WHITE PAPER

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FROM LABORATORY TO ROAD

A 2018 UPDATE OF OFFICIAL AND "REAL-WORLD" FUEL CONSUMPTION AND CO_2 VALUES FOR PASSENGER CARS IN EUROPE

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EXECUTIVE SUMMARY

Official average carbon dioxide (CO_2) emission values of new passenger cars in the European Union declined from 170 grams per kilometer (g/km) in 2001 to 119 g/km in 2017 over the New European Driving Cycle. The rate of reduction in CO_2 emission values increased from roughly 1% per year to approximately 3% per year after CO_2 standards were introduced in 2009. This rapid decline in CO_2 emission values seems to be a rousing success for CO_2 standards, but does not consider the real-world performance of vehicles.

Our *From Laboratory to Road* series focuses on the real-world performance of new European passenger cars and compares on-road and official CO_2 emission values. The studies have documented a growing divergence between real-world and official figures, and this divergence has become increasingly concerning.

This sixth update of the *From Laboratory to Road* series adds another year of data (2017), one new data source (German Mobility Panel), and approximately 200,000 vehicles to the analysis. **Data on approximately 1.3 million vehicles from 15 data sources and eight countries indicate that the divergence, or gap, between official and real-world CO_2 emission values of new European passenger cars increased from approximately 8% in 2001 to 39% in 2017** (see Figure ES- 1). With the average level virtually unchanged from 2016 to 2017, the new data confirm that the gap stabilized after 2015. We consider these findings to be robust given the considerable sample size and regional coverage; the heterogeneity of the data collected from consumers, company fleets, and vehicle tests; and the unambiguous upward trend in all samples.

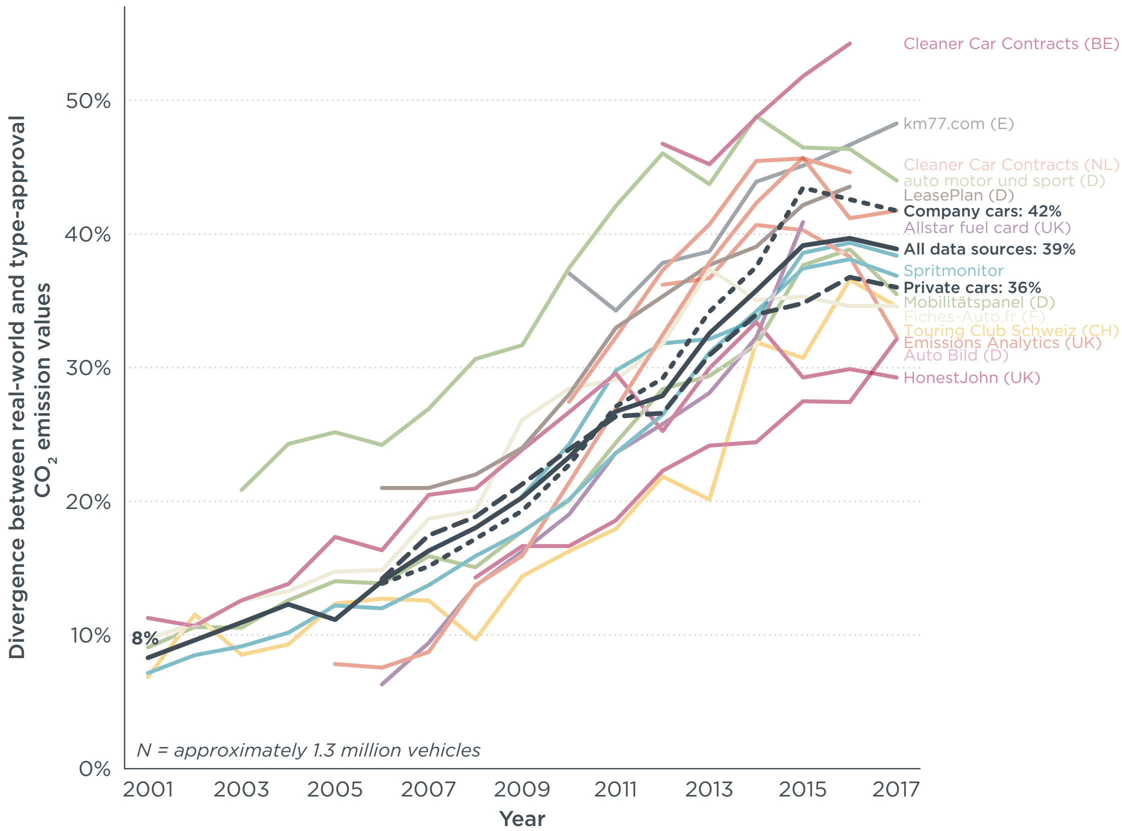

Figure ES- 1. Divergence between real-world and type-approval CO_2 emission values for various on-road data sources, including average estimates for private cars, company cars, and all data sources.

The historical growth in the divergence between official and real-world CO_2 emission values has important implications for all stakeholders:

» **For an average customer**, the divergence translates into unexpected fuel expenses of approximately 400 euros per year.

» **For society** as a whole, the continuing divergence undermines the EU's efforts to mitigate climate change and reduce fossil fuel dependence.

» **For governments**, the divergence translates into losses in vehicle tax revenue and undermines incentive schemes for low-carbon vehicles.

» **For car manufacturers**, claims about vehicle efficiency that are not attained in the real world have undermined public confidence and created an uneven playing field.

A growing body of evidence points to unrepresentative official CO_2 emission values as the culprit for the historical growth in the divergence. While the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), which is being phased in from September 2017 onward, is a step in the right direction, the WLTP is not a silver bullet and will not close the gap on its own. A number of policy and research actions are recommended to monitor and close the gap:

» Official measurements of real-world CO_2 emissions are needed. A recent regulation prescribes the utilization of fuel consumption meters in new passenger cars. These meters could furnish the required data.

» European consumers need access to realistic fuel consumption values to make well-informed purchasing decisions. Real-world fuel consumption can be estimated using a variety of quantitative models. Values on EU fuel consumption labels, which are presented at the point of purchase, should be adjusted to reflect average on-road fuel consumption, not just laboratory measurements.

» Policies and research on road transportation should factor in the divergence between type-approval and real-world figures. Accurate, up-to-date real-world adjustment factors should be used when assessing the costs and benefits of CO_2 mitigation efforts.

» More research is needed on the real-world performance of plug-in hybrid electric vehicles, light commercial vehicles, and heavy-duty vehicles. Policies need to address the high average divergence of plug-in hybrid electric vehicles.

TABLE OF CONTENTS

ABBREVIATIONS

CO_2	carbon dioxide
EEA	European Environment Agency
EU	European Union
g/km	grams per kilometer
HEV	hybrid electric vehicle
HMC	Hyundai Motor Company
ICCT	International Council on Clean Transportation
IFEU	Institute for Energy and Environmental Research Heidelberg
km	kilometer
km/h	kilometers per hour
MOP	German Mobility Panel (German: *Mobilitätspanel*)
MPG	miles per imperial gallon
NEDC	New European Driving Cycle
PEMS	portable emissions measurement system
PHEV	plug-in hybrid electric vehicle
RDE	Real Driving Emissions
TCS	Touring Club Switzerland
TNO	Netherlands Organisation for Applied Scientific Research
U.K.	United Kingdom
U.S.	United States
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

1. INTRODUCTION

In spring 2009, the European Commission set carbon dioxide (CO_2) emission standards for new passenger cars in the European Union (EU). After approximately 10 years of little progress under voluntary self-regulation, the standards set mandatory targets and specified penalties for excess emissions. A sharp increase in vehicle efficiency followed: The rate of reduction in average CO_2 emission values increased from 1% per year until 2007 to 3% per year from 2008 to 2017 (Tietge, 2018a). As a result, car manufacturers met the 2015 CO_2 target of 130 grams per kilometer (g/km) two years in advance.

The rapid improvements in vehicle efficiency following the introduction of CO_2 emission standards highlight the effectiveness of standards, a field in which the EU has played a pioneering role. Considering that passenger cars are the largest emitter of CO_2 within the transportation sector at around 12% of total EU emissions, these standards are key to climate change mitigation. In addition, reducing CO_2 emissions from road transportation implies a proportional reduction in fuel consumption, which in turn translates into fuel cost savings for consumers and decreases the EU's dependence on oil imports. In the past decade, average fuel consumption from passenger cars on the official test has decreased from 7.3 l/100km in 2001 to 5.1 l/100km (gasoline equivalent) in 2017. Furthermore, continuous research and implementation of new, clean technologies provides employment opportunities in the EU (Harrison, 2017; Summerton, Pollitt, Billington, & Ward, 2013).

Official CO_2 emission levels from new passenger cars are measured in the laboratory on a chassis dynamometer as prescribed by the New European Driving Cycle (NEDC). The controlled laboratory environment is important to ensure reproducibility and comparability of results. The NEDC was last amended in the 1990s and is gradually being replaced by the new Worldwide Harmonized Light Vehicles Test Procedure (WLTP) from 2017 to 2020 (Stewart, Hope-Morley, Mock, & Tietge, 2015).

While the rapid decline in average NEDC CO_2 emission values after the introduction of CO_2 standards is encouraging, improvements in vehicle efficiency during laboratory tests must translate into on-road improvements to ensure real-world benefits. Empirical evidence, however, points to a historical growth in the divergence between official and real-world CO_2 emission values. While a technical definition of real-world driving is elusive given the broad spectrum of driving styles and conditions, aggregating large datasets reveals clear trends in the real-world performance of cars.

The International Council on Clean Transportation (ICCT) began to investigate the divergence between type-approval and on-road CO_2 emissions in 2012. The 2012 report included real-world CO_2 emission data on 28,000 vehicles from Spritmonitor.de. The report pointed out a growing gap between official and real-world CO_2 emission values: Between 2001 and 2010, the divergence increased from 7% to 21%, with a more marked increase after 2007. In 2013, the first *From Laboratory to Road* study was published, conducted in collaboration with the Netherlands Organisation for Applied Scientific Research (TNO) and the Institute for Energy and Environmental Research Heidelberg (IFEU).

Annual updates of the *From Laboratory to Road* study echoed the findings of the 2012 analysis. The number of data sources and vehicles included in these reports increased, allowing for analyses of the gap by vehicle segment and individual manufacturer, among other categories. For instance, the 2014 update with data from more than a half-million vehicles, analyzed data trends for individual vehicle models and found that model redesigns were associated with sharp increases in the divergence.

This year's report, the sixth in the series, builds on the research from previous years, and remains the most comprehensive analysis of real-world CO_2 emission values in Europe to date. The 2018 update brings together data from 15 sources, including one new source (the German Mobility Panel), that together cover approximately 1.3 million cars from eight countries (see Figure 1). The data were gathered from online fuel tracking services, automobile magazines and associations, fuel card services, consumer surveys, and company fleets. Four data sources—LeasePlan (Germany), Allstar fuel card (United Kingdom), Cleaner Car Contracts Netherlands, and Cleaner Car Contracts Belgium—were not updated this year but are included in summary figures. For the documentation of these data sources, see the 2017 study (Tietge, Mock, German, Bandivadekar, & Ligterink, 2017).

