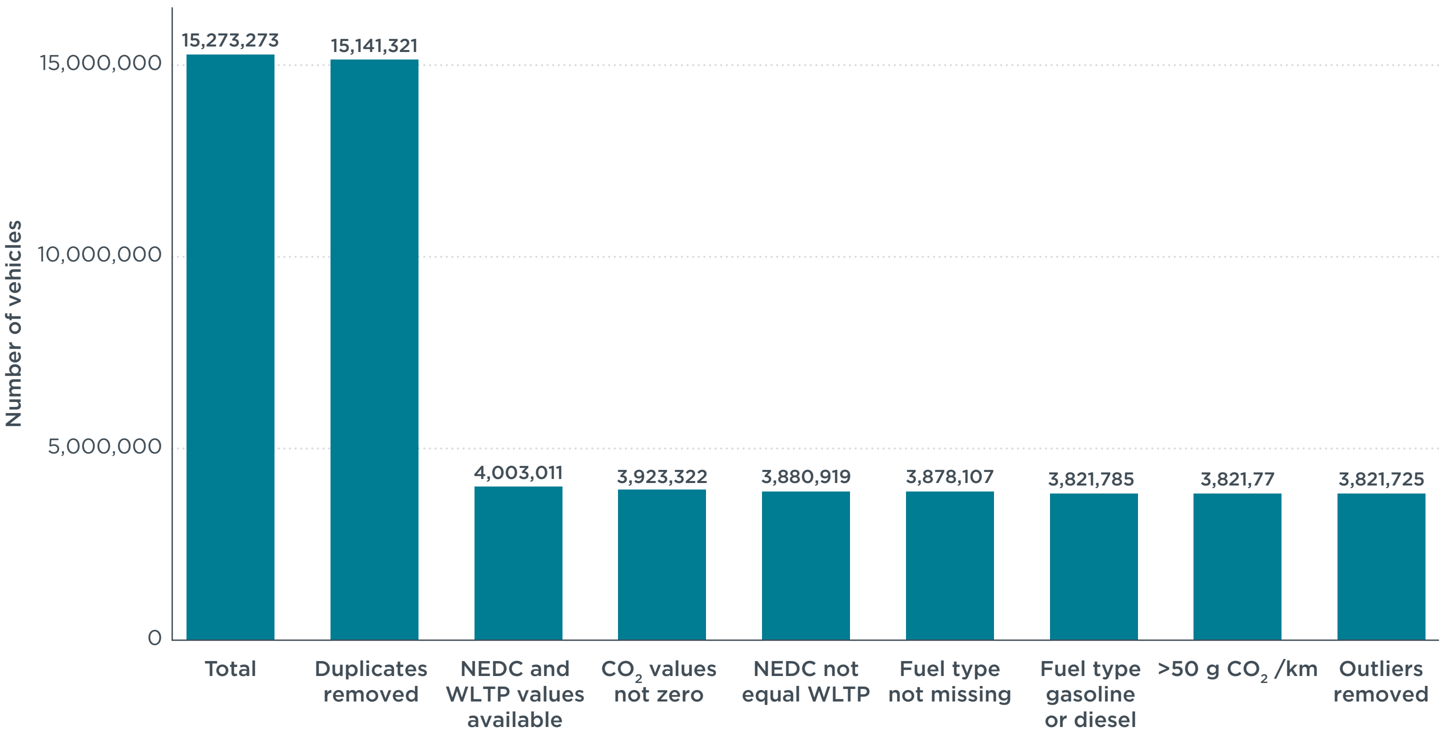

Figure 5. Filtering stages of the 2018 EEA new passenger car CO_2 monitoring dataset. Each bar represents the remaining number of entries after applying a filter.

Figure 6 plots the distribution of the WLTP-NEDC CO_2 in the filtered data. The mean ratio of the filtered dataset is still 1.21, the same as for the initial raw dataset. The range of the ratio, however, is much narrower at 0.9–1.9, thus reducing the risk of implausible values skewing the results. The mean WLTP-NEDC CO_2 ratio differs significantly between gasoline (1.19) and diesel vehicles (1.24).

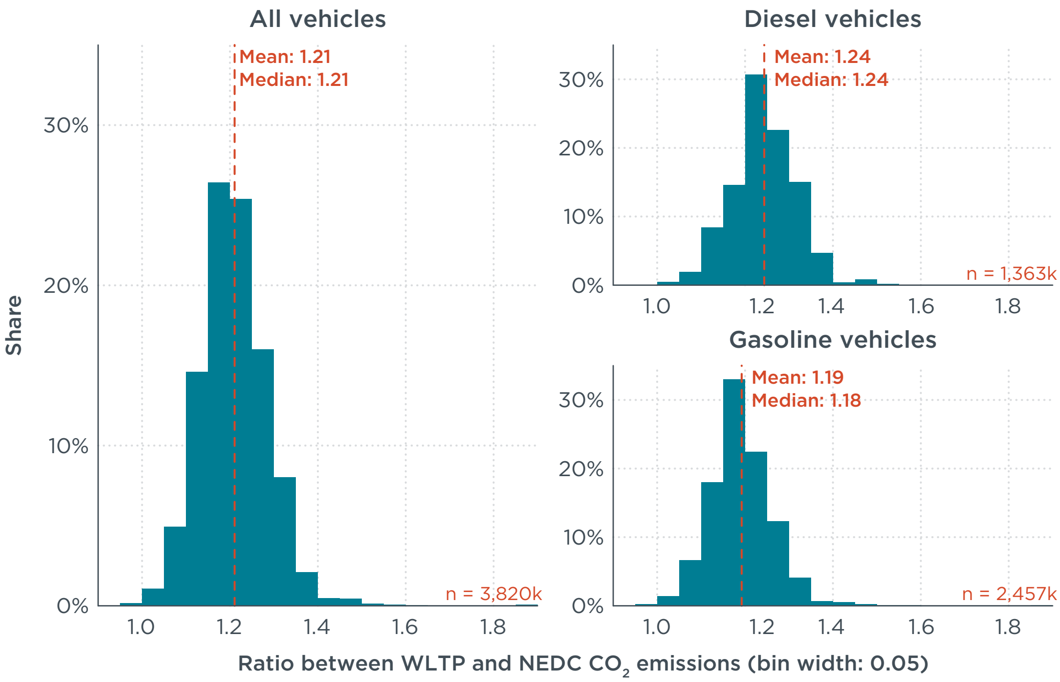

Figure 6. Distribution of the WLTP-NEDC CO_2 ratio for new gasoline and diesel cars registered in 2018.

