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ON THE WAY TO 'REAL-WORLD' CO_2 VALUES? THE EUROPEAN PASSENGER CAR MARKET AFTER 5 YEARS OF WLTP

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EXECUTIVE SUMMARY

This paper investigates how the gap between official and real-world data on CO_2 emissions has developed since the introduction of the Worldwide harmonized Light vehicles Test Procedure (WLTP) in September 2017 through the period ending December 2022. The analysis is based on official CO_2 emission data as reported by the European Environment Agency (EEA) combined with real-world CO_2 emission information from about 162,600 cars as reported by consumers on the spritmonitor.de platform.

The results indicate a growing gap or divergence between real-world and WLTP CO_2 emission data for internal combustion engine cars and hybrid cars, as observed for New European Driving Cycle (NEDC) type-approved vehicles in the past. Figure ES1 shows the development of the gap for both NEDC and WLTP. While the WLTP CO_2 emission values used in the official type approvals of vehicle models are more representative of real-world values—with a divergence of 7.7% in 2018, compared to 32.7% for NEDC in the same year—the gap increased by more than 80% in the 5 years since its introduction, reaching 14.1% in 2022.

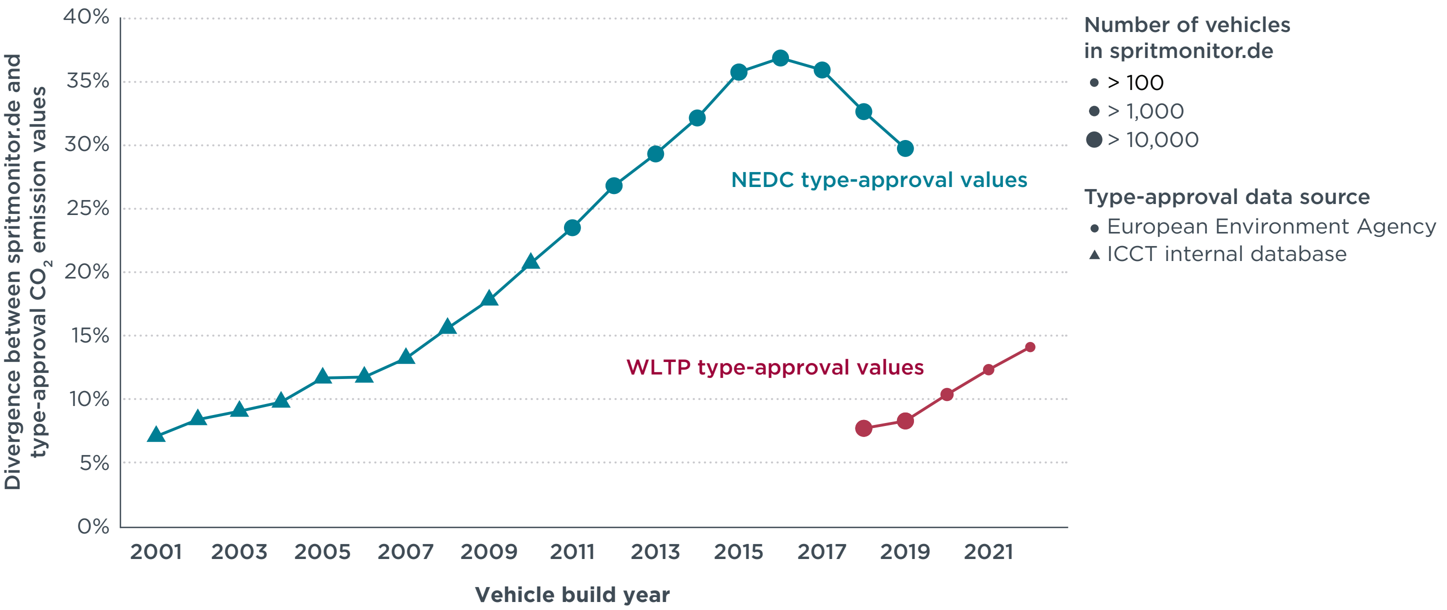

Figure ES1. Divergence between real-world and type-approval CO_2 emission values for internal combustion engine and hybrid passenger cars registered in Germany.

CO_2 reduction goals in the EU are implemented by setting lower targets for type-approval CO_2 emissions. The growing gap between official and real-world emission values leads to a lower reduction in real-world CO_2 emissions than intended by the regulators. As the comparison in Figure ES2 shows, type-approval CO_2 emissions of cars present in the spritmonitor.de dataset decreased by 19.5% between 2009, the year when the first EU passenger car CO_2 standards were adopted, and 2022.[1] During the same period, real-world CO_2 emissions decreased by 5.8%, less than one third of the reduction in type-approval CO_2 emissions.

1 For the comparison, 2022 WLTP type-approval CO_2 emissions are shown as NEDC-equivalent values by dividing by a factor of 1.21, as reported by the Joint Research Centre of the European Commission. (https://data.europa.eu/doi/10.2760/901734)

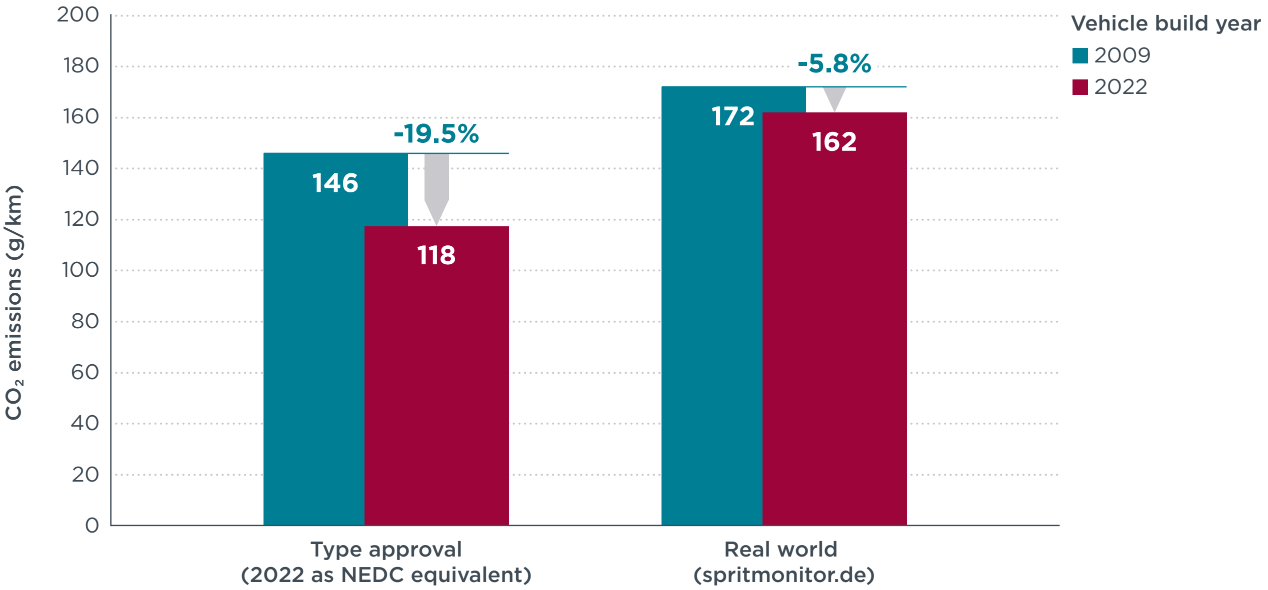

Figure ES2. Reduction of internal combustion engine and hybrid car type-approval and real-world CO_2 emissions since the adoption of CO_2 standards in the EU in 2009 and 2022. WLTP CO_2 emissions in 2022 were converted to NEDC-equivalent values using a conversion factor of 1.21.