	SOURCE	NUMBER OF ENTRIES
Belgium	Cleaner Car Contracts	835
Germany	Spritmonitor.de	186,940
	LeasePlan	250,000
	AUTO BILD	2,717
	auto motor und sport	2,649
United Kingdom	Allstar card	242,353
	HonestJohn.co.uk	152,195
	Emissions Analytics	845
Netherlands	Travelcard	356,032
	Cleaner Car Contracts Netherlands	21,540
France	Fiches-Auto.fr	32,984
Spain	km77.com	311
Sweden	*auto motor & sport*	820
Switzerland	Touring Club Schweiz	297

Figure 1. Map of Europe, indicating the data sources used for this report.

This analysis makes use of the law of large numbers, which is illustrated in two figures below based on user-reported fuel consumption values from the German web service Spritmonitor.de. Figure 2 shows how, even though individual driving styles and conditions vary, large samples tend to cluster around a central estimate. The distribution of gap measurements shifted to the right and grew wider over time, indicating that the divergence and the variance in the divergence increased. Figure 3 shows how, as the sample size of on-road fuel consumption measurements increases, the average divergence of the samples converges to a certain value. This value, again, increased over time. Taken together, the two figures illustrate that divergence estimates converge to a central estimate. Given sufficiently large samples, on-road measurements can therefore be used to estimate the divergence despite variations in driving styles and conditions. While some of the samples included in the analysis may suffer from self-selection bias (see section 4), any bias is considered to be constant over time and will not affect trends.

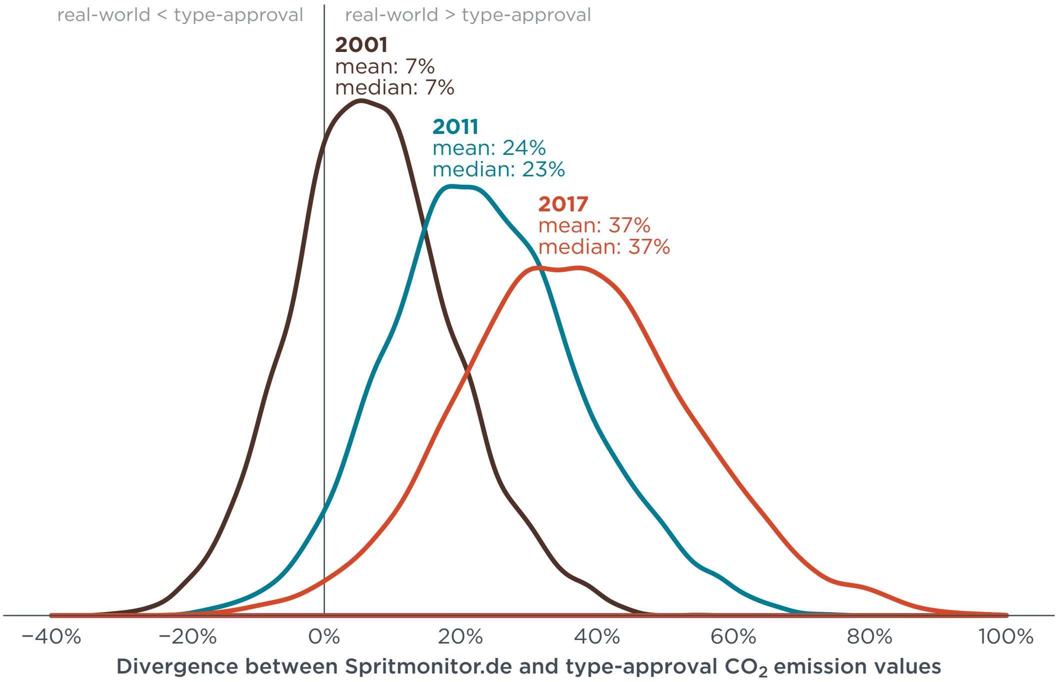

Figure 2. Distribution of the divergence between Spritmonitor.de and type-approval CO_2 emission values, comparison for vehicle build years 2001, 2011 and 2017.

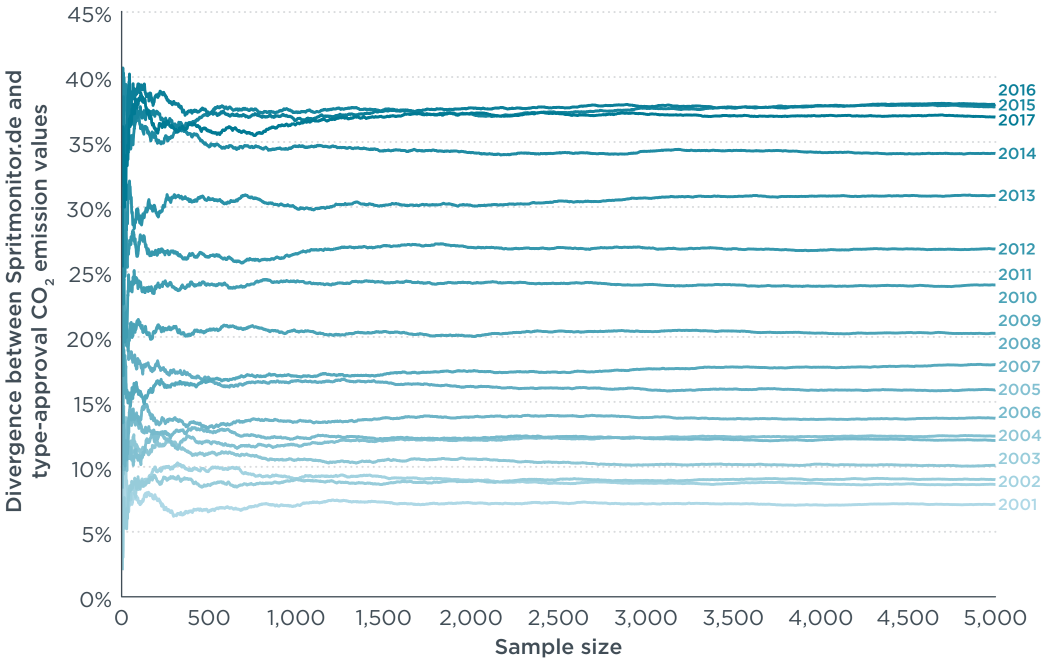

Figure 3. Annual divergence estimates as a function of sample size, based on Spritmonitor.de data.

Throughout the report, fuel consumption and CO_2 emission values are used interchangeably, as the metrics are directly related (nearly all of the carbon in the fuel is converted to CO_2 during combustion). Results and graphs are presented in terms of CO_2 emission values. The terms “official,” “type-approval,” and “laboratory” are used to describe NEDC results. The divergence is calculated as the difference between real-world and official CO_2 emission values divided by the official value.

The remainder of this study is organized in four parts. Section 2 presents 11 data sources and estimates the divergence between official and real-world CO_2 emission values.

Section 3 compares the divergence estimates from the different data sources. Section 4 discusses the underlying reasons for the historical growth in the gap and examines limitations in the data. Lastly, Section 5 summarizes the findings and presents policy recommendations. In order to make the results more accessible to policymakers and researchers, summary statistics for all data sources were published on the ICCT website's landing page for this paper.[1]

1 See http://www.theicct.org/laboratory-road-2018-update

2. DATA ANALYSIS

2.1 SPRITMONITOR.DE (GERMANY)

Data type	On-road, user-submitted
Data availability	2001–2017, on average 10,000 vehicles per build year
Data collection	Fuel consumption data entered by drivers into a publicly available online database
Fleet structure, driving behavior	Mostly private cars; urban and extra-urban driving; some information on driving style

Description

Spritmonitor.de[2] is a free web service that tracks fuel consumption. Launched in Germany in 2001, the website aims to provide drivers with a simple tool to monitor their fuel consumption and makes real-world fuel consumption figures available to the public. Spritmonitor.de has approximately 500,000 registered users, data on more than 700,000 vehicles, and is available in German, English, 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 a reference for calculations of fuel consumption. In addition to mileage and fuel volume data, Spritmonitor.de users can provide details on driving behavior, route type, and use of the air conditioning system with each entry.

Because Spritmonitor.de users add fuel consumption data on a voluntary basis, there is a risk of self-selection bias. Section 4 discusses this issue.

Methodology

Spritmonitor.de provided anonymized data on approximately 700,000 vehicles. The dataset included total mileage and total fuel consumption of each vehicle, as well as the following specifications: brand name, model name, build year (the year a vehicle was manufactured), fuel type, engine power, and transmission type. For each vehicle, the real-world fuel consumption value was 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. Car-derived vans (e.g., VW Caddy), non-car derived vans (e.g., VW Transporter), and pickups were excluded from the analysis as they are typically registered as light commercial vehicles. Vehicles built before 2001 or after 2017 were discarded.

Vehicles with erroneous on-road fuel consumption values were removed based on thresholds defined by Peirce's criterion.[3] After removing incomplete entries and outliers, a sample of approximately 186,000 vehicles remained. The model variants included in the analysis cover approximately 86% of the model variants sold in the German market.

The Spritmonitor.de sample consists of on-road fuel consumption measurements, so the sample was complemented with type-approval fuel consumption figures from an ICCT database (ICCT, 2018), here referred to as "joined values," to calculate the divergence between official and real-world figures. Approximately one-third of users did, however, enter their vehicles' type-approval figures on Spritmonitor.de. These user-submitted type-approval fuel consumption values were used to gauge the accuracy of the joined values.

2 See http://www.spritmonitor.de. The complete dataset used for this analysis was acquired in October 2018.
3 For a description of Peirce's criterion and its application, see Tietge, Mock, Franco, et al. (2017)

Figure 4 plots the distribution of ratios between the joined and user-submitted type-approval values. The figure shows strong agreement between the two sets of values: The median of the ratio is 100% and the mean is 99%, with 32% of all vehicles within ±1 percentage points agreement and 70% of all vehicles within ±5 percentage points agreement.

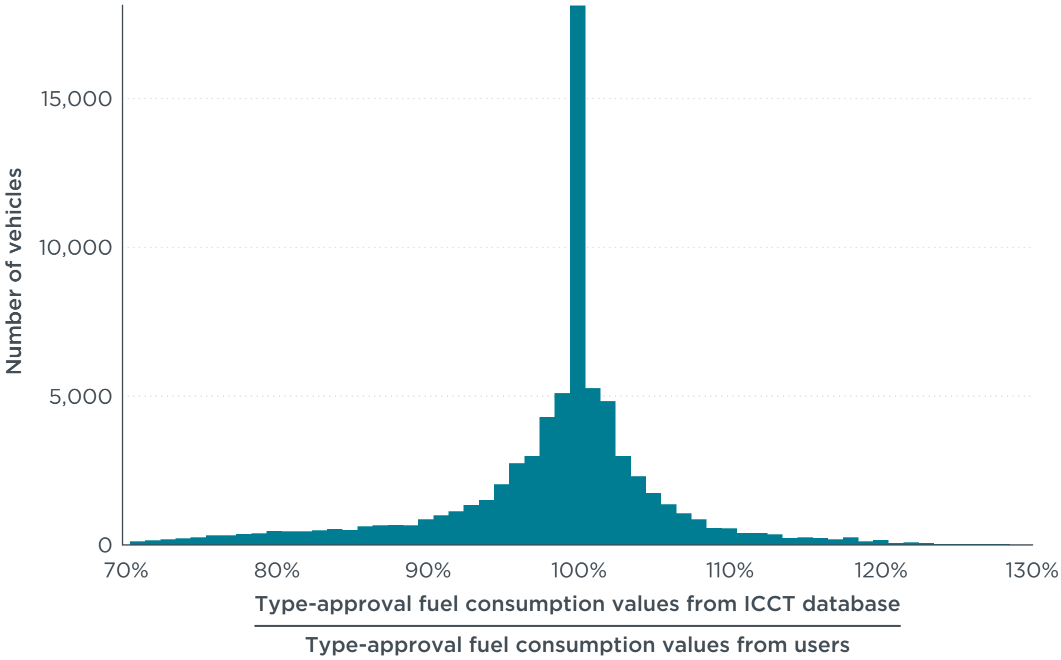

Figure 4. Distribution of the ratio between joined and user-submitted type-approval fuel consumption values for Spritmonitor.de.