The average ratio also varies significantly among manufacturers, ranging from a level of 1.15 in the case of Hyundai to 1.24 for Nissan (see Figure 7). The WLTP-NEDC CO_2 ratio for diesel cars tends to be higher than for gasoline vehicles, but this pattern is more pronounced for some manufacturers than for others. Fiat Chrysler Automobiles (FCA), Toyota-Mazda, BMW and Daimler have comparatively narrow diesel-gasoline spreads, below 0.02. Nissan has a significantly wider spread of 0.14.

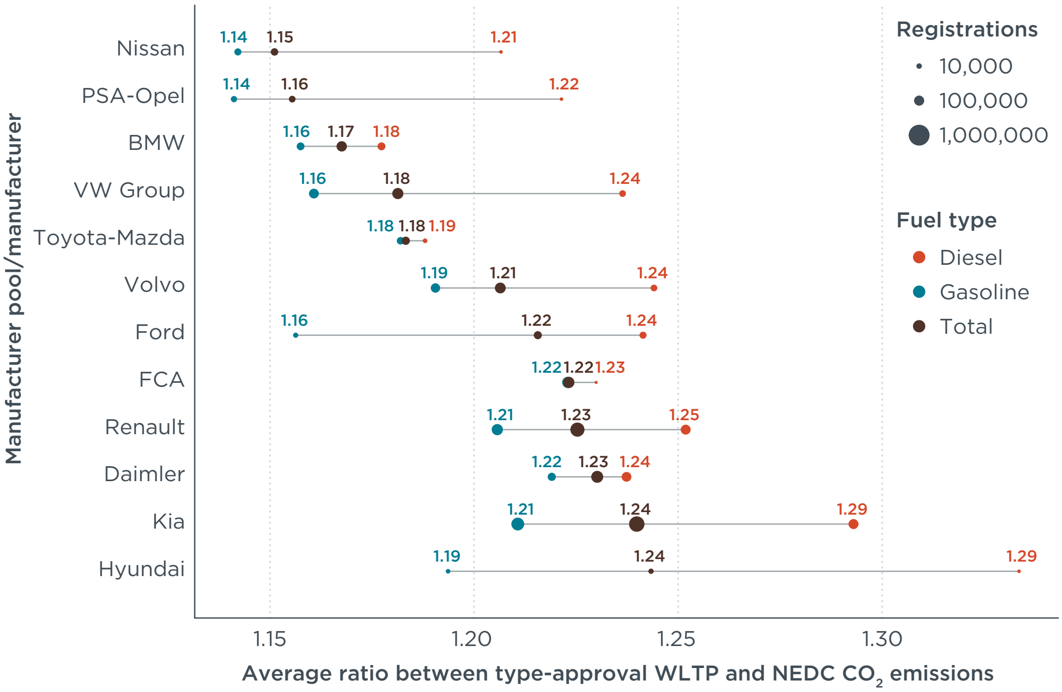

Figure 7. Average WLTP- NEDC CO_2 emission ratios for new gasoline and diesel cars registered in 2018, by vehicle manufacturer.

The average WLTP-NEDC CO_2 ratios observed from the preliminary EEA dataset are roughly in line with an analysis of manufacturer reported values for 205 type approvals carried out by (Chatzipanagi et al., 2019) and the values used by the European Commission in past exercises. This analysis concluded that the average ratio was 1.14–1.19 for gasoline cars and 1.18–1.27 for diesel cars, with the lower end of the ranges referring to vehicle L and the upper end to vehicle H CO_2 values.

An analysis of new passenger car registrations in the Netherlands between September 2017 and April 2019 concluded that the WLTP-NEDC type-approval CO_2 ratio for an average car with an NEDC type-approval value of 120 g/km was about 1.20 for gasoline and 1.25 for diesel vehicles (Ligterink et al., 2019). These findings are in line with the mean WLTP-NEDC CO_2 ratio of 1.21 in the preliminary EEA dataset. The authors attribute the higher ratio for diesel cars to potentially being the "result of technologic changes to accommodate [the newly introduced] Real Driving Emissions (RDE) legislation."

Two limitations of the CO_2 monitoring data should be noted. First, EEA data of vehicles that were type-approved after amendment (EU) 2043/2018 to the correlation procedure was published in December 2018 will become available starting in 2020. This amendment disincentivizes inflating WLTP-NEDC CO_2 ratios and could thus result in lower WLTP CO_2 values. Second, the type-approval data reported by EEA contains only declared WLTP CO_2 emission levels. Because inflating declared WLTP CO_2 values is one of the principal mechanisms for producing higher WLTP-NEDC CO_2 ratios, we turn to an additional dataset, provided by ADAC, in the following section.

ADAC DATA

The ADAC, Europe's largest car drivers' association, regularly tests a number of new vehicle models as part of its EcoTest program. For our analysis, ADAC provided a dataset containing results of 183 WLTP type-approved vehicles tested in a laboratory environment between January 2018 and November 2019. The raw dataset includes 80 diesel, 98 gasoline, and five natural gas passenger cars. Of the gasoline vehicles, 11 are full-hybrid electric and six are plug-in hybrid electric vehicles. For each vehicle, the ADAC data contain NEDC and WLTP type-approval CO_2 values as stated in the Certificate of Conformity as well as WLTP values measured by the ADAC. The WLTP tests performed for the EcoTest program deviate from the regulatory procedure in the points shown in Table 1 (ADAC, 2019).

Table 1: Procedural differences in WLTP testing for type approval and for the ADAC EcoTest

Subject	Type-approval test	ADAC EcoTest	EcoTest CO_2 is...
Automatic air conditioning	Off	Set to 20°C	Higher
Vehicle test mass	Fuel tank: 90% full Payload: 15% of max. payload	Fuel tank: 100% full Payload: 100 kg	Higher
Fuel	Reference fuel	Market fuel	Higher
Ambient temperature correction	Correction from 23°C to 14°C applied	No correction applied	Lower
Battery charge level correction	Correction applied	No correction applied	Lower
Gear selection	WLTP gearshift tool used	Gearshift indicator used	Higher

The procedural differences listed in Table 1 influence the measured CO_2 emissions as follows:

» **Air conditioning:** Using air conditioning increases fuel consumption and thus CO_2 emissions. Because the test temperature of 23°C is only slightly higher than the desired interior temperature of 20°C, the effect from modern demand-responsive systems is expected to be relatively small.