The European Commission has been tasked through the CO_2 standards regulation with developing a mechanism or process that prevents this gap from growing. For this purpose, real-world fuel consumption data recorded by on-board fuel and energy consumption monitoring (OBFCM) devices should be used. However, while the availability of OBFCM data will allow the implementation of such a mechanism by 2027, regulators foresee this measure starting in 2030.

Based on our analysis we offer the following recommendations, primarily for the European Commission:

» The European Commission could develop a mechanism that prevents further growth of the gap, and a proposal for such a mechanism is provided in this paper. The described mechanism intends to both mitigate the growing gap and compensate for the excess real-world CO_2 emissions released prior to the introduction of a correction mechanism.

» The availability of OBFCM real-world consumption data would support applying the correction mechanism starting in 2027.

» Real-world fuel consumption estimates could be displayed on vehicle efficiency labels for consumers.

» Anonymized OBFCM data could be made publicly available.

» OBFCMs could be made mandatory for electric vehicles to ensure the availability of real-world energy consumption data.

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INTRODUCTION

The European Union (EU) adopted its first CO_2 emission standards for passenger cars in 2009 (Regulation (EC) 443/2009, 2009). Two years later, CO_2 standards were also adopted for vans (Regulation (EU) 510/2011, 2011). New standards set in 2020 and revised in 2023 require further reductions in CO_2 emissions in 2025 and 2030, concluding with a target of zero tailpipe CO_2 emissions for cars and vans from 2035 onward (Regulation (EU) 2019/631, 2019; Regulation (EU) 2023/851, 2023). The European standards set fleet-average CO_2 emission targets for all cars and vans produced by a manufacturer or a pool of manufacturers registered in one calendar year. The target value relates to the official, manufacturer-declared CO_2 emissions value, as demonstrated in the laboratory during the type-approval procedure.

While type-approval CO_2 emissions were falling over time, in line with the targets set by the regulation, the CO_2 emissions generated by the vehicles during real-world usage did not decline the same way. This is reflected in an increasingly larger gap between the manufacturer-declared and the real-world CO_2 emissions, as we have shown conclusively for internal combustion engine vehicles (ICEVs) and hybrid electric vehicles (HEVs) in our "From laboratory to road" series (Mock et al., 2012, 2013; Mock, Tietge, et al., 2014; Tietge et al., 2015, 2016, 2017, 2019).[2]

The growing gap undermines the policy objectives of reducing CO_2 emissions since the real-world CO_2 reduction does not follow the progress required by the regulation. Furthermore, it increases the cost of operating a vehicle as the advertised fuel economy is not reflected in real-world fuel consumption. In addition, it unduly reduces revenue from CO_2-based taxation systems that only take into account type-approval emission values.

With the goal of making the CO_2 type-approval values more representative of real-world driving, the European Commission gradually replaced the former New European Drive Cycle (NEDC) type-approval procedure with the Worldwide harmonized Light vehicles Test Procedure (WLTP) (Mock, 2013; Mock, Kühlwein, et al., 2014; Pavlovic et al., 2018). This transition started in 2017 and concluded in 2020. Since then, all newly registered cars and vans in the EU must be WLTP type approved.

Some gap is expected to remain between the WLTP CO_2 emission values and the real-world emission values because of the differences between laboratory testing under controlled conditions and the variability of real-world driving. In 2020 we estimated the gap for WLTP type-approved cars to be about 14% for vehicles registered in 2018, based on a small data sample of about 500 vehicles (Dornoff et al., 2020).

This analysis provides an update of the real-world to WLTP type-approval emissions gap for combustion engine and hybrid cars registered in 2018, based on a larger number of vehicles, and assesses how the gap evolved between 2018 and 2022. Plug-in hybrid vehicles are not considered in this study because an extensive analysis of their real-world to type-approval gap was published recently in other ICCT papers (Plötz et al., 2020, 2022). Battery electric vehicles and fuel cell vehicles are out of the scope of this study as they do not have tailpipe CO_2 emissions. Applying the methodology of our previous paper, we base our analysis on a comparison of user-reported fuel consumption values from the public website spritmonitor.de and official CO_2 type-approval data published by the European Environment Agency (European Environment Agency [EEA], 2023a, 2023b).

2 These publications can also be accessed through links on the ICCT "From laboratory to road" homepage: https://theicct.org/series/from-lab-to-road/.

The paper is organized as follows: Section 2 describes the datasets used for the analysis and the methodology applied. Section 3 presents the development of the real-world to type-approval CO_2 emissions gap and how it affects the evolution of real-world CO_2 emissions over time. In Section 4, we compare our findings with a preliminary gap analysis performed by the European Commission using on-board fuel and energy consumption monitoring (OBFCM) data. We also present a mechanism that would mitigate the detrimental effect of a growing real-world to type-approval CO_2 gap and could prevent the gap from growing. Section 5 summarizes the findings and offers recommendations to foster the reduction of real-world CO_2 emissions from cars and vans in Europe.

METHODOLOGY FOR CALCULATING THE CO_2 EMISSIONS GAP

This section describes the methodology applied for calculating the CO_2 emissions gap and presents the characteristics of the used datasets. It also discusses the limitations of the study.

The combined gap for combustion engine and hybrid cars is analyzed. Due to data limitations, the separation of mild-hybrid and full-hybrid vehicles in the EEA dataset is not possible.[3] However, as hybrid vehicles are a form of efficient ICEVs and because the share of mild-hybrid vehicles is continuously increasing, we consider hybrid vehicles as ICEVs for the purpose of this analysis (Dornoff et al., 2022). Since the majority of ICEVs and HEVs use either diesel or gasoline engines, only vehicles with those fuel types have been analyzed.

The WLTP test procedure was introduced in the EU in September 2017 to be used for the type approvals of new models of cars and small vans. Starting in September 2018, the WLTP test was required for all new vehicles in the car and small van categories, including models previously approved under the NEDC. For larger vans, the introduction dates were delayed by one year. Due to the novelty and complexity of the procedure, the data on reported type-approval CO_2 emissions in the first year might be less reliable. Furthermore, the first-year data contains WLTP values for only a fraction of the fleet. Therefore, we did not include in our analysis the WLTP data on cars registered in 2017.

The analysis includes the COVID-19 pandemic period of 2020 and 2021, which led to a drop in new vehicle registration numbers, shifts in travel behavior, and reduced fuel prices (Ecke et al., 2021). The number of passenger car registrations in the EU-27 in 2021 was 26% lower than in 2019 (Monteforte it al., 2023). However, the annual report of the German Mobility Panel on everyday mobility, which is based on car-usage surveys of German households, shows that the pandemic had no significant effect on average fuel efficiency (Vallée et al., 2022). Therefore, we do not expect the COVID-19 pandemic to have a considerable effect on the results of this study.