For comparison purposes, Figure 5 plots the average annual divergence according to ICCT joined values and according to user-submitted type-approval fuel consumption values. The figure includes only vehicles for which both joined and user-submitted values were available (approximately 72,000 vehicles). The graph indicates that the slight differences between joined and user-submitted type-approval fuel consumption values affect annual averages by up to 5 percentage points, and that the difference is more manifest in recent years. It is, however, not possible to determine whether the process of joining type-approval values from the ICCT database or transcription errors in the user input are the source of the discrepancy. Because using type-approval fuel consumption values from the ICCT database allowed for a much greater coverage (186,000 vehicles versus 72,000 vehicles), the ICCT joined values were used for the rest of the analysis.

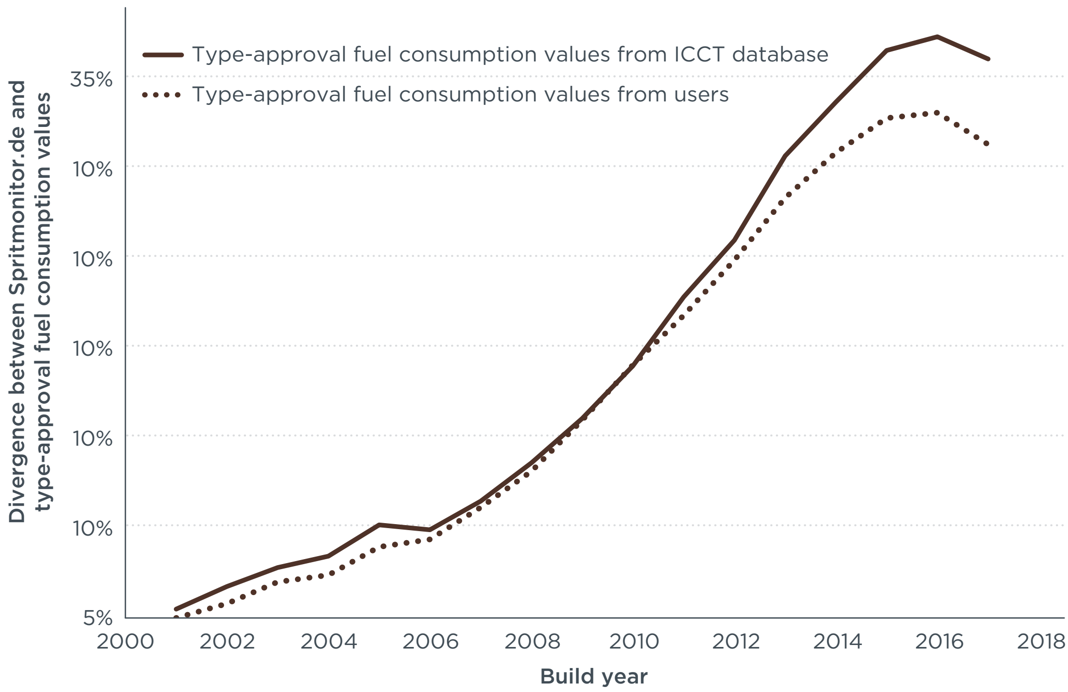

Figure 5. Divergence between real-world and type-approval CO_2 emission values according to ICCT and user-submitted type-approval fuel consumption values, from a subset of the Spritmonitor.de data.

Results

Figure 6 plots the divergence between type-approval and Spritmonitor.de fuel consumption values by fuel type. The gap declined to 37% in 2017 from a high of 38% in 2016. Despite the recent decline, the gap remains at levels that are four times higher than in 2001. The gap increased rapidly during the first phase of EU CO_2 standards, from 2009, when standards were implemented, until 2015, the target year of the standard. In 2016, the growth of the gap slowed and then declined in 2017.

Fuel and power train types played a significant role in the recent decline in the gap. The difference between the average divergence of diesel and gasoline cars has been gradually increasing since 2010, with the gap for diesel vehicles leveling off at 41% in 2017, which is 7 percentage points higher than the gap for gasoline cars. 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 (see bottom graph in Figure 6). The recent drop in the diesel share caused the fleetwide gap to decline in 2017 although the respective diesel and gasoline gap values remained stable compared to 2016.

Sufficient data on the real-world performance of hybrid electric vehicles (HEVs) was available since build year 2004. HEVs consistently exhibited average divergence values well above the levels of conventional power train vehicles, and increased from 22% to 47%.

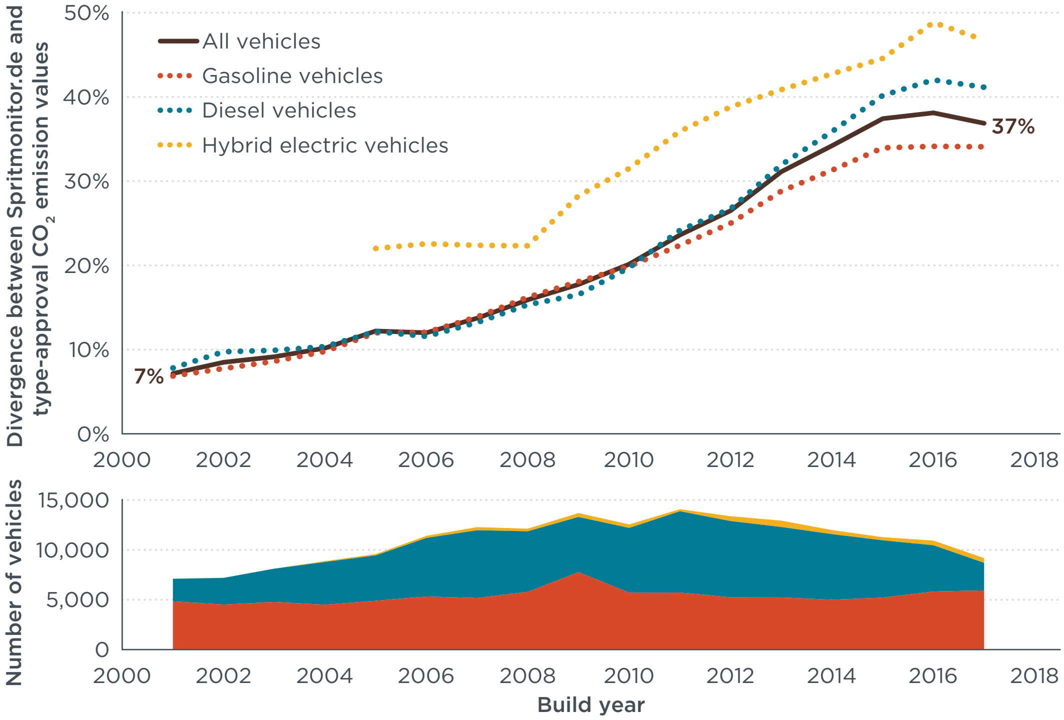

Figure 6. Divergence between Spritmonitor.de and type-approval CO_2 emission values by fuel/power train type. The bottom graph displays the number of vehicles per fuel/power train type and build year.

In addition to variations among fuel types, the divergence between on-road and official CO_2 emission values also varies by the type of transmission, as shown in Figure 7. The average divergence from vehicles with automatic transmissions was higher than that of vehicles with manual transmission after 2006, and the difference between transmission types was at its highest in 2017 at 8 percentage points. The share of cars with automatic transmissions steadily increased over time. Vehicles with automatic transmissions accounted for roughly 16% of the Spritmonitor.de vehicles built in 2001 and grew to 54% of the sample in build year 2017.

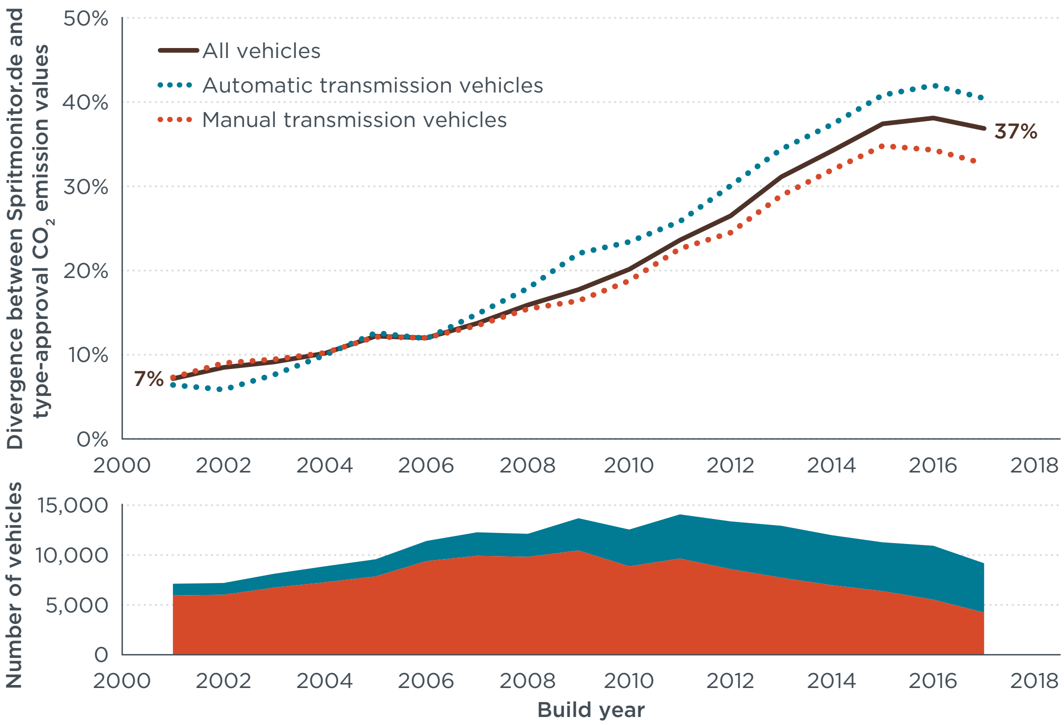

Figure 7. Divergence between Spritmonitor.de and type-approval CO_2 emission values by transmission type. The bottom graph displays the number of vehicles per transmission type and build year.

Given the large sample size, it is possible to examine the divergence between Spritmonitor.de and official CO_2 emission values by vehicle segment and by manufacturer/brand. Figure 8 shows the trend in the divergence for the six most popular vehicle segments.[4] The lower medium segment historically accounted for the highest share of entries in the Spritmonitor.de dataset (approximately 40%). Lower medium vehicles thus follow the market trend closely. The small and medium vehicle segments also made up relatively high annual shares of the Spritmonitor.de sample, around 17%–18% each, and thus also overlap with the market trend to a large extent. The upper medium segment stands out with the highest average divergence values and was one of the only segments to see a growing gap in 2017. The divergence values for the off-road segment have fallen below the market average over the past several years, as the segment's share in the dataset increased from around 1% in build year 2001 to 24% in build year 2017. In recent years, average divergence values from the mini segment have dropped below the market average but continued to grow in 2017.