» **Vehicle test mass:** Although the vehicle test mass for type approval includes a 90% full fuel tank and a payload corresponding to 15% of the maximum allowed payload, the ADAC EcoTest considers a 100% full fuel tank and a fixed payload of 100 kg. Even for the vehicle with the highest payload tested by ADAC, a Mercedes GLE 350d, the resulting test mass for ADAC was higher than during type approval. For smaller vehicles with less payload, the difference in test mass typically exceeds 80 kg. Considering a CO_2 penalty of 4.2 g/km for each 100 kg (Rohde-Brandenburger, 2014), the test mass can considerably increase the EcoTest CO_2 emissions.

» **Fuel:** Manufacturers develop their vehicles to demonstrate low CO_2 emissions during type approval where reference fuel is used. It can therefore be assumed that CO_2 emissions with market fuel, as used for the EcoTest, are at least the same or higher than the type-approval values.

» **Ambient temperature correction:** For type approval, the WLTP CO_2 emissions determined at 23°C are corrected to an ambient temperature of 14°C, which is considered representative for Europe. This correction is not applied by ADAC. A 2018 JRC study considers an average increase in CO_2 attributed to the change in temperature of 3.9%, when switching from NEDC at 28°C to WLTP at 14°C (Pavlovic et al., 2018). Taking into account the smaller temperature difference of 9°C instead of 14°C, we expect the effect on the ADAC results to be 1% to 2%.

» **Battery charge level correction:** During type approval, the measured CO_2 emissions are corrected for changes in battery charge level to account for the corresponding lower power demand for the combustion engine. This correction is not applied by ADAC. The effect is estimated to be 2 g CO_2/km on average (Ligterink et al., 2015).

» **Gear selection:** The gear selection in WLTP for vehicles with manual transmission is calculated based on vehicle parameters prior to the test. ADAC instead used the dashboard gearshift indicator. Considering that manufactures aim for low type-approval CO_2 emissions while presumably focusing more on drivability and performance when programming the gearshift indicator, we assume that the effect of different gear selection methods results in the same or higher CO_2 emissions during the ADAC EcoTest.

The intensity of the abovementioned different effects can vary substantially for different vehicles. Because some procedural differences have a CO_2 increasing effect while others result in lower CO_2 emissions, the net effect can lead to higher or lower CO_2 emissions in EcoTest compared to a test under type-approval conditions. For the following analysis, we therefore decided to present uncorrected values as measured by ADAC.

Where not explicitly defined, the WLTP and NEDC CO_2 values in the following sections refer to the manufacturer declared values.

For the analysis of the EcoTest data, all vehicles with a WLTP-NEDC CO_2 ratio equal to 1.0 or less than 0.9 were removed, in line with the filter applied to the EEA data. Furthermore, only conventional gasoline and diesel vehicles are considered, leaving out all hybrid and natural gas models. After filtering, test results for a total of 158 passenger cars (81 gasoline and 77 diesel vehicles) from 32 different manufacturer brands remain for further analysis.

Figure 8 plots the distribution of the WLTP-NEDC CO_2 ratio in the ADAC data. The mean ratio is 1.21—the same as for the EEA dataset (1.21) shown in Figure 6. As in the EEA data, the ratio is higher for diesel (1.24) than for gasoline vehicles (1.18). For both fuel types, the ratios vary from less than 1.0 to greater than 1.4.

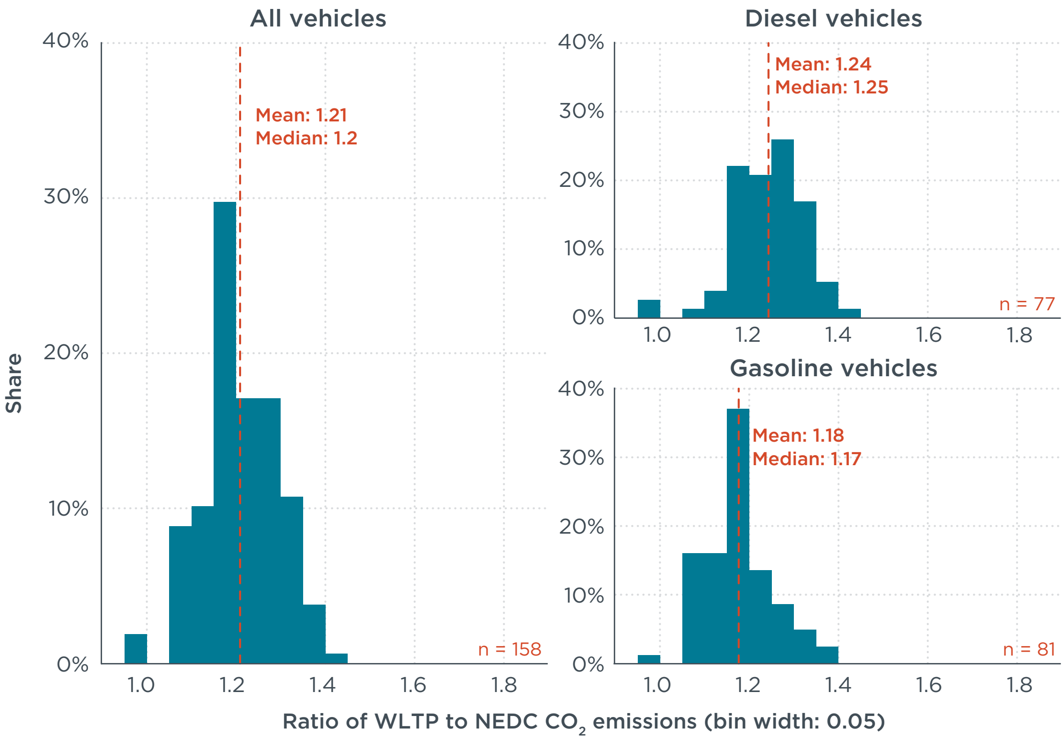

Figure 8. Distribution of the $WLTP_{declared}$-$NEDC_{declared}$ CO_2 ratio for gasoline and diesel cars tested by the ADAC.