DATA SOURCES

Type-approval data – European Environment Agency

Type-approval CO_2 emission values, determined by laboratory testing, were retrieved from the dataset on manufacturer CO_2 performance published annually by the European Environment Agency (EEA, 2023a). Parameters from the EEA data used for this analysis are vehicle registration year, registration country, manufacturer name, commercial name of the model, NEDC and/or WLTP CO_2 emission values, vehicle mass, engine capacity, engine power, fuel type, and fuel mode.[4] Additional details on the EEA type-approval CO_2 emissions dataset can be retrieved from the ICCT manufacturer CO_2 performance briefing published in 2022 (Tietge et al., 2022). While our previous CO_2 gap analysis covered vehicles registered until 2018, which was the first year when all new car models were type-approved using the WLTP, this paper covers a broader range of WLTP type-approved vehicles registered up to and including 2022.

3 Full hybrid vehicles can operate some distance in purely electric mode while the low voltage system and small battery of a mild hybrid vehicle only allows the electric motor to assist the internal combustion engine.

4 The fuel mode parameter provides additional information about the vehicle powertrain. It indicates whether a vehicle's powertrain is battery electric, hybrid, or plug-in hybrid. For conventional combustion engine vehicles and fuel cell electric vehicles, it can take the values mono-, bi-, or flex-fuel.

Real-world data – spritmonitor.de

Previous papers in our “From laboratory to road” series showed that the spritmonitor.de data is in good agreement with data from other real-world sources for predominantly privately owned cars (Tietge et al., 2019). Therefore, spritmonitor.de data for Germany is used as the sole source for real-world CO_2 emission data in this paper, similar to our first analysis of the gap between real-world and WLTP type-approval emission data (Dornoff et al., 2020).

Spritmonitor.de is a crowdsourced free-of-charge platform where users can voluntarily document their vehicles’ fuel efficiency by logging both distances driven and fuel consumption. The dataset acquired in August 2023 contains records for about 1.1 million vehicles. It contains for each vehicle the country of registration, build year (year the vehicle was manufactured), manufacturer, model name, powertrain type, fuel type, transmission type, distance driven, and the amount of fuel consumed.

HOW THE DATA WAS PROCESSED

Type approval data – European Environment Agency

The EEA type-approval data was cleaned to harmonize make and model names as well as powertrain and fuel types. As in previous papers in the “From laboratory to road” series, each vehicle model is assigned to a vehicle segment using EU vehicle segmentation. Based on the segment information, we distinguished between the two vehicle categories of cars and vans. Vans, that is vehicles belonging to the car-derived van, non-car-derived van, or pickup vehicle segments, are not analyzed in this study.

We determined the mean type-approval CO_2 emission value for each combination of year of first registration, registration country, powertrain type, fuel type, make, model, and engine power. As we were limited by the number of vehicle parameters available in the EEA dataset, each combination can contain various versions of a vehicle model, such as vehicles with manual and automatic transmission. Therefore, the CO_2 emissions for each combination are calculated as the average, weighted by the number of registrations, of all vehicles registered per combination.

Real-world data – spritmonitor.de

In spritmonitor.de, users report the volume of fuel consumed and the distance driven between refueling. Based on these values, we calculate each vehicle’s average real-world fuel consumption. The correlating real-world CO_2 emissions are determined using a conversion factor of 26.8 gCO_2/km per liter of fuel/100km for diesel vehicles, and 23.4 gCO_2/km per l/100km for gasoline vehicles, taken from the ICCT conversion tool and as used in our previous analyses (International Council on Clean Transportation, n.d.).

From the raw spritmonitor.de data, only vehicles registered for the first time between 2011 to 2022 were selected. Trucks and motorcycles were identified based on their make and model names and removed from the dataset. Vehicles driven less than 1,500 km were also excluded from the analysis. Following the approach of our prior work, entries with an average fuel consumption lower than 2 l/100 km or higher than 25 l/100 km are considered outliers and therefore removed from the dataset. Only vehicles registered in Germany—about 206,400 vehicles, or 75% of all vehicles in the dataset—were used for the analysis. The remaining 25% of vehicles are scattered throughout many countries, with Austria having the second-highest share of registrations at 3.5%.

Using the same parameters as for the EEA data, the spritmonitor.de vehicles are grouped as combinations of build year, powertrain type, fuel type, make, model, and engine power. Given the crowdsourced nature of the spritmonitor.de dataset, it can be expected that some of the reported values contain invalid data. Therefore, individual vehicles of the same combination are considered outliers if their average reported CO_2 emissions are above the 75th quartile plus 1.5 times the interquartile range, or below the 25th percentile minus 1.5 times the interquartile range. Outliers are voided. Applying these criteria over the period 2011–2022, 6.6% of the gasoline ICEVs and HEVs and 5.5% of the respective diesel cars were considered outliers and removed from the dataset.

Merging real-world with type-approval data

To obtain both the type-approval and real-world CO_2 emission values for each vehicle combination, the cleaned spritmonitor.de and EEA datasets are merged, using the powertrain type, fuel type, make, model, build year, and engine power as matching parameters.

Figure 1 shows the effect of removing the outliers from the spritmonitor.de dataset on the average real-world CO_2 emissions per build year and fuel type of vehicles in the merged dataset. After voiding the outliers, the average real-world CO_2 emissions across the 2011–2022 period, weighted by the number of registrations, are about 0.3% lower for gasoline cars and about 0.5% lower for diesel cars than the averages calculated when including all vehicles. At the same time, dropping the outliers reduces the standard deviation of real-world CO_2 emission values by 2.8 g/km for gasoline vehicles and 2.6 g/km for diesel vehicles over the same period.

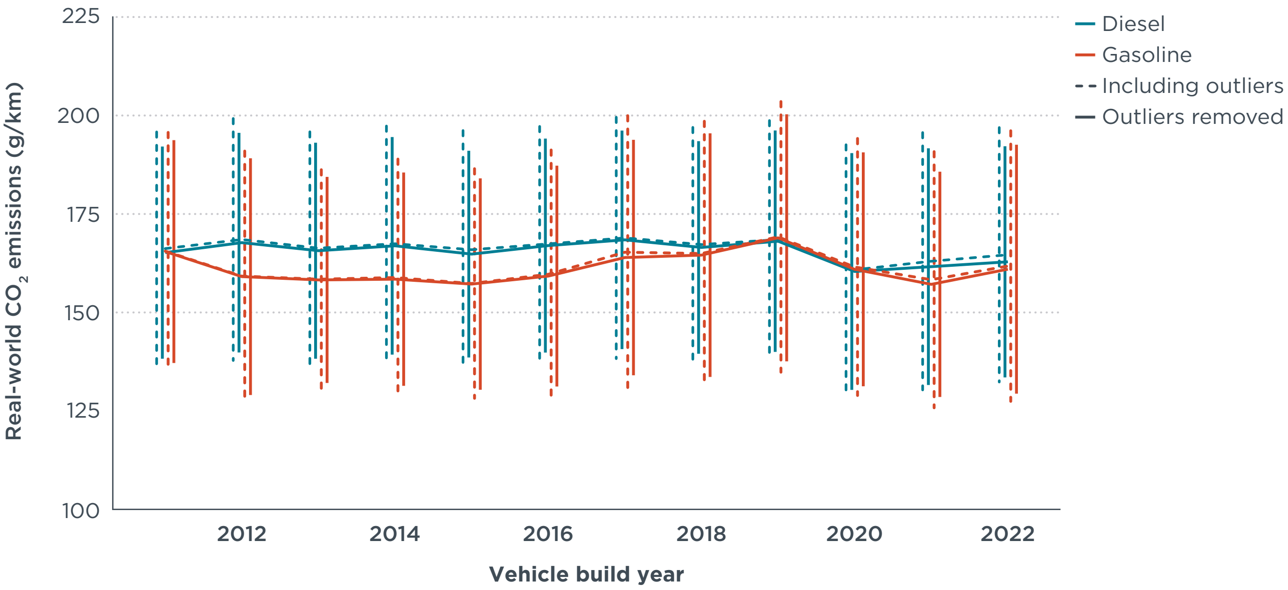

Figure 1. Effect of removing outliers in merged EEA and spritmonitor.de dataset on average real-world CO_2 emissions of internal combustion engine and hybrid cars by fuel type in the period 2011–2022. The horizontal lines represent the average CO_2 emissions for each build year. The vertical bars show the error as one standard deviation.