4 Vehicle segments are defined as: mini (e.g., smart fortwo), small (e.g., VW Polo), lower medium (e.g., VW Golf), medium (e.g., VW Passat), upper medium (e.g., Mercedes-Benz E-Class), and off-road (e.g., BMW X5).

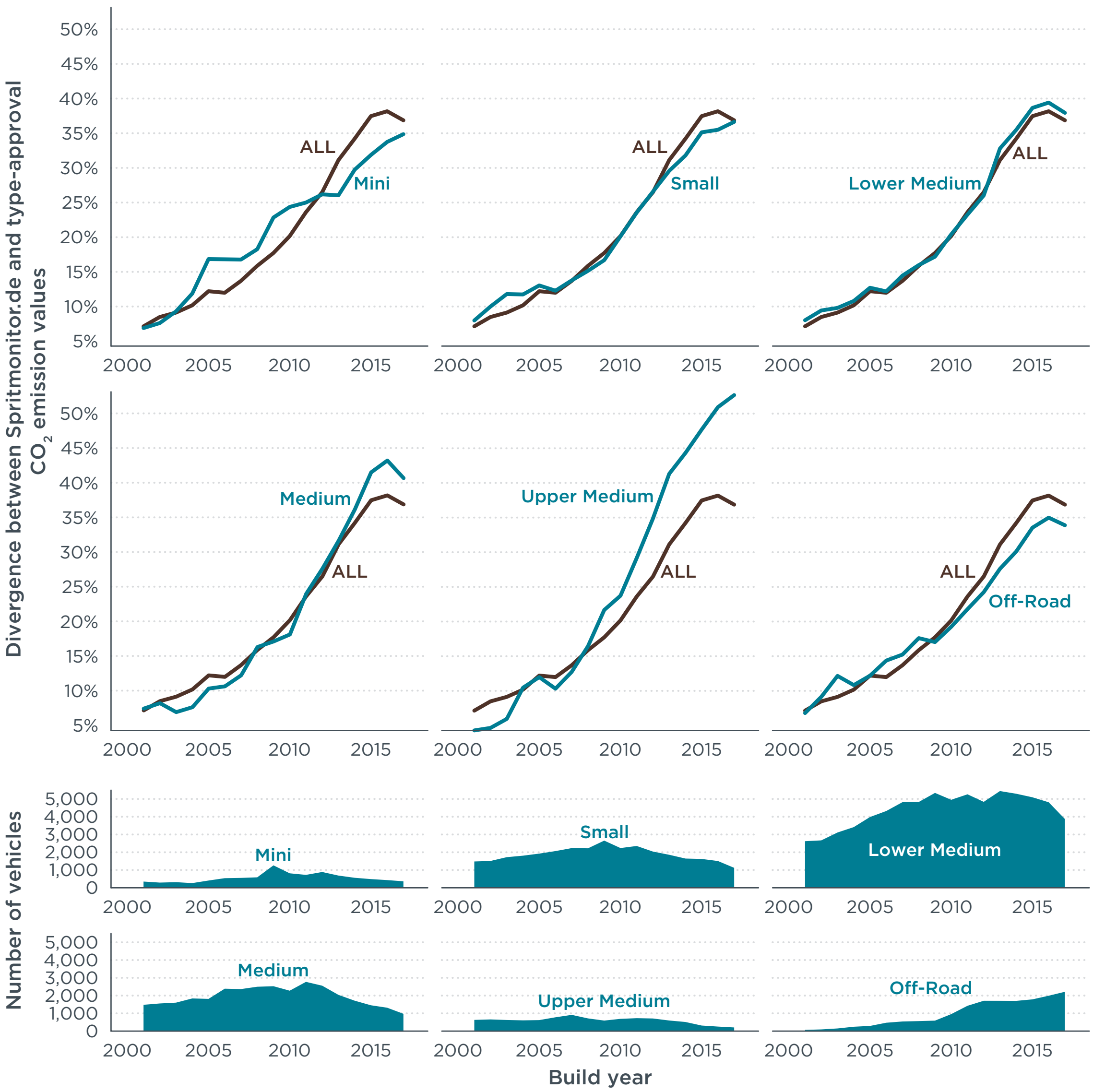

Figure 8. Divergence between Spritmonitor.de and type-approval CO_2 emission values by vehicle segment. The bottom graphs display the number of vehicles per segment and build year.

Figure 9 plots the trend in the divergence between Spritmonitor.de and official CO_2 emission values for a selection of 12 top-selling manufacturer groups.[5] European premium manufacturers Audi, BMW, Daimler, and Volvo stand out with the highest average divergence. BMW and Daimler experienced a sharp increase in the gap around build years 2008 and 2009, when the fuel-saving technology packages *EfficientDynamics* (BMW) and *BlueEFFICIENCY* (Daimler) were introduced. These packages consisted of stop/start systems, low rolling resistance tires, and weight-saving measures, among others. Although BMW has converged with the market trend since build year 2009, the divergence for Daimler vehicles has grown at a faster pace. In 2017, the average gap of European premium manufacturers leveled off or declined by up to 3 percentage points.

5 Manufacturers (brands) included are: BMW (BMW, Mini), Daimler (Mercedes-Benz, smart), Fiat Chrysler Automobiles (Alfa Romeo, Chrysler, Dodge, Fiat, Jeep, Lancia), Ford (Ford), Honda (Honda), Hyundai Motor Company (Hyundai, Kia), Mazda (Mazda), PSA (Citroën, Opel, Peugeot), Renault-Nissan (Dacia, Infiniti, Renault, Mitsubishi, Nissan), Toyota (Daihatsu, Lexus, Toyota), and Volkswagen (Audi, Porsche, Seat, Škoda, VW), Volvo (Volvo).

Toyota also has divergence values above the market average because of the large share of HEVs among Toyota entries in the Spritmonitor.de data (around 79% in build year 2017). As seen in Figure 6, HEVs have average divergence levels significantly higher than those of conventional power trains. Excluding HEVs, Toyota has one of the lowest average divergence values of all manufacturer groups. In build year 2017, the average divergence from conventional Toyota models was 28%, 9 percentage points below the market average.

Two manufacturer groups, Honda and Mazda, tied for the lowest gap values in 2017 at 24%. Although Mazda saw a steep decline in the gap after 2014, Honda consistently has had lower-than-average gap values since 2009. The Hyundai Motor Company (HMC), another Asian manufacturer group, dipped below the market average in recent years.

Volkswagen and Renault-Nissan historically remained below the market average but recently have converged with the market average. Fiat Chrysler Automobiles (FCA), Ford, and the PSA group have tracked the market average trend closely throughout the years.

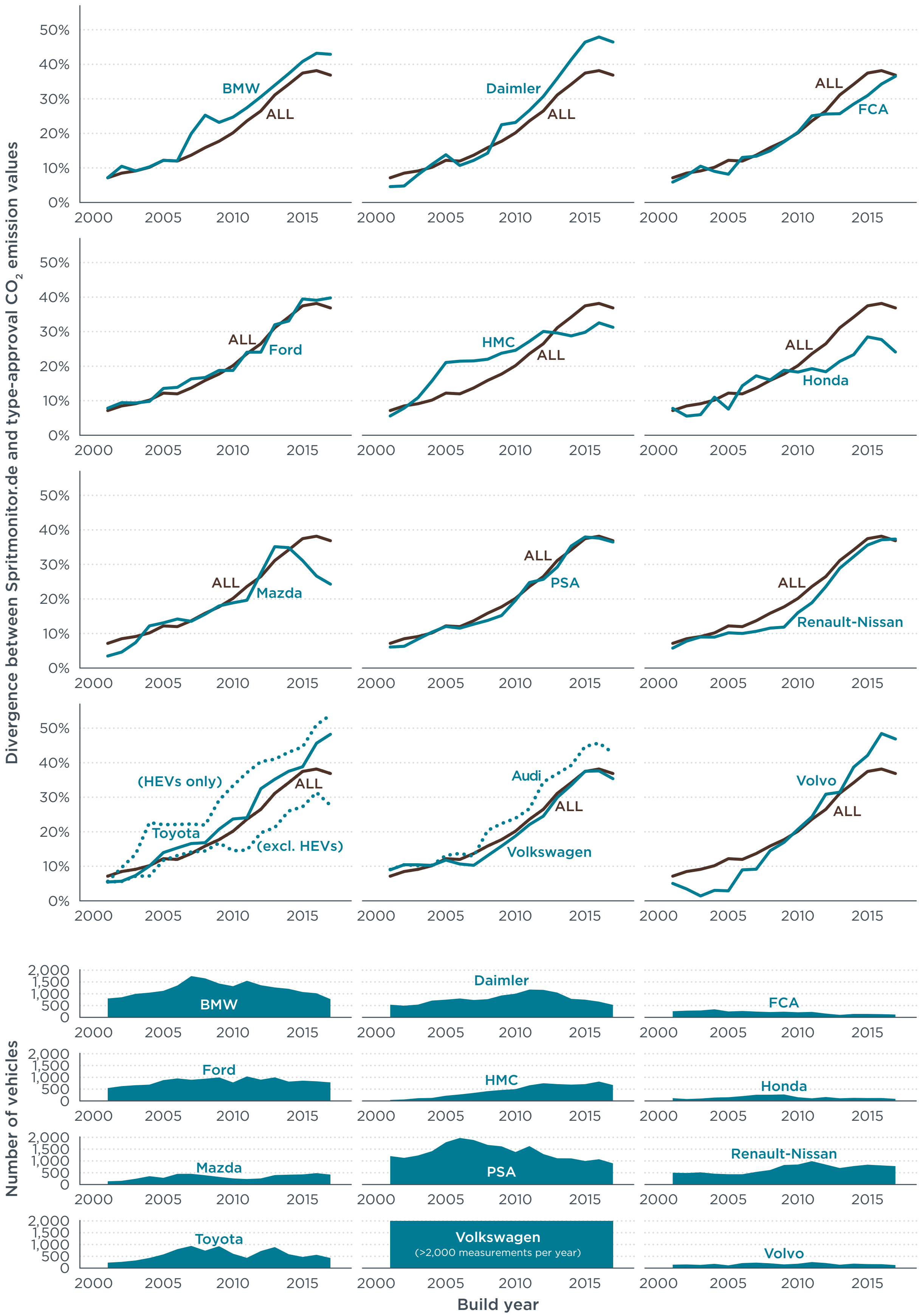

Figure 9. Divergence between Spritmonitor.de and type-approval CO_2 emission values by manufacturer group. The bottom graphs display the number of vehicles per manufacturer group and build year.

Figure 10 plots the trend in the divergence for the top-selling models of the following brands: BMW, Mercedes-Benz, Peugeot, Renault, Toyota, and VW. The average divergence of each brand is also shown in the chart for comparison. Models' contributions to their respective 2017 brand sales in Germany are stated in the top left of each graph, while the minimum and maximum number of Spritmonitor.de entries per build year and model are presented in the bottom right. Circular markers denote the introduction of new model generations or major model facelifts, which imply new emissions type-approval certificates. Markers are placed the year before the facelift penetrated the German market. The erratic trend of some of the models is due to a low number of entries in the Spritmonitor.de sample.