Conformity with the EEA data was also confirmed when comparing the resulting curves of a regression analysis of the WLTP-NEDC CO_2 ratio versus NEDC CO_2, as shown in Figure 9. The overall trend of the curve is almost identical to the EEA data. This indicates vehicles selected for testing by the ADAC are reasonably representative of the market in this respect.

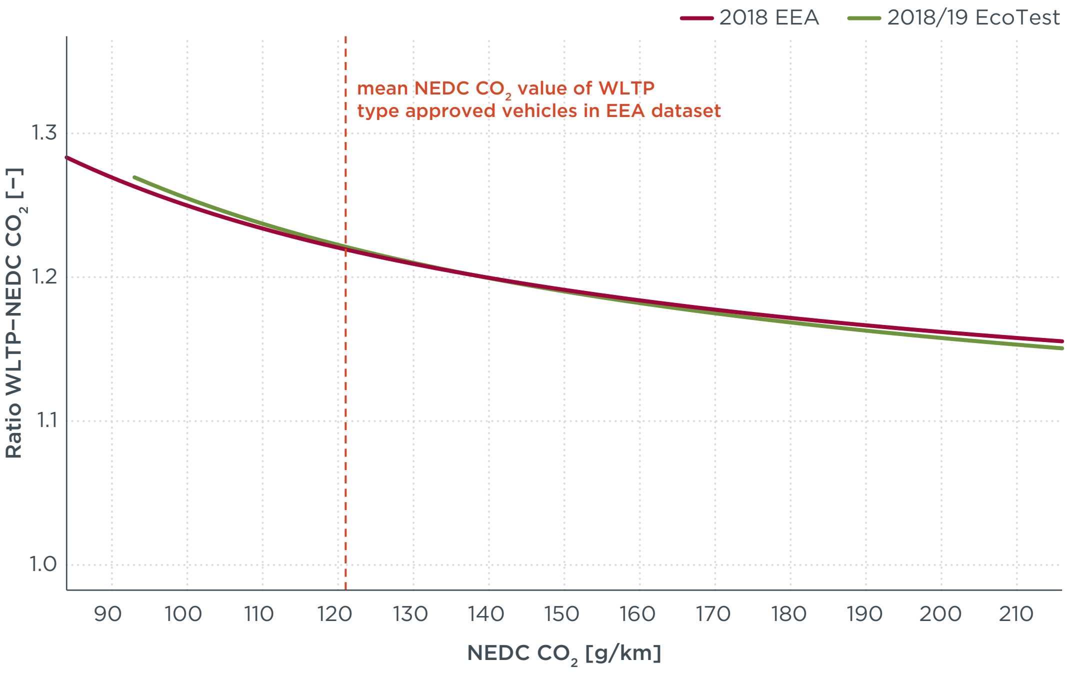

Figure 9. Regression analysis of the $WLTP_{declared}$-$NEDC_{declared}$ CO_2 ratio versus $NEDC_{declared}$ for evaluated entries in the EEA and ADAC data. The good agreement of both curves indicates a representative vehicle selection by ADAC for the EcoTest.

Figure 10 shows the WLTP-NEDC CO_2 ratio both for declared and independently measured WLTP CO_2 values by manufacturer group. As in the EEA data, notable differences between manufacturer groups and between vehicles within the same manufacturer group are evident. The differences between the WLTP-NEDC ratio based on declared and on measured WLTP CO_2 vary substantially, but the available data do not allow for a more in-depth analysis because of the aforementioned procedural differences.