The gap for each vehicle combination is calculated as the difference between average real-world and weighted-mean type-approval CO_2 emissions relative to the type-approval value. With this data, the sales-weighted gap per build year, fuel type, and manufacturer is calculated.

Of the 206,400 combustion engine and hybrid cars in the cleaned spritmonitor.de dataset, about 162,600 remain in the merged dataset. Except for 2012, the number of cars for each registration year between 2011 and 2019 is higher than 15,000, as shown in Figure 2. From 2020 onwards, the number of registered vehicles drops progressively, reaching about 2,700 cars in 2022. This drop in the number of vehicles in recent years is related to the fact that many of them have not reached the minimum mileage threshold of 1,500 km to be considered in the analysis. It also coincides with the start of the COVID-19 pandemic, which triggered a drop in registration numbers in Germany of 19% and 27% in 2020 and 2021, respectively, compared to 2019 (Kraftfahrt-Bundesamt, n.d.). Furthermore, the share of plug-in hybrid and battery electric vehicles in spritmonitor.de is increasing each year. As a result, the number of combustion engine and hybrid vehicles in spritmonitor.de has declined.

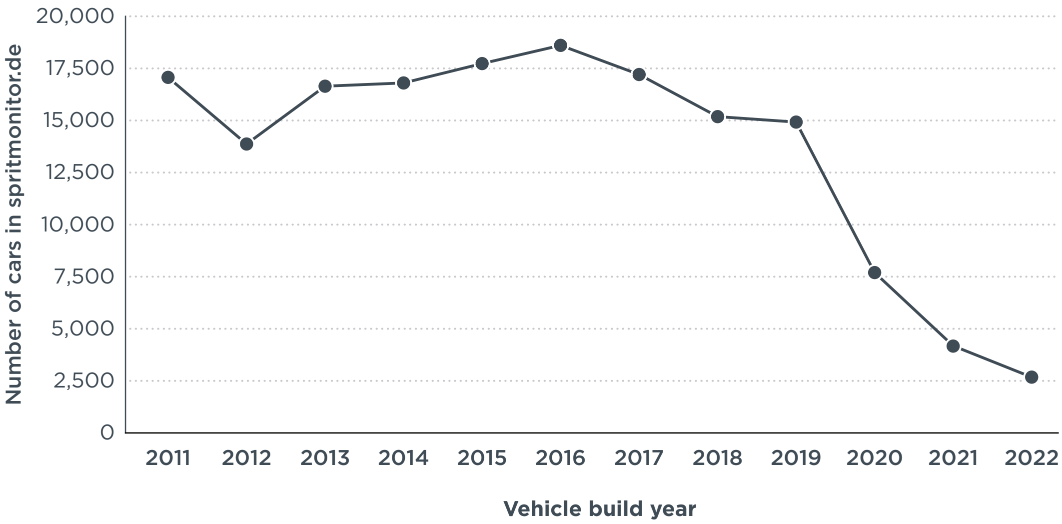

Figure 2. Number of cars registered in Germany in the merged spritmonitor.de dataset per build year.

HOW REPRESENTATIVE THE ANALYZED DATASET IS FOR THE EU AND GERMANY

For the following reasons, we assume that trends in the development of CO_2 emission levels of the new vehicle fleet in Germany will be a good proxy for developments at the EU level. Germany is the largest vehicle market in Europe, accounting for about one quarter of all new car registrations in the EU. In terms of fleet composition, the German market of non-electric vehicles, meaning excluding battery electric and plug-in hybrid vehicles, closely mirrors the EU average.[5] In 2022, 96% of all new light-duty vehicle registrations in Germany were cars, compared to 97% for the EU, and the share of gasoline-powered cars in Germany was 69%, similar to the entire EU's share of 72%. The vehicle segments in the German fleet also share similar characteristics with the EU fleet. Sport utility vehicles make up 43% of all the vehicles newly registered in Germany and 45% of vehicles registered in the EU. However, average WLTP type-approval CO_2 emissions of cars in Germany are about 9% higher than the EU average. This is in line with new cars registered in Germany in 2022 having a 7% higher fleet average mass and a 23% higher average engine power compared to the EU fleet. This difference in fleet average CO_2 emission levels constantly increased over the 2018–2022 period, starting at 6.4% in 2018.

The vehicle combinations in spritmonitor.de represent a subset of the car combinations contained in the EEA dataset. The merged spritmonitor.de and EEA dataset is therefore smaller than the EEA dataset, which contains data on the entire German fleet. Figure 3 compares the average type-approval CO_2 emissions of the merged dataset to the full EEA dataset of Germany from 2011 through 2022. The difference in average emissions between the merged dataset and the EEA-only dataset is largest for WLTP type-approved diesel and gasoline cars manufactured in 2020, 2021, and 2022. However,

5 Derived from the 2018 to 2022 datasets on manufacturer CO_2 performance published annually by the European Environment Agency (see European Environment Agency, 2023b).

the trends in average type-approval CO_2-emissions development are similar over time. Therefore, we conclude that the spritmonitor.de dataset is sufficiently representative of the German vehicle fleet.