As can be seen in Figure 10, the average divergence between on-road and official CO_2 emission values for a certain vehicle model tends to increase sharply following the introduction of a new model generation. Once the facelifted model has fully penetrated the market, the trend plateaus. This pattern has become more noticeable in recent years. For example, the gap of the VW Passat jumped and plateaued after the 2010 facelift and the introduction of the eighth model generation, B8, in 2014. The same is true for the release of the Mercedes-Benz C-Class W205 in early 2014. Both hybrid electric models displayed in the figure, the Toyota Yaris and Toyota Auris, exemplify the general tendency of HEVs to exhibit average divergence levels well above those of conventional power trains.

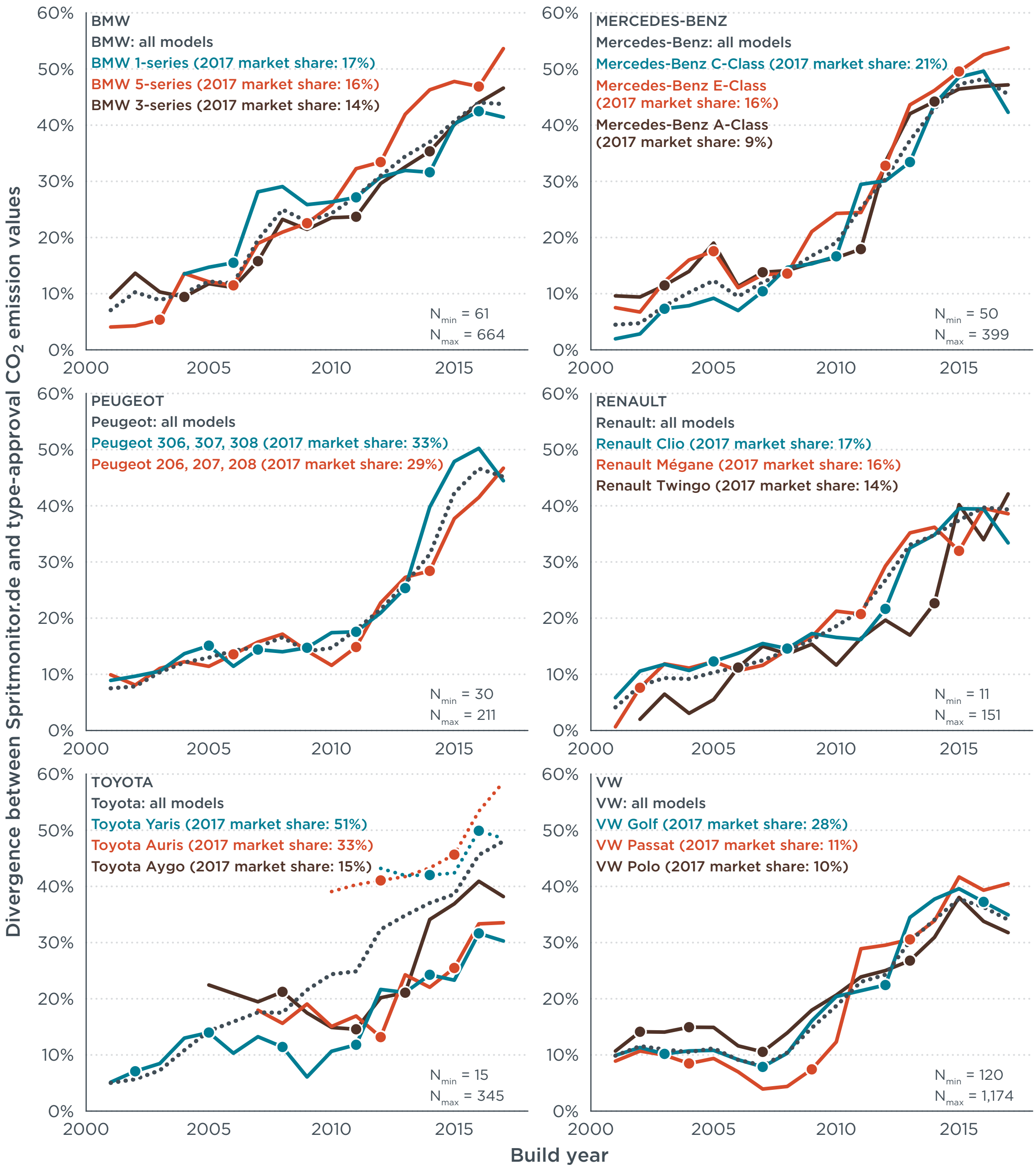

Figure 10. Divergence between Spritmonitor.de and type-approval CO_2 emission values by brand and by top-selling models.[6] Circles indicate the year before a major technical overhaul. Dotted lines represent the brand average.

Figure 11 shows how the average CO_2 divergence evolved between build years 2001 and 2017 for select top-selling vehicle models, grouped by vehicle segment (small, lower medium, medium, and upper medium) and target market (premium and mass market). As in Figure 10, the contribution of each model to its market's 2017 sales in Germany is provided in the top left of each graph, whereas the minimum and maximum number of Spritmonitor.de entries per build year and model are specified in the bottom right. Again, circular markers in the graph indicate the year before the introduction of a new model generation or major technological overhaul.

6 2017 market share: models' contribution to their respective brands in Germany in 2017; $N_{min/max}$: minimum and maximum annual number of data entries for vehicle models.

As already shown in Figure 8, average divergence estimates increased over time in all vehicle segments. Smaller vehicles tend to have lower average divergence values than larger ones. Mass-market popular models usually exhibit lower divergence levels than premium market models. Some segments show rather homogeneous upward trends across vehicle models, while other segments have first-movers and laggards. Models in the small, mass-market segment, or the medium and upper medium premium segments, exhibit fairly uniform divergence patterns. In the lower medium, mass-market segment, however, the Škoda Octavia clearly lagged behind the Opel Astra and the VW Golf, which experienced steep increases in their average divergence values after model facelifts entered the market in 2008 and 2009, respectively. The Škoda Octavia caught up with the segment average trend only after the third generation arrived in the market in 2013. A similar development was found in the lower medium, premium market segment, where the BMW 1-series stands out as a clear first-mover compared with the Audi A3 and the Mercedes A-Class. The BMW 1-series also is a clear example of the pattern described above: The divergence sharply increases following a major facelift and then plateaus as the updated model fully penetrates the market.

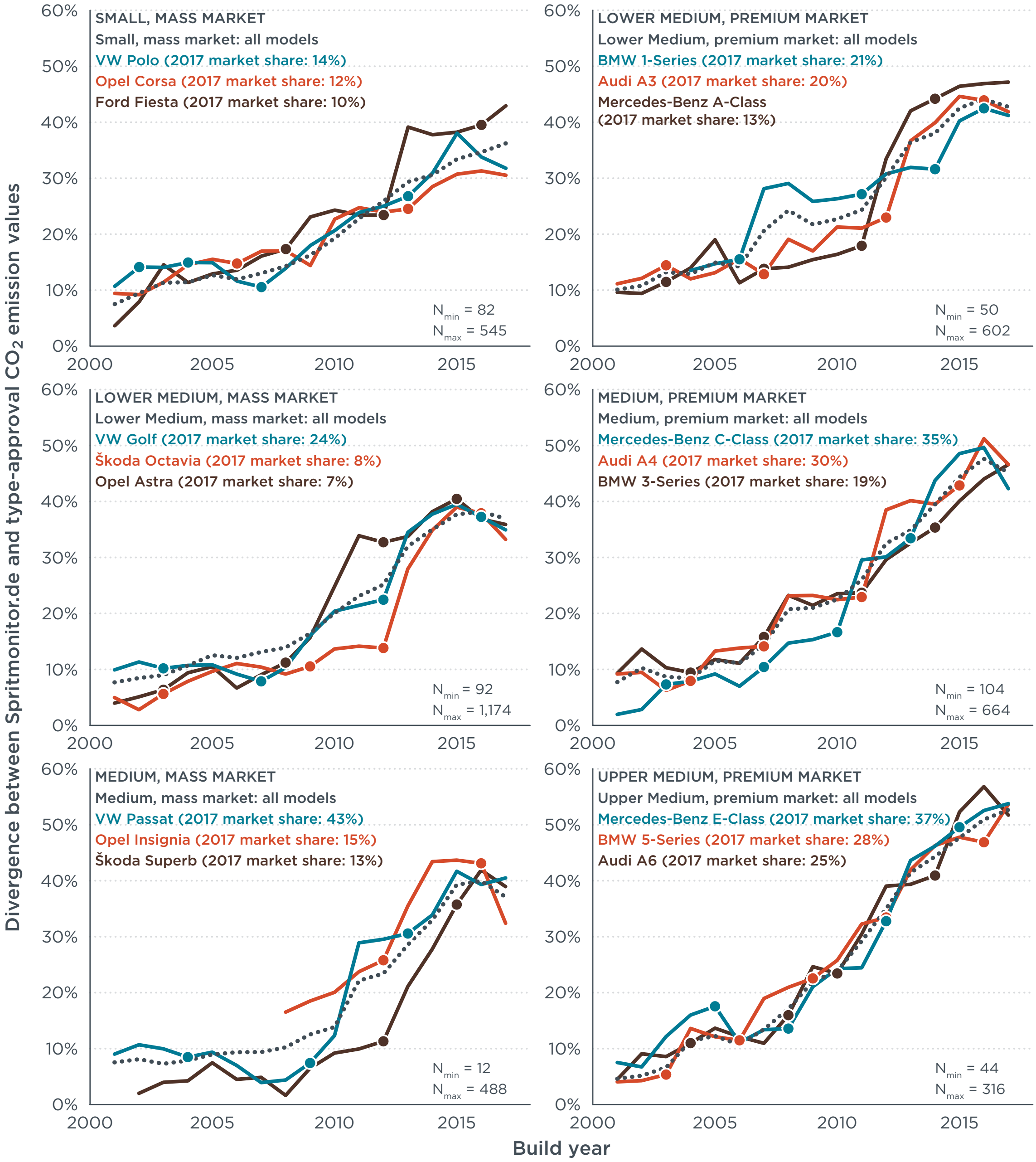

Figure 11. Divergence between Spritmonitor.de and type-approval CO_2 emission values by vehicle segment and their top-selling mass market (left) and premium market (right) models.[7] Circles indicate the year before a major technical overhaul. Dotted lines represent the segment/market average.

The analysis of the average divergence between Spritmonitor.de and type-approval CO_2 emission values at the vehicle model level (Figure 10 and Figure 11) provides an explanation for how the divergence of the entire Spritmonitor.de sample increases over time: Step-wise increases in individual models' gap estimates after model facelifts add up to an overall increase in the average divergence. Type-approval CO_2 emission values typically decrease with each facelift. However, the analysis of real-world fuel consumption data reveals that the improvement in fuel efficiency that the model achieves in the laboratory is not fully reflected on the road. Artificially low official CO_2 emission values may result from manufacturers exploiting technical tolerances and imprecise definitions in the test procedure. Additionally, new fuel-saving technologies, such as engine stop/start systems, sometimes prove more effective in the laboratory than under real-world driving conditions (see Section 4 for more details).