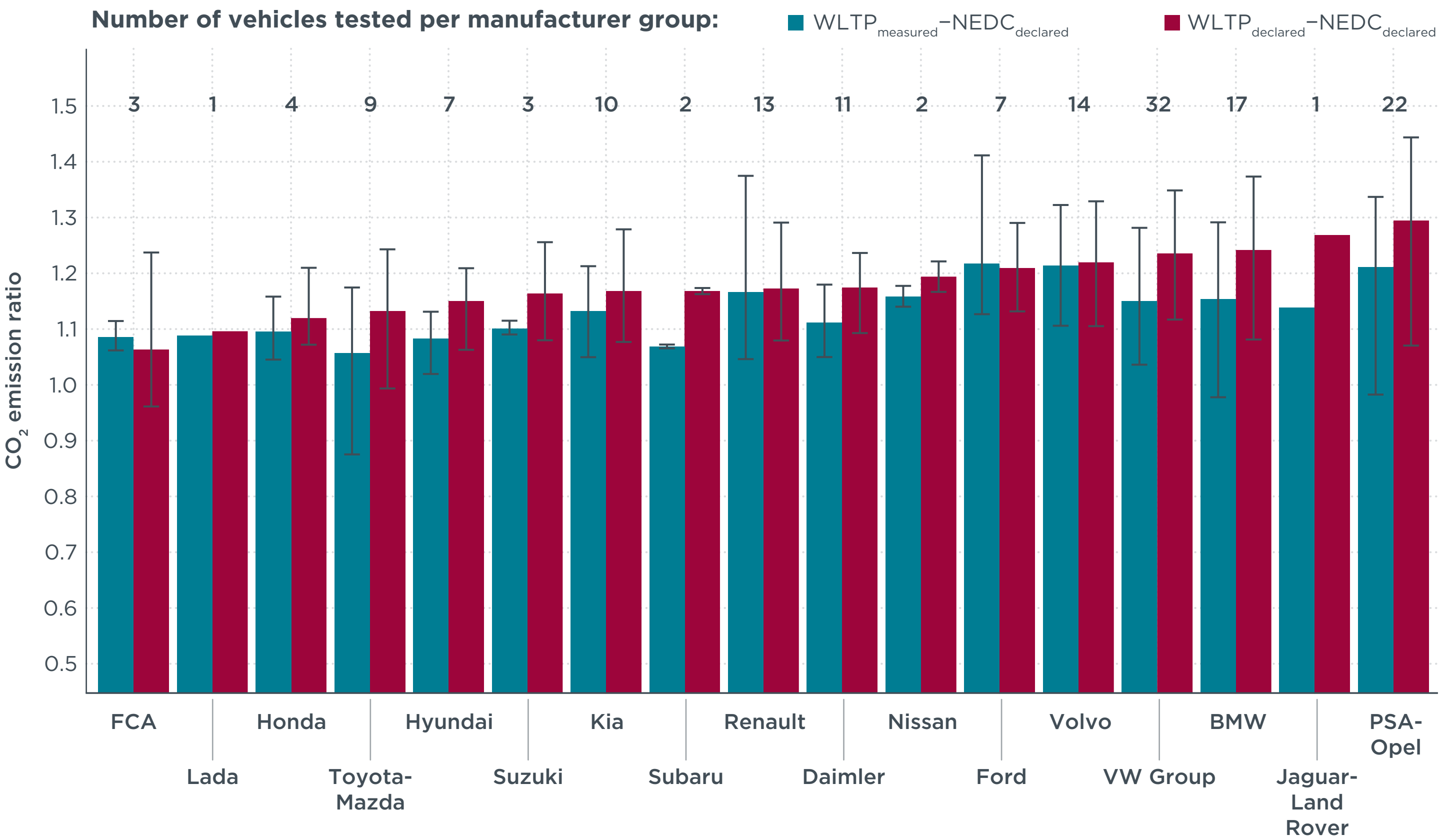

Figure 10. Comparison of WLTP-NEDC CO_2 ratio by manufacturer group, sorted by increasing $WLTP_{declared}$-$NEDC_{declared}$ ratio. The error bars show the range between minimum and maximum ratio for each manufacturer group when more than one vehicle was tested. Both the ratio based on the declared (red columns) as well as on the measured (blue columns) WLTP CO_2 values show a high variability among the manufacturer groups but also for different vehicles within the same manufacturer group.

COMPARING TYPE-APPROVAL AND REAL-WORLD DATA

Since 2012, the ICCT has been documenting the difference between official type-approval and real-world CO_2 emission levels of new passenger cars across Europe. The most recent update of the *From Laboratory to Road* report series covered data on approximately 1.3 million passenger cars from 15 data sources and eight countries (Tietge et al., 2019). The analysis showed how the divergence between official and real-world CO_2 emission levels increased from approximately 8% in 2001 to 39% in 2017. The most recent analysis also indicated that the gap has been stabilizing after 2015 and remained virtually unchanged from 2016 to 2017, after growing sharply from 2009 to 2015.

The potential reasons for the real-world to NEDC CO_2 gap stabilizing or even declining from 2016 onward have been discussed in previous *From Laboratory to Road* reports and include limited regulatory pressure on car makers after the 2015 CO_2 targets were met (Tietge et al., 2019).

For this analysis, we focus on one data source used in the *From Laboratory to Road* reports, Spritmonitor.de, instead of comparing the results for as many different datasets as possible. We first update our analysis of high-level trends in the Spritmonitor.de sample and then attempt to disentangle the effects of different type-approval procedures.

LONG-TERM TRENDS IN SPRITMONITOR.DE DATA

Spritmonitor.de[7] is a free web service that allows users to track the fuel consumption of their vehicles. Launched in Germany in 2001, the website aims to provide drivers with a simple tool to monitor their fuel consumption and make real-world fuel consumption figures available to the public. Spritmonitor.de has approximately 540,000 registered users, data on more than 800,000 vehicles, and is available in German, English, Spanish, and French.

To register a vehicle on the website, the user provides a number of basic vehicle specifications. For the initial fueling event, users are requested to fill the fuel tank to capacity, as the first event serves as the reference for calculating fuel consumption. In addition to mileage and fuel volume data, Spritmonitor.de users can provide details on driving behavior, driving conditions, and use of auxiliaries with each entry.

For this analysis, Spritmonitor.de provided anonymized data on approximately 800,000 vehicles. The dataset includes total mileage and total fuel consumption for each vehicle, as well as brand name, model name, build year, fuel type, engine power, and transmission type. For each vehicle, the real-world fuel consumption value is calculated as the total fuel consumption of the vehicle divided by its total mileage.

Only German passenger cars with a minimum recorded mileage of 1,500 km were analyzed. Vehicles built before 2001 or after 2018 are discarded. Vehicles with erroneous on-road fuel consumption values are removed based on thresholds defined by Peirce's criterion.[8] After removing incomplete entries and outliers, a sample of approximately 210,000 vehicles remains.

The on-road fuel consumption measurements from the Spritmonitor.de sample are complemented with type-approval fuel consumption figures and German registration numbers from an ICCT database (ICCT, 2018) to calculate the divergence between type-approval and real-world CO_2 emission levels, following the same methodology as in previous *From Laboratory to Road* reports.

7 See http://www.spritmonitor.de. The complete dataset used for this analysis was acquired in May 2019.

8 For a description of Peirce's criterion and its application, see Tietge, Mock, Franco, & Zacharof, 2017.

Figure 11 plots the resulting divergence between type-approval and Spritmonitor.de fuel consumption values by fuel type. On average, the gap increased from 6% in 2001 to 39% in 2018. Following a steep incline in the gap between the years 2009 and 2015, the gap reached a high of 40%[9] in 2016 and then stabilized at around 39%. Despite the recent stabilization, the gap remains at levels that are 6 times higher than in 2001.