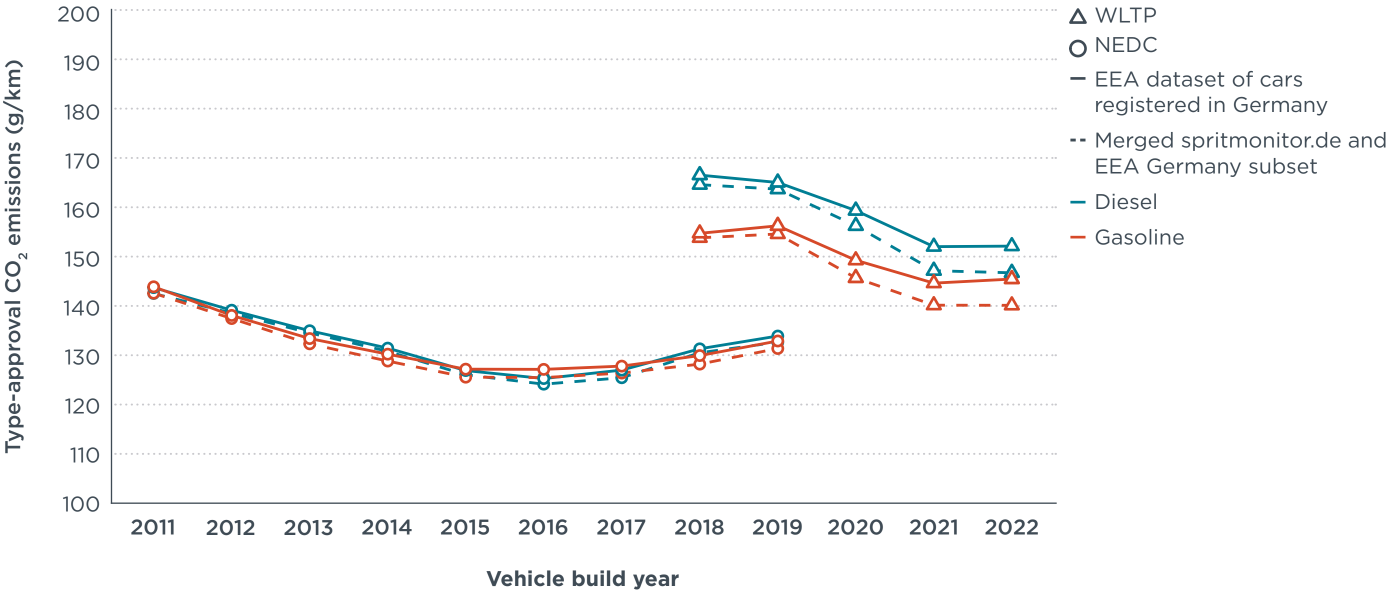

Figure 3. Comparison of fleet average type-approval CO_2 emissions of internal combustion engine and hybrid cars registered in Germany derived from the EEA and from the merged EEA/spritmonitor.de dataset, by fuel type for build years 2011 to 2022.

DEVELOPMENT OF THE CO_2 EMISSIONS GAP SINCE THE INTRODUCTION OF WLTP

Based on the merged EEA and spritmonitor.de dataset, the average deviation between real-world and type-approval emissions of cars registered in Germany is determined separately for each build year.

As previously observed for NEDC type-approved vehicles, our analysis indicates a growing CO_2 emissions gap for WLTP type-approved vehicles, as shown in Figure 4. The results show an average real-world to type-approval divergence for combustion engine and hybrid cars built in 2018 of 7.7%, increasing to 14.1% for 2022 vehicles. This means the gap increased by more than 80% during the first five years after the introduction of the WLTP. Compared to our first analysis of the gap for WLTP type-approved vehicles performed in 2020, the divergence for 2018 is lower than the 14% determined at that time (Dornoff et al., 2020). However, the previous analysis relied on data points for only 526 individual vehicles while the new analysis is based on about 15,200 WLTP type-approved vehicles for the same registration year, representing about 9,900 gasoline vehicles and 5,300 diesel vehicles.

Figure 4: Registration-number-weighted divergence between real-world and type-approval CO_2 emission values for NEDC and WLTP type-approved combustion engine and hybrid cars by fuel type. The number of vehicles in the merged spritmonitor.de and EEA dataset, shown in the bottom figure, includes vehicles type-approved under both NEDC and WLTP.

For NEDC type-approved vehicles, the gap increased from less than 10% in 2001 (not shown in the figure) to 24% in 2011, peaking at 37% in 2016. Coinciding with the introduction of WLTP as the type-approval procedure, the NEDC gap started to decrease in 2017, reaching a level of about 30% in 2019.

Figure 4 also shows that under the NEDC, diesel cars were found to have a substantially larger real-world CO_2 gap than gasoline vehicles. Under WLTP, the data indicates that vehicles of both fuel types exhibit similar gaps with a tendency of a smaller gap for diesel vehicles.

DEVELOPMENT OF THE GAP BY MANUFACTURER

In this section, we present how the CO_2 emissions gap of combustion engine and hybrid cars developed for the top nine manufacturers in terms of the number of car registrations. These manufacturers represent 73% of EU registrations for combustion engine and hybrid cars in the period since the WLTP implementation.

As shown in Figure 5, the divergence between real-world and type-approved CO_2 emissions varies among the manufacturers under both the NEDC and WLTP testing procedures.

- For 2022, the cars of four of the nine manufacturers show a real-world to type-approval CO_2 gap above the 14% average gap of all manufacturers; the highest gap was for Opel at 21%, followed by Hyundai at 20% and Ford and Seat, both at 15%.
- The lowest gap in 2022 is observed for Mercedes at 11%, followed by Volkswagen, BMW, and Audi, all at 12%.
- BMW and Ford show a faster increase in the gap than the average for all manufacturers until 2021, but the gap decreases to near the average in 2022. Mercedes shows a similar trend, with the gap peaking in 2020 and decreasing since then.
- The gap for Volkswagen and Audi vehicles type approved under WLTP is consistently lower than the average gap for all manufacturers. This is notable in the case of Audi because Audi vehicles type approved under NEDC show a gap that is consistently higher than the average.

Figure 5. Divergence between real-world and type-approval CO_2 emission values for the nine vehicle manufacturers having the highest number of registrations for internal combustion engine and hybrid cars during the five years from 2018 through 2022. The shaded bands around the manufacturer-specific lines reflect the 95% confidence interval. The bottom plot indicates the number of valid entries in spritmonitor.de used to calculate the CO_2 gap. The number of spritmonitor.de entries for Volkswagen exceeded 2,000 vehicles (the top range of the graphs) for the years 2012–2019, peaking at 3,631 vehicles for vehicles built in 2012.

IMPACT OF THE GAP ON REAL-WORLD CO_2 EMISSIONS REDUCTION

The growing gap undermines the intended impact of the CO_2 emission standards. As Figure 6 shows, NEDC type-approval CO_2 emissions of combustion engine and hybrid cars registered in 2019 are about 11.4% lower than for cars registered in 2009, the year when the first EU CO_2 standards for cars were adopted. However, due to the growing gap, the reduction in real-world CO_2 emissions over the same period is substantially lower at only 2.0%. WLTP type-approval CO_2 emission values are more representative of real-world emissions, but the gap is growing for WLTP type-approved cars since 2018. Type-approval CO_2 emission values of WLTP vehicles decreased by 7.3% between 2018 and 2022, while real-world emission values decreased by 2.3%—less than one-third of what type-approval data shows.