7 2017 market share: models' contribution to their respective brands in Germany in 2017; $N_{min/max}$: minimum and maximum annual number of data entries for vehicle models.

2.2 TRAVELCARD (NETHERLANDS)

Data type	**On-road, fuel card**
Data availability	2005–2017, approximately 30,000 vehicles per year
Data collection	Fuel consumption data, recorded using a fuel card when refueling at gas stations
Fleet structure, driving behavior	Company cars; urban and extra-urban driving; fuel is usually paid for by the employer

Description

Travelcard Nederland BV is a fuel card provider based in the Netherlands.[8] Fuel cards are used as payment cards for fuel at gas stations and frequently are used by companies to track fuel expenses of their fleets. Travelcard passes are accepted in all Dutch fuel stations, as well as in more than 43,000 fuel stations across Europe.

The Travelcard fleet is a large, homogeneous group of drivers, who typically drive new cars and change vehicles every few years. Most cars are less than four years old. Employers typically cover fuel expenses of Travelcard users. Travelcard drivers may thus have a lower incentive than private car owners to drive in a fuel-conserving manner. Nevertheless, Travelcard has a Fuel Cost Saving program in place to encourage drivers to conserve fuel. For example, the company awards loyalty points to users with relatively low fuel consumption, and the fuel pass also can be used for public transport.

For this study, TNO analyzed fuel consumption data from a sample collected in June 2018 of approximately 367,000 common vehicles with build years ranging from 2005 to 2017. Given the sample size, estimates from the Travelcard data are considered representative of real-world CO_2 emissions from Dutch company cars. A detailed discussion of the representativeness of the Travelcard data can be found in the 2013 *From Laboratory to Road* study (Mock et al., 2013).

Methodology

Travelcard data provided by TNO covered real-world and type-approval CO_2 emission values by fuel type. TNO estimated real-world CO_2 emissions based on pairs of consecutive fueling events, using odometer readings, as recorded by the drivers, and fuel volume, as automatically recorded by the Travelcard system.

The sample analyzed for this report corresponds to the current Travelcard fleet. It includes updated fuel consumption values for preexisting vehicles based on additional data collected since the last report. These additional data are valuable because the gap tends to stabilize after approximately one year of data collection.

Results

Figure 12 plots the divergence between type-approval and Travelcard CO_2 emission values from build year 2005 to 2017. The divergence between real-world and official CO_2 emission values increased following the introduction of CO_2 emission standards in the EU around 2009. The gap then peaked at 46% in 2015 and declined to 41%–42% in 2016–2017. The sharp drop from 2015 to 2016 is explored toward the end of this chapter. Diesel vehicles consistently exhibited a higher average divergence than gasoline vehicles. HEVs are included in the figure, but plug-in hybrid electric vehicles (PHEVs) are excluded. PHEV data are presented in Figure 13 and TNO regularly publishes analyses of PHEVs in the Travelcard fleet (see van Gijlswijk & Ligterink, 2018).

8 See http://www.travelcard.nl/

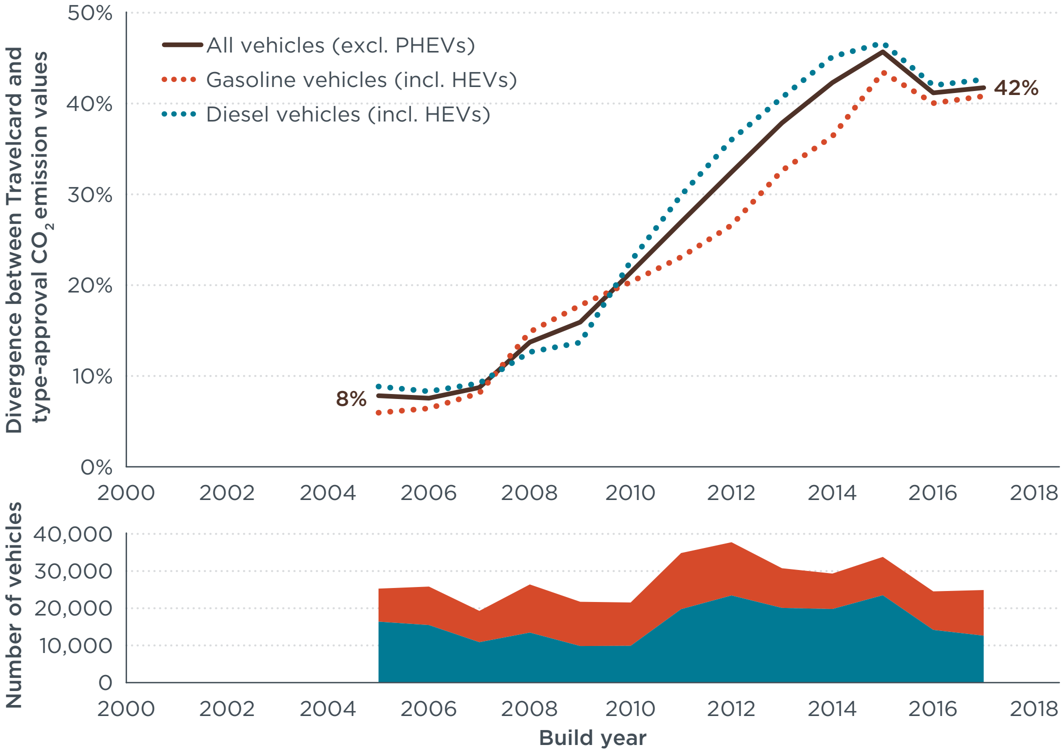

Figure 12. Divergence between Travelcard Nederland BV and type-approval CO_2 emission values by fuel type. The bottom graph displays the number of vehicles per fuel type and build year.

Figure 13 plots the average divergence between type-approval and Travelcard CO_2 emission values by power train type for all vehicle build years. Although vehicles with conventional power trains and HEVs on average exceed type-approval CO_2 values by 25% to 30%, PHEVs stand out with a gap of 221%.

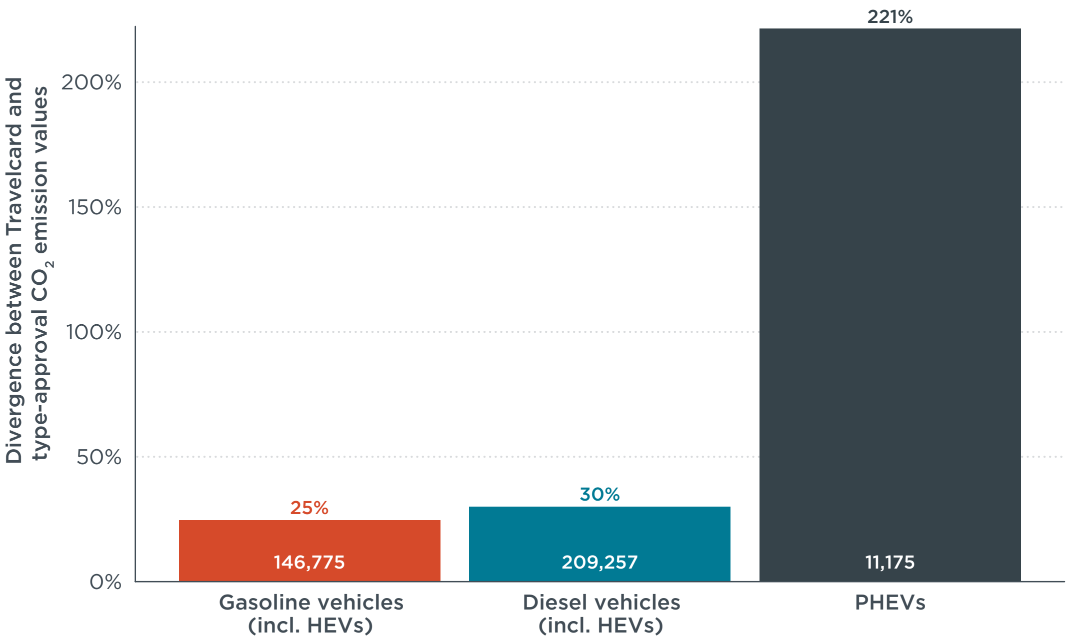

Figure 13. Divergence between Travelcard Nederland BV and type-approval CO_2 emission values by fuel/power train type for all build years. The number of vehicles per category is presented at the base of each bar.

Figure 14 shows how the shares of Travelcard vehicles, grouped by 10 g/km type-approval CO_2 emission bins, evolved between build years 2005 and 2017. The fill color gradient indicates the average divergence between on-road and official CO_2 emission values.

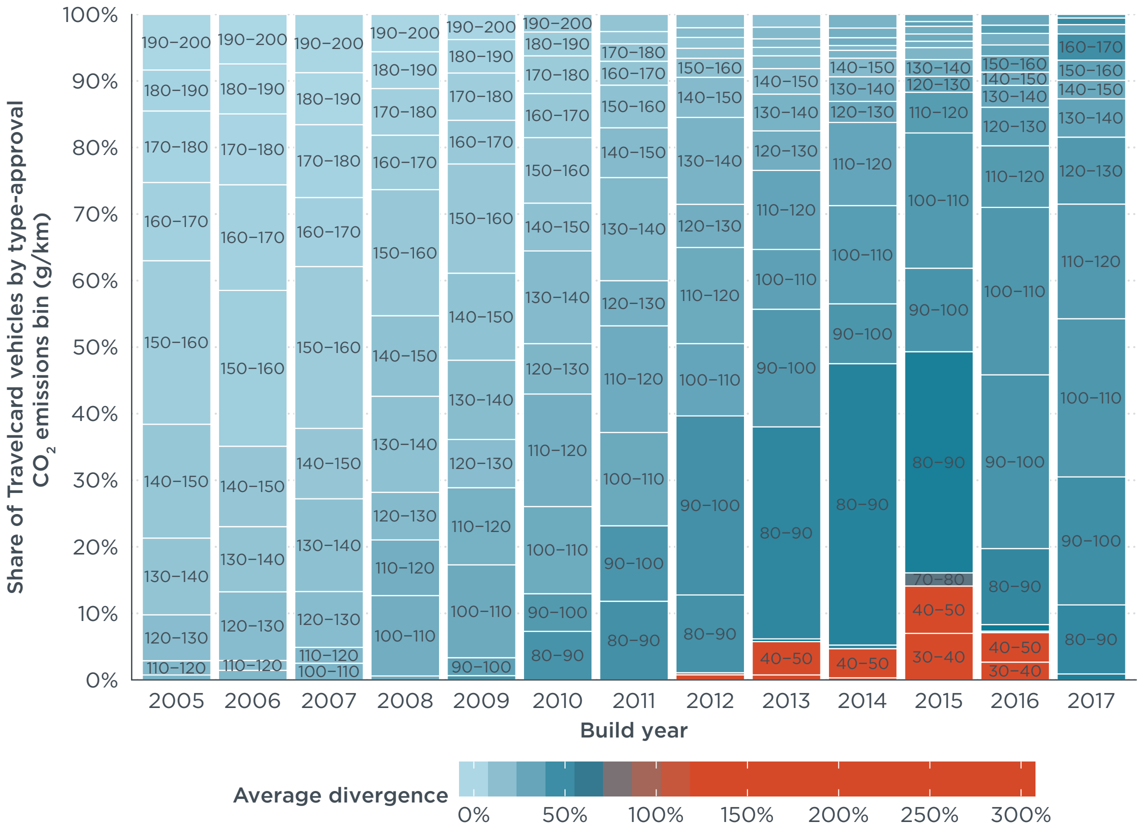

Figure 14. Share of Travelcard Nederland BV vehicles by type-approval CO_2 emissions bin. The color scale indicates the average divergence between Travelcard and type-approval CO_2 emissions per bin.