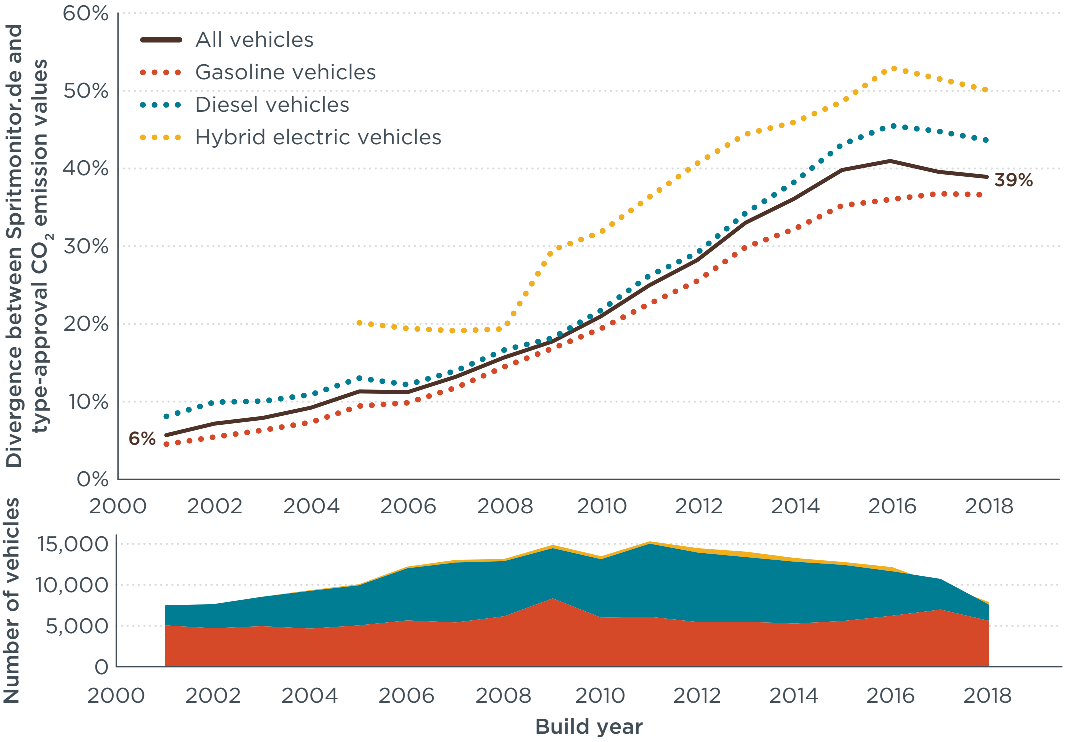

Figure 11. Divergence between Spritmonitor.de and type-approval NEDC CO_2 emission values by fuel/power train type. The bottom graph displays the number of vehicles per fuel/power train type and build year.

As in previous reports, the real-world CO_2 gap for diesel cars (44%) remains higher than for gasoline cars (37%). The share of diesel vehicles among new passenger car registrations in Germany declined after September 2015 in the wake of dieselgate. This decline was reflected in the Spritmonitor.de sample, with diesel cars accounting for only 25% of vehicles in 2018, compared to a high of 59% in 2012.

Sufficient data on the real-world performance of hybrid electric vehicles[10] are available for vehicles built after 2004. Hybrid electric vehicles consistently exhibit average divergence levels well above the levels of conventional power train vehicles, increasing from a level of 20% in 2005 to levels of around 50% after 2015.

DIVERGENCE BETWEEN SPRITMONITOR.DE AND TYPE-APPROVAL CO_2 VALUES BY TYPE-APPROVAL PROCEDURE

Approximately one quarter of new passenger cars registered in 2018 were type-approved to the WLTP. To identify the real-world CO_2 gap specifically for these vehicles, we complement the Spritmonitor.de sample with type-approval fuel consumption figures from the preliminary 2018 EEA CO_2 monitoring data, the official source of type-approval NEDC and WLTP CO_2 values.

Because EEA CO_2 monitoring data do not include information on vehicle transmission type, EEA and Spritmonitor.de data are combined according to the make, model, fuel

9 As Spritmonitor.de users keep adding data for vehicles of previous build years, the results of our analysis change slightly with every update and therefore may deviate from the figures quoted in preceding editions of our *From Laboratory to Road* series.

10 Only considering conventional hybrid electric vehicles here, excluding plug-in hybrid electric vehicles.

type, and engine power of the vehicles. The classification of hybrid electric vehicles in the EEA monitoring data is unreliable, so the analysis focuses only on conventional gasoline and diesel passenger cars.

In total, there are 9,195 vehicles of build year 2018 in the Spritmonitor.de dataset. For 7,171 of those vehicles (a share of 78%), a match with EEA data was successful. We further identify 536 vehicles as clearly type-approved to the WLTP. A vehicle is considered type-approved to the WLTP if more than 95% of sales in the EEA 2018 data matched to the vehicle were assigned WLTP CO_2 values. Similarly, we identify 1,962 vehicles as type-approved to the NEDC. The majority of vehicles—the remaining 6,697 vehicles—cannot clearly be identified as NEDC- or WLTP-certified.

Of the vehicles that can be clearly identified as type-approved to either the NEDC or the WLTP, we focus on those that have recorded real-world CO_2 values between 70 and 600 g/km and apply a statistical filter for outlier removal. This leaves us with a total of 2,418 vehicles variants.

Figure 12 plots the results next to the data from Figure 11. The average real-world to NEDC CO_2 gap for 2,417 Spritmonitor records was 35%. This figure is similar to the result of 39% from our comparison of 2018 Spritmonitor.de to the ICCT-internal vehicle database (see Figure 11) despite the differences in methodology. For those 526 vehicles that were clearly WLTP type-approved, the resulting average real-world CO_2 gap was 14% when compared to the WLTP type-approval value.

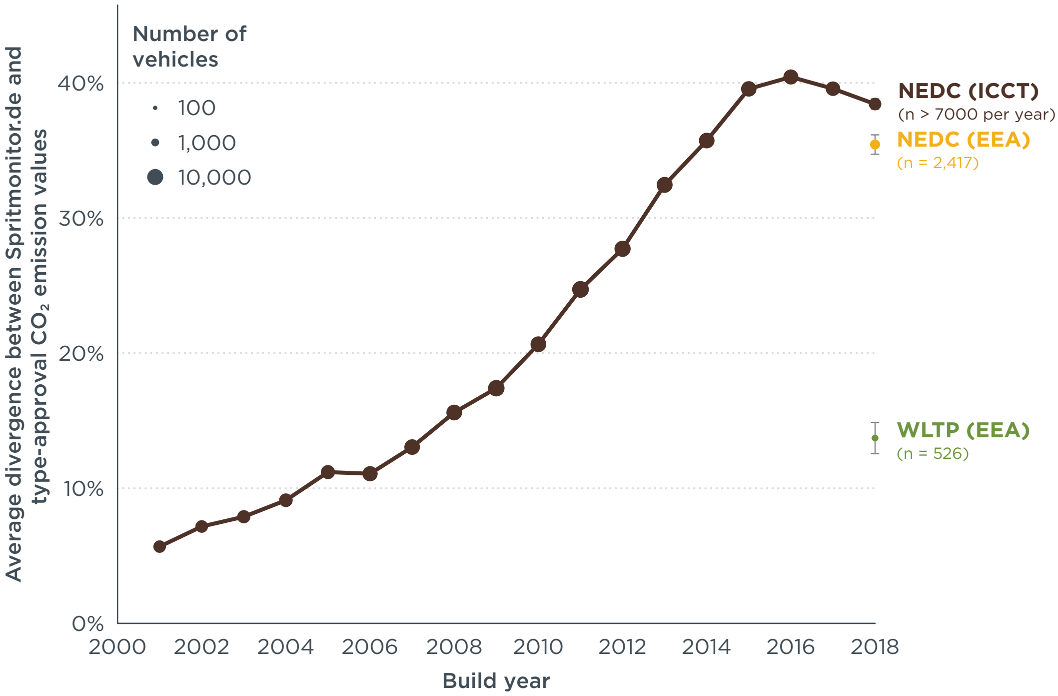

Figure 12. Divergence between Spritmonitor.de and type-approval CO_2 emission values over time, including a differentiation of the divergence for those vehicles that were registered in 2018 and were type-approved to the WLTP.