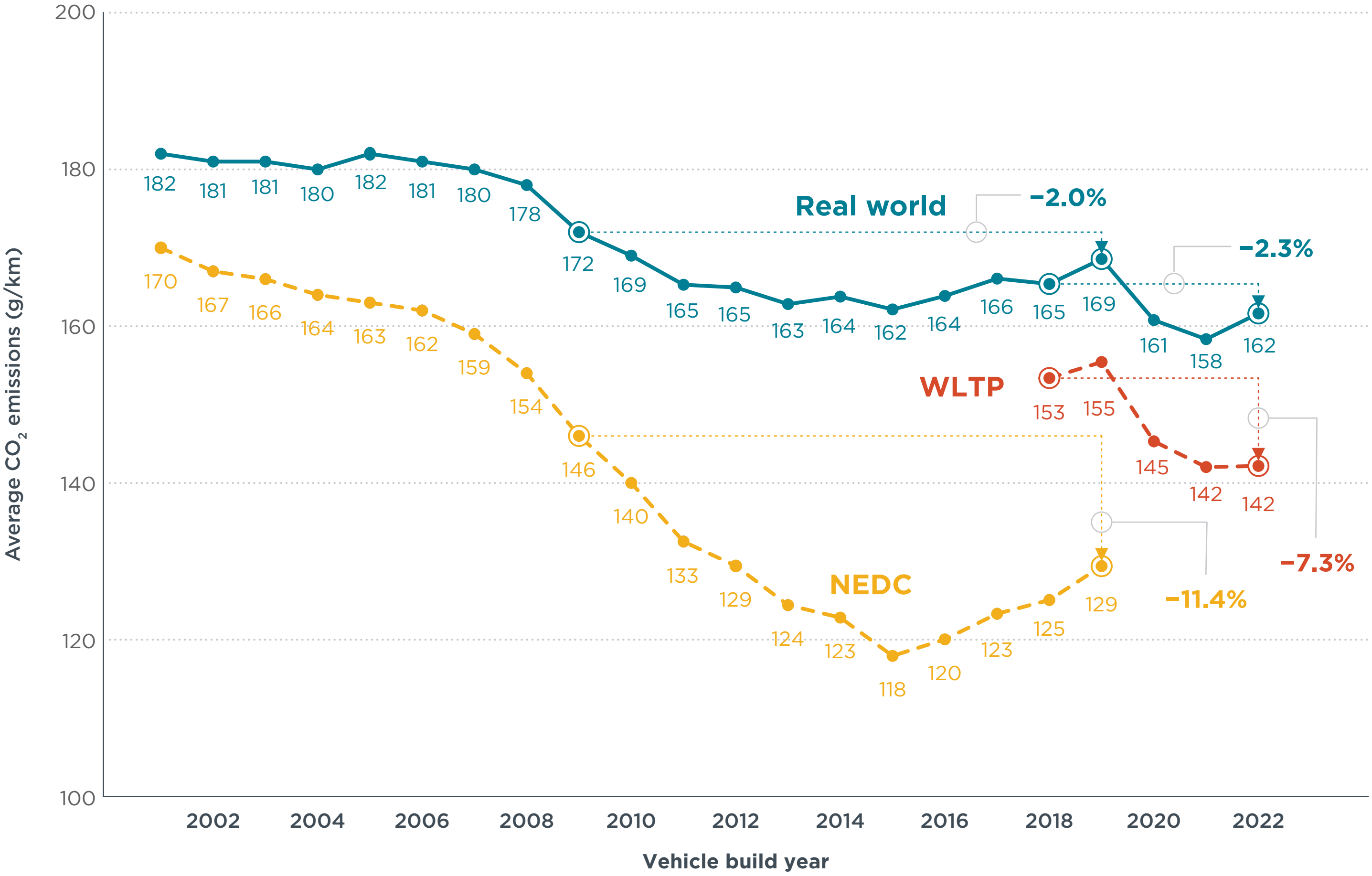

Figure 6. Fleet average real-world and type-approval CO_2 emissions for internal combustion engine and hybrid cars in Germany per build year, based on merged spritmonitor.de and type-approval data. The percentages indicate the change in CO_2 emissions between the years 2009 and 2019 and between the years 2018 and 2022.

USING OBFCM DATA TO DETERMINE AND MITIGATE THE CO_2 GAP

The European Commission is required by the CO_2 standards regulation to assess the development of a mechanism that prevents the real-world gap from growing (Regulation (EU) 2019/631, 2019). This is to be done by adjusting the manufacturers' CO_2 emissions performance based on real-world data, as automatically recorded by on-board fuel and energy consumption monitoring (OBFCM) devices. OBFCM devices are mandatory for all new combustion engine and hybrid cars as well as plug-in hybrid passenger cars and most vans since 2021. For heavy vans, the requirement applies one year later from 2022 (Dornoff, 2019).

The OBFCM device records the lifetime fuel and energy consumption as well as the total vehicle mileage. If the vehicle owner consents, OBFCM data is retrieved from the vehicles during repair and maintenance and periodic technical inspections. All the data retrieved over a year is collectively transmitted to the European Commission in the following year. In addition, OBFCM data collected by manufacturers using telemetry is also reported to the Commission (Commission Implementing Regulation (EU) 2021/392, 2021). Based on this data, the Commission determines for each vehicle the lifetime average fuel consumption and subsequently the equivalent CO_2 emissions, using conversion factors of 23.0 g CO_2/km per l/100km for gasoline and 26.2 CO_2/km per l/100km for diesel (Joint Research Centre [JRC], 2023). These factors are about 2% lower than the ones we use in our calculations. Applying the factors used by the Commission would result in a slightly lower calculated gap. For consistency, we continue to use the factors used in previous reports.

COMPARISON OF CO_2 GAP BASED ON SPRITMONITOR.DE DATA AND PRELIMINARY OBFCM DATA

In this section, we compare the gap determined by the European Commission for 2021 based on preliminary OBFCM data to the gap we calculated from the spritmonitor.de dataset for the same year. The first set of OBFCM data was made available to the European Commission in April 2022. The results of a preliminary real-world to type-approval CO_2 gap analysis were presented by the Joint Research Centre (JRC) of the European Commission in March 2023 (JRC, 2023).

The OBFCM dataset contained valid entries for about 608,000 passenger cars registered in 2021; 23% of the entries were hybrid vehicles, 58% were ICEVs, and the remainder were plug-in hybrid vehicles. Of the ICEVs, about 56% were gasoline-powered and about 44% used diesel fuel. Compared to the EU market shares in the same registration year, where 29% of the ICEVs used diesel and 71% used gasoline, diesel vehicles are over-represented in the OBFCM dataset.

As shown in Figure 7, the JRC determined—based on the OBFCM data for 2021 ICEVs and HEVs—an EU-average gap of about 22%. For cars registered in Germany alone, the gap was about 20%. This is substantially higher than the 12.3% we derived in our analysis for the same year based on spritmonitor.de data. The OBFCM data shows a gap of 24% for gasoline vehicles and of 17% for diesel vehicles. We also observed a larger gap of 13% for gasoline vehicles than for diesel vehicles (11%).