Figure 14 shows that, from 2008, the share of vehicles with type-approval CO_2 values between 80 and 110 g/km experienced a significant increase, while the shares of those vehicles with higher type-approval CO_2 emission values decreased. Multiple studies show that the introduction of tax incentives stimulated the purchase of low-carbon cars in the Netherlands (Kok, 2011; van Meerkerk, Renes, & Ridder, 2013). Within each build year, vehicles with low CO_2 emission values have the highest divergence, thus undermining the benefits of the tax incentives. The figure also shows that the gap typically increased in all type-approval CO_2 bins over time.

Figure 14 offers an explanation for the 5-percentage-point decline in the gap from build year 2015 to 2016 (see Figure 12). The private use of company cars is taxed in the Netherlands as a so-called taxable benefit, which is defined as a percentage of the vehicle list price. Historically, efficient vehicles received significant reductions of the taxable benefit, but these reductions have been phased out over time. Consequently, the average type-approval value has increased in the last two years. This development likely contributed to the decrease in the share of vehicles with comparatively low type-approval CO_2 values in 2016–2017. Because the share of bins with low official CO_2 values and high gaps declined from build year 2015 to 2016, the average gap displayed in Figure 12 declined as well. In short, the year 2016 was exceptional because many fuel-efficient vehicles were registered in 2015 for tax benefits. Excluding 2016, the absolute difference between real-world and type-approval CO_2 emission values increased every year since 2005. The relative gap decreased after 2015 because average type-approval CO_2 values increased.

2.3 GERMAN MOBILITY PANEL (GERMANY)

Data type	**On-road, consumer-reported data**
Data availability	2001–2017, approximately 400 vehicles per year
Data collection	Fuel consumption data recorded by panel survey participants for eight consecutive weeks in fuel logbooks in paper form
Fleet structure, driving behavior	Mostly private cars (~90%); urban, extra-urban, and highway driving

Description

The German Mobility Panel (*Deutsches Mobilitätspanel* in German, or MOP) is a longitudinal panel study initiated in 1994 by the German Federal Ministry of Transportation to track changes in private mobility patterns of German citizens over time.[9] The study has been carried out every year since 1994.

As a longitudinal panel study, MOP repeatedly measures a set of mobility-related variables, such as the number of trips made per day and per person, by following a sample of households over time and by collecting the data from consecutive annual interviews, the so-called waves. Each fall, sampled households are requested to keep a detailed record of the trips of each of their members for seven consecutive days. In addition, during the spring of the following year, car drivers among the survey participants are asked to fill out a fuel log for each car in the household for a period of eight weeks. Fuel logs include odometer readings at the start and at the end of the observation period, fuel volume and mileage for each fueling event, and key vehicle characteristics. For electric cars, MOP offers analogous charging logs.

Sampled households are encouraged to participate in the study for up to three consecutive years. Each year, part of the households leave the survey and new households are recruited. MOP is thus referred to as a panel study with a rotating panel sample of three cohorts, each comprising approximately 500 households. MOP recruits about 650 new households per year in order to keep a total annual sample of at least 1,500 households reporting simultaneously. Participation in the survey is voluntary.

A key feature of MOP is that it gathers mobility data representative of the entire German population. It follows a stratified random sampling strategy, which involves dividing the population into homogeneous groups and selecting random samples from each of them. The current MOP stratification criteria are local population size, household type, and number of cars in the household. After extensive plausibility checks of survey responses, the data undergo various weighting procedures to offset differences between sample characteristics and the German population.

After an initial recruiting call, those households willing to participate receive the survey questionnaires, which can be filled in online or in paper form. Currently, the market research company Kantar TNS conducts the fieldwork under the scientific supervision of the research institute Institut für Verkehrswesen am Karlsruher Institut für Technologie (KIT), which is also in charge of analyzing the data, including the plausibility checks. The transportation division of the German Aerospace Center (DLR) makes MOP data for all survey years available upon request.

In the most recent wave, 2016–17, 755 new households joined the survey and the sample size amounted to 1,776 households, comprising 3,643 individuals and 67,065 recorded trips (Eisenmann, Chlond, Hilgert, von Behren, & Vortisch, 2018). After removing implausible data, 1,757 households, 2,874 individuals, and 66,109 trips

9 See https://www.bmvi.de/SharedDocs/DE/Artikel/G/deutsches-mobilitaetspanel.html

remained. In the same wave, fuel consumption data from 1,633 passenger cars were collected, of which 34 were removed during plausibility checks. The fuel log sample included 7,335 fueling events.[10]

Methodology

DLR provided validated, anonymized data from the 1994–1995 to 2016–2017 waves, out of which 13,339 fuel logbooks were collected in the 2001–2002 to the 2016–2017 waves. Vehicles built before 2001 were discarded in this analysis. For each entry, the datasets included information on household characteristics, vehicle specifications, driving conditions, and fuel consumption.

The MOP datasets did not include vehicles' type-approval fuel consumption values. To calculate the divergence between the average on-road fuel consumption value of a vehicle during the reporting period and its corresponding official figure, the sample was complemented with type-approval fuel consumption figures from an ICCT database (see ICCT, 2018). After removing vehicles for which type-approval fuel consumption values could not be retrieved, 7,242 vehicles remained.

Results

Figure 15 plots the divergence between the German Mobility Panel and type-approval fuel consumption values by fuel type. The gap reached 36% in 2017, up from 9% in 2001 but down from its peak of 39% in 2016. On average, approximately 400 vehicles were measured each build year. However, only 26 vehicles of build year 2017 were analyzed because more time must pass for survey participants to enter data for recent models. Since 2012, the gap has been consistently higher for diesel vehicles than for gasoline vehicles.

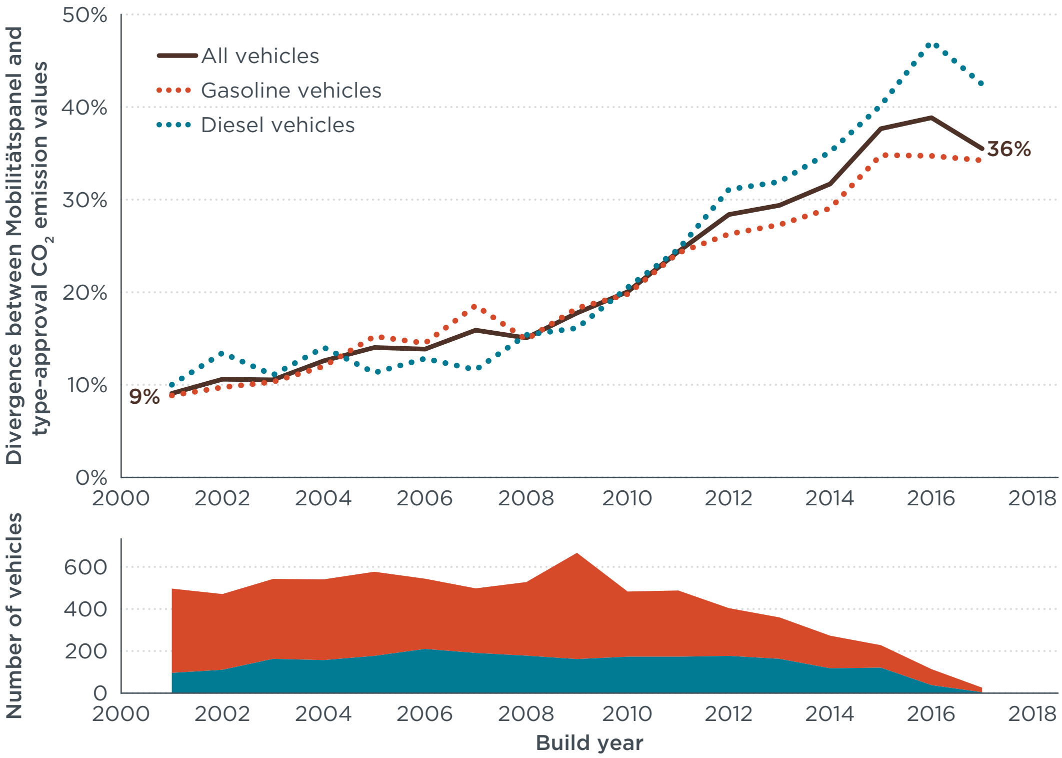

Figure 15. Divergence between the German Mobility Panel and type-approval CO_2 emission values by fuel type. The bottom graph displays the number of vehicles per fuel type and build year.

10 For a detailed description of MOP methodology, sample composition, and summary statistics of each survey year see MOP annual scientific reports under https://mobilitaetspanel.ifv.kit.edu/Downloads.php

2.4 HONESTJOHN.CO.UK (UNITED KINGDOM)

Data type	On-road, user-submitted
Data availability	2001–2017, approximately 9,000 vehicles per year
Data collection	Fuel consumption data, entered by vehicle drivers into a publicly available online database
Fleet structure, driving behavior	Mostly private cars; urban and extra-urban driving

Description

HonestJohn.co.uk[11] is a British consumer website that focuses on automotive news, reviews, and advice for consumers. Besides regularly publishing car reviews and road test results, the site runs the service "Real MPG," which allows anyone to submit real-world fuel consumption data.

Users of the Real MPG service first select their vehicle model and engine configuration and then enter annual mileage and fuel consumption data. Fuel economy values are directly entered in imperial miles per gallon (mpg), contrary to Spritmonitor.de, which calculates fuel consumption values from fuel purchases and odometer readings. Model year, which is to say the year the model was introduced to the market, is used to date vehicles.

Approximately 160,000 fuel economy estimates have been submitted to the site. When entering real-world fuel economy estimates, users can select "mostly city," "mostly motorway," or "mixed" to describe their driving. The vast majority of users indicate that they drive under mixed conditions, and the ratio of city and highway driving is stable over all model years. The available data thus indicate that any biases related to driving conditions appear to be consistent over time and should not affect the observed trends. For a discussion of the representativeness of the HonestJohn.co.uk sample, see Mock et al. (2013). Because the HonestJohn.co.uk database is continuously updated with new user submissions, the results for all model years may differ slightly from previous *From Laboratory to Road* reports.

Methodology

The HonestJohn.co.uk dataset included type-approval and real-world fuel economy data on approximately 152,000 vehicles with most of the vehicles ranging from model years 2001 to 2017. Fuel economy values were converted from miles per gallon to fuel consumption values in the calculation of the divergence.

Results

The average trend in the divergence between HonestJohn.co.uk and type-approval CO_2 emission values is presented in Figure 16. The divergence increased from 11% in 2001 to 29% in 2017, peaking at 34% in 2014. There is no persistent difference between diesel and gasoline vehicles. PHEVs accounted for more than 1% of the vehicles in model year 2017 and increased the average gap by almost 2 percentage points due to their high gap (163% in 2017).