Compared with the NEDC, the WLTP closes the gap between real-world and type-approval CO_2 values, at least for 2018 data. Figure 12 shows that the WLTP closes the gap by 22 to 24 percentage points compared to the NEDC. However, after the European Commission's modifications of the original WLTP-NEDC correlation procedure in December 2018, it is conceivable that WLTP CO_2 levels will decline in future years, which, in turn, would cause the gap between WLTP and real-world CO_2 values to grow. It is therefore still too early to draw any definite conclusions about the real-world vs. WLTP CO_2 gap.

CONCLUSIONS AND RECOMMENDATIONS

The mean WLTP-NEDC CO_2 ratio for 2018 vehicles, calculated from the EEA CO_2 monitoring data, corresponds to an offset of 21%. A similar analysis of a dataset from the ADAC EcoTest, with CO_2 data for 158 passenger cars, shows the same result, in effect indicating that WLTP CO_2 levels are on average about 21% higher than NEDC CO_2 levels.

As a consequence, when analyzing fueling records for WLTP type-approved vehicles from the consumer website Spritmonitor.de, we observe a strong drop in the real-world CO_2 gap for data collected in 2018, to a level of approximately 14%. This is compared to a level of around 40% for NEDC type-approved vehicles. In other words, WLTP type-approved vehicles from 2018, on average, emit about 14% more CO_2 under real-world driving conditions than suggested by the official WLTP figures and therefore come with a significantly more realistic indication of their real-world behavior than is the case for NEDC type-approved vehicles of the same year.

However, these results for 2018 vehicles should be regarded as preliminary findings and should not be extrapolated to future years. For one, the amount of data for WLTP vehicles was still relatively low in 2018. Both NEDC and WLTP CO_2 values were available for only about 26% of new passenger cars. The remaining vehicles had to be discarded from the analysis.

More importantly, it is conceivable that the observed WLTP-NEDC CO_2 ratios will change for vehicles type-approved from 2019 onward. This is due to a revision of the WLTP-NEDC correlation procedure, implemented by the European Commission in December 2018, as well as provisions in the post-2020 CO_2 standards, aiming to close earlier regulatory loopholes. Before the revision, it was possible for manufacturers to apply different operating strategies during WLTP and NEDC type-approval testing to artificially increase the WLTP-NEDC CO_2 ratio. Furthermore, manufacturer-declared WLTP CO_2 values would have previously been used to determine 2025 and 2030 fleet CO_2 targets. However, the ratio between declared and measured values is now closely monitored by the European Commission and measured WLTP CO_2 values are being used to determine 2025 and 2030 fleet CO_2 targets.

Differences in declared versus measured WLTP CO_2 values by manufacturer group could be studied in this paper only by using ADAC EcoTest data. Despite procedural differences between the EcoTest and the type-approval WLTP, notable differences between manufacturer groups are apparent but also between vehicles within the same manufacturer group.

Having reduced the possibilities and incentives for manufacturers to exploit the WLTP-NEDC correlation procedure by simultaneously understating NEDC and overstating WLTP CO_2 values, it is to be expected that the average WLTP-NEDC CO_2 ratio for new passenger cars type-approved in 2019 and later will be lower than in 2018. Therefore, the average real-world gap would then be higher than observed for 2018 vehicles.

Although the procedure for determining 2025 and 2030 fleet CO_2 targets was switched from declared to measured values, there still remains an incentive for manufacturers to influence the procedure for determining 2021–2024 fleet targets, which remain based on declared WLTP CO_2 values. Furthermore, it remains possible for manufacturers to deflate declared NEDC CO_2 values by up to 4%, affecting both 2021–2024 and 2025/2030 CO_2 targets, Manufacturers also can declare only the (higher) WLTP CO_2 value of vehicle H instead of applying the interpolation method for determining emission levels within a vehicle family. Similar analyses based on the declared and measured WLTP CO_2 values provided by the manufacturers to the European Commission should therefore be carried out on a regular basis.

Based on our analyses, we derive the following recommendations for policy makers:

» **Increase transparency**. Currently it is not possible to differentiate between measured and declared CO_2 values in the EEA CO_2 monitoring database and publicly accessible member state datasets. To monitor manufacturers' performance and to understand the underlying reasons for the observed WLTP-NEDC CO_2 ratio, it is important to have access to both values. These values should be reported by the European Commission and member states to the general public.

» **Continue monitoring**. The 2018 cohort of vehicles is the first for which a significant amount of WLTP CO_2 data is available. Type-approval NEDC and WLTP values should be closely monitored and the underlying reasons for the observed WLTP-NEDC CO_2ratio should be scrutinized. If CO_2-based vehicle taxation schemes at the EU member state level are transposed to WLTP, it is important to take into account that the observed WLTP-NEDC CO_2 ratio for 2018 is likely not representative of future years.

» **Implement correction mechanisms**. With its revision of the WLTP-NEDC correlation procedure at the end of 2018, the European Commission strengthened the procedure and made it more difficult for manufacturers to exploit regulatory loopholes. However, manufacturers still can declare unreasonably high WLTP CO_2 emission values to arrive at less stringent target levels for 2021–2024. We therefore recommend implementing a correction mechanism that would lower a manufacturer target value from 2021 onward in case an intentional inflation of the WLTP-NEDC CO_2 ratio is observed.