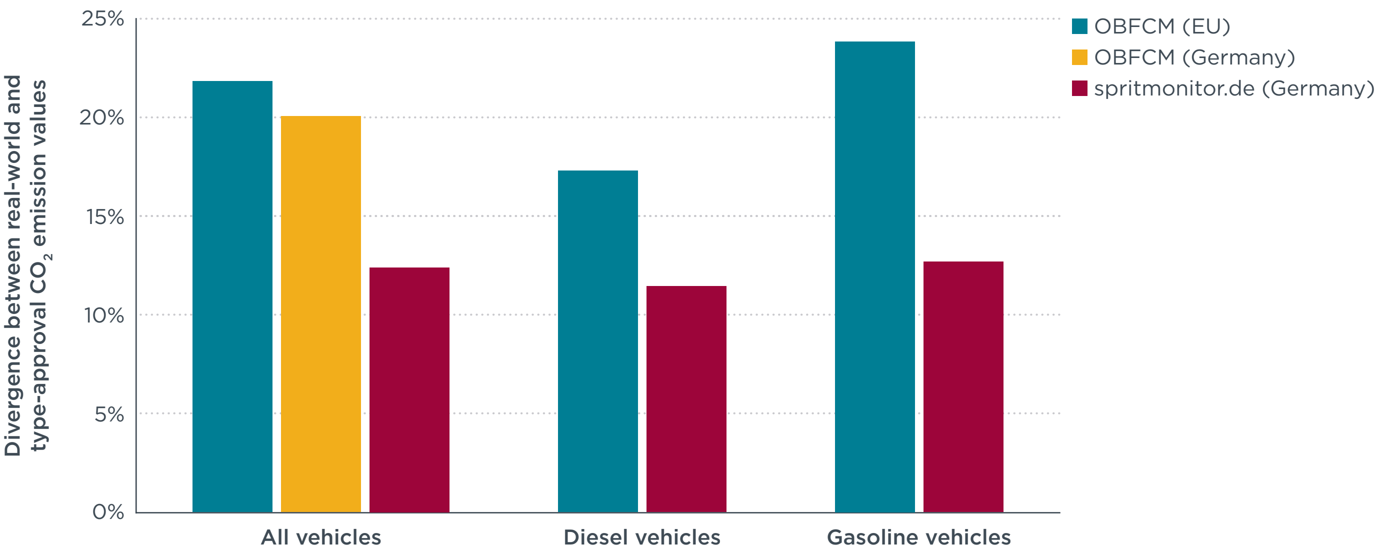

Figure 7. Gap between real-world and type-approval CO_2 emissions for combustion engine and hybrid cars manufactured in 2021, based on spritmonitor.de data in comparison to preliminary OBFCM data, as reported by the Joint Research Centre of the European Commission.

Differences in the analyses based on OBFCM and spritmonitor.de data can have manifold reasons. The gap resulting from OBFCM data was calculated as the average of all valid reported values. Our analysis calculates the gap based on sales-weighted vehicle combinations contained in the merged spritmonitor.de and type-approval dataset. Furthermore, the availability and quality of reported data for different manufacturers in the analyzed OBFCM dataset varies significantly; some brands are overrepresented while others are not represented at all. In addition, OBFCM data is expected to cover all types of drivers. Though spritmonitor.de includes a very broad dataset, the information is reported by users who are motivated to understand real-world fuel consumption. A more in-depth analysis of the causes of the discrepancy is not feasible as OBFCM raw data is not publicly available.

USING OBFCM DATA TO MITIGATE A GROWING CO_2 EMISSIONS GAP

OBFCM data availability

Data collection frequency is dependent on maintenance and periodic technical inspection intervals. Therefore, comprehensive OBFCM data for a single registration year becomes available to the Commission after a delay of 3 years. This means the Commission will have comprehensive data in 2025 to analyze the emissions gap for vehicles registered in both 2021 and 2022. One year later, comprehensive OBFCM data for vehicles registered in 2023 and for a large share of vehicles registered in 2024 will be available, allowing a projection of the gap for 2027 (Dornoff, 2021). Therefore, while the CO_2 standards currently foresee the use of OBFCM data for mitigating a growing gap only from 2030 onwards, data availability would support implementing a correction mechanism by 2027. The parameters available in the OBFCM data allow for determining the gap separately for cars and vans, for each manufacturer individually, and by fuel and powertrain type.

Design considerations for a correction mechanism

The gap-correction mechanism presented in this section aims at mitigating the excess CO_2 emissions produced during real-world driving in case of a growing gap. It is based on the principle that real-world CO_2 emissions should be proportional to the type-approval values, using the average gap of vehicles registered in the years 2021 and 2022 as a baseline. The gap would be determined individually for each combination of manufacturer, vehicle category, fuel type, and powertrain type. The correction mechanism would then be applied to the emissions of each vehicle parameter combination. If the gap in later years is higher than the baseline, manufacturers will be required to compensate for these excess emissions by lowering their average type-approval CO_2 emissions. Details of the mechanism are shown in Figure 8 and explained below. An example is also provided of the performance correction for the 2027 type-approval CO_2 emissions of gasoline cars produced by one manufacturer.

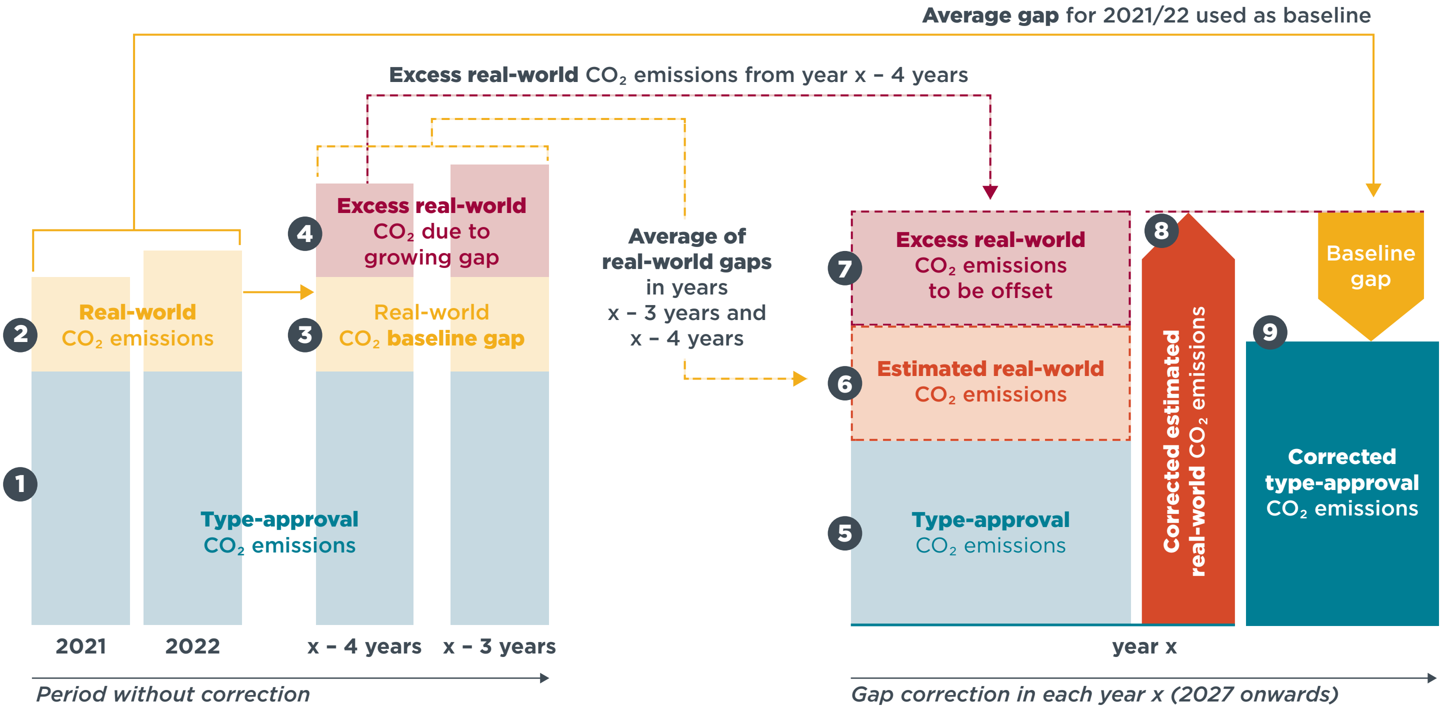

Figure 8. Design considerations for a mechanism to mitigate a growing real-world to type-approval CO_2 gap using data from on-board fuel and energy consumption monitors, assuming the correction mechanism applies from 2027 onwards.

Calculation of excess real-world CO_2 emissions in period without correction

In 2025, comprehensive OBFCM data for 2021 and 2022 will be available. Based on type-approval values (1) and real-world CO_2 emission data from OBFCM devices (2), the average gap in the years 2021 and 2022 is calculated as a baseline (3) per manufacturer, vehicle category, fuel type, and powertrain type.

Excess CO_2 emissions (4) are the result of a growing gap between real-world emissions and the 2021/22 baseline gap.

Calculation of corrected CO_2 emissions in year x

OBFCM data for vehicles registered in 2023 will become available in 2026, and therefore, a correction can first be applied in 2027. If the correction starts in 2027, the excess CO_2 emissions of the period 2023 to 2026 will be compensated for between 2027 and 2030, considering the 4-year delay.

Based on the average type-approval CO_2 emissions (5) in year x, the estimated real-world CO_2 emissions (6) are approximated using the average of the gaps determined for 3 years earlier (x – 3 years) and 4 years earlier (x – 4 years). Excess real-world CO_2 emissions to be offset in year x (7) are approximated by taking the real-world gap of 4 years earlier and subtracting from it the 2021/22 baseline gap, then multiplying this value by the number of vehicles registered 4 years earlier and distributing it over the number of vehicles registered in year x.

Corrected estimated real-world CO_2 emissions for year x (8) are determined by adding together the estimated real-world (6) and excess emissions (7).

Applying the principle that real-world and type-approval CO_2 emissions should remain proportional over time, we calculate the corrected type-approval CO_2 emissions value (9) by dividing the corrected estimated real-world CO_2 emissions (8) by the 2021/22 baseline gap (3). The corrected type-approval value (9) is used to assess the manufacturer's CO_2 performance in meeting its CO_2 target. Therefore, in the case of a growing gap, a manufacturer would need to lower its type-approval CO_2 emissions (5) to meet its CO_2 targets.

This mechanism would compensate for a growing emissions gap and thereby ensure the intended contribution of the vehicle fleet to the EU CO_2 reduction pathway. In addition, monitoring of real-world CO_2 emissions and adjusting future fleet CO_2 performance could have a positive effect on real-world CO_2 performance even before the correction mechanism applies. It could thereby foster the implementation of vehicle technologies that improve real-world fuel efficiency while discouraging manufacturers from pursuing operating strategies designed mainly to achieve low CO_2 emissions during type approval.

EXAMPLE CO_2 PERFORMANCE CORRECTION

This correction is for 2027 type-approval CO_2 emissions of gasoline cars produced by one manufacturer. The CO_2 correction for vans and cars of other fuel types and powertrain types of the same manufacturer is done separately applying the same methodology. The corrected manufacturer fleet average performance is then calculated as the value, weighted by registration numbers, of all corrected type-approval CO_2 emission values of its cars and vans.

We assume the average type-approval CO_2 emissions of gasoline cars produced by one manufacturer is 100 g/km in 2023 and 80 g/km in 2027 to meet its fleet target. We further assume that the average gap between real-world and type-approval CO_2 emissions for these vehicles increases from 12% in the 2021/22 baseline years to 16% in 2023 and 20% in 2024. The number of registered gasoline cars made by this manufacturer is 95,000 in 2023 and 100,000 in 2027.

First, we calculate the estimated real-world CO_2 emitted by this manufacturer's cars in 2027, using the average of the gap for 3 years and 4 years earlier. With the type-approval CO_2 emissions of 80 g/km in 2027 and the average gap of 18% in 2023/24, the estimated real-world CO_2 emissions value in 2027 is 94.4 g/km.

Next, we determine the excess real-world CO_2 emissions to be offset in 2027. Excess real-world CO_2 emissions are the gap larger than the 2021/22 baseline gap and are compensated for with a 4-year delay. Therefore, excess CO_2 emissions of vehicles registered in 2023 are offset in 2027. They are calculated using the type-approval CO_2 emissions of 2023 vehicles and the difference between the larger 2023 gap and the 2021/22 baseline gap. This calculates to 100 g/km • (1.16 – 1.12) = 4 g CO_2/km per vehicle. Multiplying this value by the number of vehicles registered in 2023 (95,000) and distributing it over the number of vehicles registered in 2027 (100,000) results in 3.8 g CO_2/km of excess real-world CO_2 emissions.

Adding the excess CO_2 emissions of 3.8 g/km to the estimated 2027 real-world CO_2 emissions of 94.4 g/km gives a corrected real-world CO_2 emissions value of 98.2 g/km. Dividing the corrected real-world emissions by the 2021/22 baseline gap of 12%, results in a corrected type-approval CO_2 emissions value in 2027 of 87.7 g/km. This is 7.7 g/km higher than the 80 g/km required of the manufacturer for the gasoline cars registered in 2027 to meet its fleet target.

To still meet its 2027 CO_2 target, the manufacturer needs to compensate for the correction by either lowering the average type-approval CO_2 emissions of its gasoline cars by 7.7 g/km or by increasing the share of low-CO_2 emission vehicles in its fleet.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Even though type-approval CO_2 emissions under the WLTP testing procedure are more representative of real-world emissions than those of the former NEDC procedure, our analysis indicates a continuously growing divergence between real-world and type-approval CO_2 emissions for WLTP type-approved cars as well. The gap for WLTP-tested combustion engine and hybrid cars, excluding plug-in hybrid vehicles, increased from about 8% for vehicles registered in Germany in 2018 to 14% for vehicles registered in 2022.

As a consequence, the reduction of real-world CO_2 emissions is less than that implied by the type-approval values. Under WLTP, car type-approval CO_2 emissions values decreased by 7.3% between 2018 and 2022; real-world emissions declined by just 2.3% during the same 5-year period.

Based on our findings we offer the following recommendations, primarily for the European Commission:

Preventing the CO_2 emissions gap from growing: Using its mandate from the CO_2 standards regulation, the European Commission could develop a mechanism that averts further growth of the emissions gap in the future. This mechanism could be designed and adjusted so that, in the case of a growing gap, manufacturers must improve their fleet average type-approval CO_2 emissions performance to meet their targets.

Mitigating excess CO_2 emissions from previous years: In the years before a correction mechanism takes effect, the gap between type-approval and real-world emission values may continue to grow. To compensate for the related excess real-world emissions, manufacturers' CO_2 emissions performance could be further adjusted once the mechanism applies, requiring even lower emission levels of their fleet.

Applying the correction mechanism earlier: Enabled by the availability of OBFCM real-world consumption data, and considering the indications of a fast-growing gap, the correction mechanism could apply starting in 2027 rather than 2030, as foreseen by the CO_2 standards.

Informing consumers about real-world consumption: Using the OBFCM data, consumers could be correctly informed about the environmental impact and expected cost by displaying a real-world fuel consumption estimates on the efficiency labels.

Making OBFCM data public: Anonymized OBFCM data merged with relevant vehicle characteristics could be made publicly available, allowing for independent research using representative real-world fuel and energy consumption data.

Analyzing the gap for electric vehicles: Real-world energy consumption data of electric vehicles could be collected and analyzed by the European Commission to determine the real-world to type-approval gap and to avoid the gap growth observed for internal combustion engine vehicles. Making OBFCM devices mandatory for electric vehicles would be necessary to gather this data.

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