» **Ensure real-word CO_2 reduction.** As part of the CO_2 standards regulation, the European Commission is required to assess how data from fuel consumption meters may be used to prevent the real-world gap from growing, by June 2023 at the latest. In 2027, the European Commission must furthermore assess the feasibility of adjusting each manufacturer's average CO_2 emissions to its real-world performance, beginning in 2030. With respect to the tremendous importance of realistic CO_2 emission values for the success of the European Green Deal, this timeline should be expedited.

REFERENCES

ADAC. (2019). *ADAC Ecotest Test- und Bewertungskriterien (ab 2/2019)*. https://www.adac.de/_mmm/pdf/30119_338652.pdf

Chatzipanagi, A., Pavlovic, J., Komnos, D., Ciuffo, B., & Fontaras, G. (2019, May 16). WLTP and NEDC CO2 emissions of new Euro 6D – Temp passenger cars in EU. *Poster Sessions*. TAP 2019, Thessaloniki, Greece.

Commission Regulation (EU) 2017/1151 of 1 June 2017 supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) No 1230/2012 and repealing Commission Regulation (EC) No 692/2008, Pub. L. No. OJ L 157,01.06.2017, 1 (2017). http://data.europa.eu/eli/reg/2017/1151/oj

Commission Implementing Regulation (EU) 2017/1153 of 2 June 2017 setting out a methodology for determining the correlation parameters necessary for reflecting the change in the regulatory test procedure and amending Regulation (EU) No 1014/2010, Pub. L. No. OJ L 175, 02.06.2017, p.679, 29 (2017). http://data.europa.eu/eli/reg_impl/2017/1153/oj

Commission Implementing Regulation (EU) 2018/2043 of 18 December 2018 amending Implementing Regulation (EU) 2017/1153 to clarify the WLTP test conditions and provide for the monitoring of type approval data, Pub. L. No. OJ L 327, 58 (2018). http://data.europa.eu/eli/reg_impl/2018/2043/oj

EEA. (2019). *Monitoring of CO2 emissions from passenger cars – Regulation (EC) No 443/2009* [Data]. European Environment Agency. https://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-16

European Commission. (2018). *Non-paper: CO2 Regulations for cars/vans—Risk of inflated starting point for calculating the 2025 and 2030 targets*. https://www.transportenvironment.org/sites/te/files/2018_07_18_Commission_non-paper_WLTP_manipulation.pdf

Fontaras, G., Valverde, V., Arcidiacono, V., Tsiakmakis, S., Anagnostopoulos, K., Komnos, D., Pavlovic, J., & Ciuffo, B. (2018). The development and validation of a vehicle simulator for the introduction of Worldwide Harmonized test protocol in the European light duty vehicle CO2 certification process. *Applied Energy*, *226*, 784–796. https://doi.org/10.1016/j.apenergy.2018.06.009

ICCT. (2018). *European vehicle market statistics—Pocketbook 2018/2019*. International Council on Clean Transportation. https://www.theicct.org/publications/european-vehicle-market-statistics-20182019

Ligterink, N. E., Cuelenaere, R. F. A., & Stelwagen, U. (2019). *Aspects of the transition from NEDC to WLTP for CO2 values of passenger cars—Phase 3: After the transition* (TNO 2019 R10952). TNO. https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2019/07/11/bijlage-tno-onderzoek-naar-wltp-testmethode/bijlage-tno-onderzoek-naar-wltp-testmethode.pdf

Ligterink, N. E., van Mensch, P., F.A. Cuelenaere, R., Hausberger, S., Leitner, D., & Silberholz, G. (2015). *Correction algorithms for WLTP chassis dynamometer and coast-down testing*.

Mock, P. (2013). *World-Harmonized Light-Duty Vehicles Test Procedure* [Policy update]. International Council on Clean Transportation. http://www.theicct.org/wltp-november2013-update

Mock, P., Kühlwein, J., Tietge, U., Franco, V., Bandivadekar, A., & German, J. (2014). *The WLTP: How a new test procedure for cars will affect fuel consumption values in the EU*. International Council on Clean Transportation. http://www.theicct.org/sites/default/files/publications/ICCT_WLTP_EffectEU_20141029.pdf

Pavlovic, J., Ciuffo, B., Fontaras, G., Valverde, V., & Marotta, A. (2018). How much difference in type-approval CO2 emissions from passenger cars in Europe can be expected from changing to the new test procedure (NEDC vs. WLTP)? *Transportation Research Part A Policy and Practice*, *111*. https://doi.org/10.1016/j.tra.2018.02.002

Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (Text with EEA relevance.), Pub. L. No. 32019R0631, 111 OJ L 13 (2019). http://data.europa.eu/eli/reg/2019/631/oj/eng

Rohde-Brandenburger, K. (2014). Bewertungsansätze zu Verbrauch und Fahrleistung. In *Energiemanagement im Kraftfahrzeug*. Springer Fachmedien Wiesbaden. https://www.springerprofessional.de/bewertungsansaetze-zu-verbrauch-und-fahrleistung/4293078?searchResult=1.Bewertungsans%C3%A4tze%20zu%20Verbrauch%20und%206%20Fahrleistung&searchBackButton=true

Stewart, A., Hope-Morley, A., Mock, P., & Tietge, U. (2015). *Quantifying the impact of real-world driving on total CO2 emissions from UK cars and vans Final report for The Committee on Climate Change*. https://www.theccc.org.uk/wp-content/uploads/2015/09/Impact-of-real-world-driving-emissions-for-UK-cars-and-vans.pdf

Tietge, U. (2019). *CO2 emissions from new passenger cars in the EU: Car manufacturers' performance in 2018*. International Council on Clean Transportation. https://theicct.org/publications/CO2-emissions-PVs-Europe-2018

Tietge, U., Díaz, S., Mock, P., Bandivadekar, A., Dornoff, J., & Ligterink, N. (2019). *From laboratory to road: A 2018 update of official and "real-world" fuel consumption and CO2 values for passenger cars in Europe*. International Council on Clean Transportation. https://www.theicct.org/publications/laboratory-road-2018-update

Tietge, U., Mock, P., Franco, V., & Zacharof, N. (2017). From laboratory to road: Modeling the divergence between official and real-world fuel consumption and CO2 emission values in the German passenger car market for the years 2001–2014. *Energy Policy*, *103*, 212–222. https://doi.org/10.1016/j.enpol.2017.01.021

Tsokolis, D., Dimaratos, A., & Samaras, Z. (2014, January 13). *Update on the LAT work for the NEDC-WLTP correlation exercise*.