11 See HonestJohn.co.uk

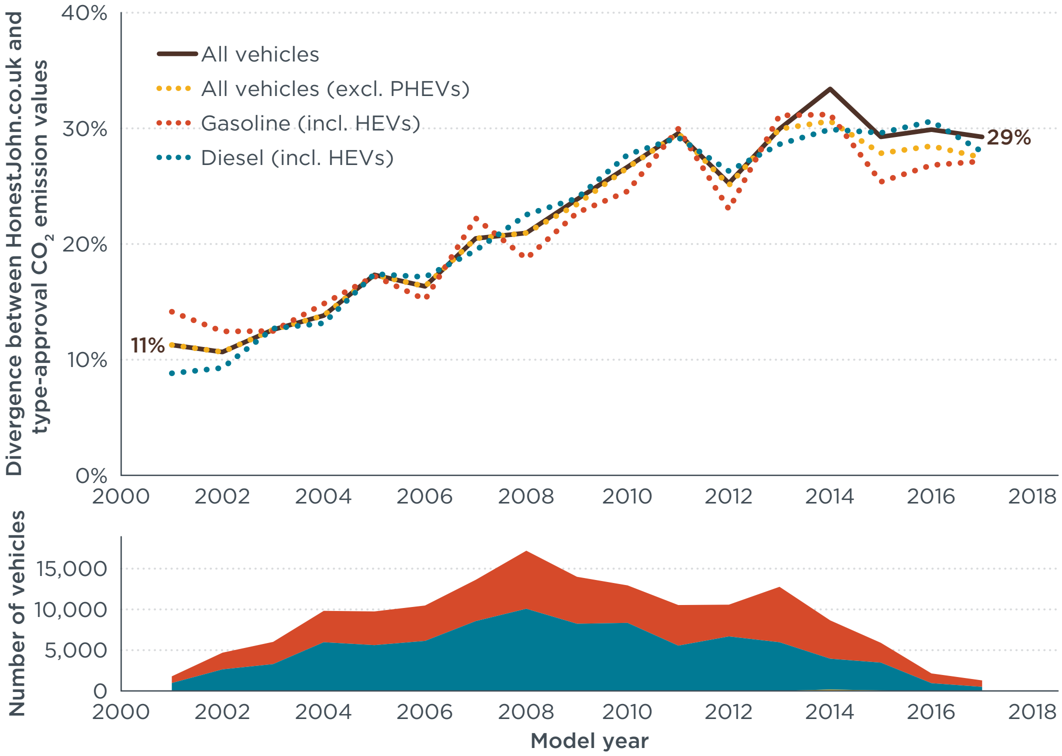

Figure 16. Divergence between HonestJohn.co.uk and type-approval CO_2 emission values by fuel/power train type. The bottom graph displays the number of vehicles per fuel/power train type and model year.

2.5 FICHES-AUTO.FR (FRANCE)

Data type	On-road, user-submitted
Data availability	2001–2017, approximately 2,000 vehicles per year
Data collection	Fuel consumption estimates entered by vehicle owners as part of vehicle reviews
Fleet structure, driving behavior	Mostly private cars; varied driving conditions

Description

The French website Fiches-Auto.fr provides automobile news and a wide range of car-related consumer information. The website publishes technical reviews of popular vehicle models and encourages visitors to share their own experiences. Fiches-Auto.fr has collected more than 69,000 user-submitted reviews.

To review a vehicle model, users fill out a form where they select the engine configuration of their vehicle, provide an estimate of their average on-road fuel consumption, and estimate the share of city and highway driving. The form also allows users to comment on the general performance of the vehicle.

Methodology

Fiches-Auto.fr provided roughly 52,000 user estimates of on-road fuel consumption for almost 500 model variants, with most vehicles ranging from model years 2000 to 2017. Because fuel consumption estimates were embedded in comments, text mining was performed to extract the numerical values. The Fiches-Auto.fr sample also included each vehicle's model name, model year, engine displacement, engine power, and fuel type. This information was used to join type-approval fuel consumption values from an ICCT database (ICCT, 2018).

After removing entries with missing or inextricable fuel consumption estimates, entries that could not be joined with the ICCT database, and extreme outliers, roughly 33,000 vehicles remained in the sample. The annual number of entries is approximately 2,000 vehicles, although this number drops off to approximately 100 vehicles in model year 2017 because more time must pass for users to enter data for recent models.

Users directly entered on-road fuel consumption estimates on the website, so the method of measuring these values varies. Based on user comments, it appears common methods include copying values from the onboard computer and keeping a fueling log, but the data also indicate that a large number of users heuristically estimated fuel consumption values. Figure 17 shows that, whereas on-road fuel consumption estimates clearly cluster around a central estimate, liter and half-liter increments tend to be more common than decimal values. This pattern indicates that users estimated or rounded fuel consumption values.

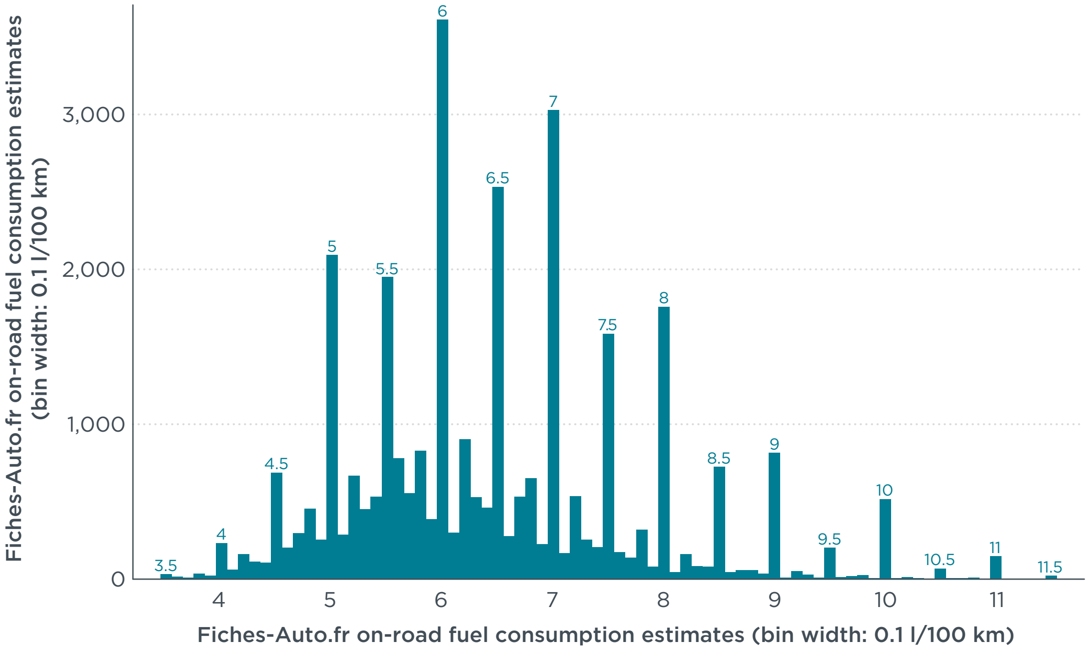

Figure 17. Distribution of on-road fuel consumption estimates by Fiches-Auto.fr users.

Research on U.S. vehicles suggests that measurement methods significantly affect on-road fuel consumption estimates: Both onboard computer readings and user estimates were found to underestimate on-road fuel consumption compared with fuel log data (Greene et al., 2015). The opposite effect was observed in the Fiches-Auto.fr sample: Rounded values tended to overestimate the gap by roughly 2 percentage points compared with unrounded on-road fuel consumption estimates, and this effect is consistent over time. The Fiches-Auto.fr data may thus slightly overestimate the gap, although this effect is small compared with the increase in the divergence over time.

Results

Figure 18 plots the average divergence between type-approval and Fiches-Auto.fr fuel consumption values. The gap increased from roughly 10% in model year 2001 to 35% in 2017. After peaking at 37% in 2013, the gap stabilized at 35% from 2014 to 2017. Because of the comparatively low number of entries for recent models, separate estimates for different power trains are not presented.

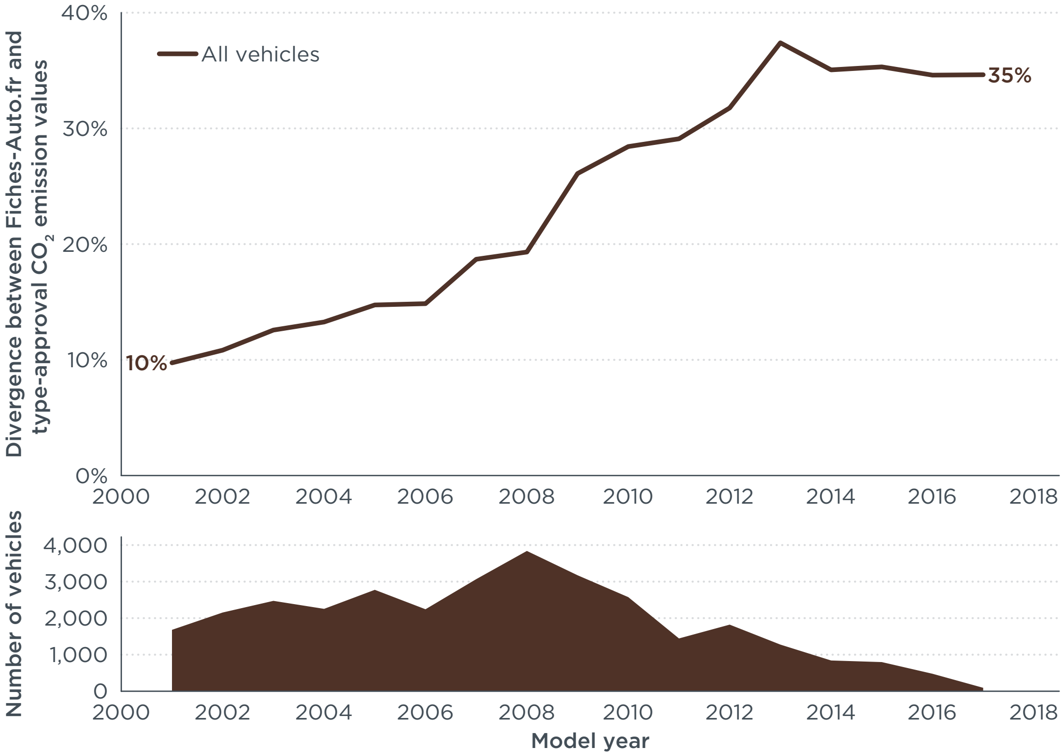

Figure 18. Divergence between type-approval and Fiches-Auto.fr CO_2 emission values. The bottom graph displays the number of vehicles per model year.

2.6 *AUTO BILD* (GERMANY)

Data type	**On-road, test route**
Data availability	2008–2017, approximately 300 vehicles per year
Data collection	Fuel consumption data, measured before and after a 155 km test drive
Fleet structure, driving behavior	Vehicles selected for testing by *AUTO BILD*; urban, extra-urban, and highway driving; professional drivers; strict adherence to speed limits and normal engine speed

Description

AUTO BILD is a German automobile magazine first published in 1986 with a current circulation of more than 300,000. The magazine conducts a number of on-road tests on a regular basis, some of which measure real-world fuel consumption. These tests are conducted on a 155 km route that includes 61 km of extra-urban, 54 km of highway (20 km without speed limit), and 40 km of urban driving. According to *AUTO BILD*, test drivers adhere to speed limits and maintain normal engine speeds. To estimate on-road fuel consumption, the car tank is filled to capacity before and after the test drive.

Methodology

AUTO BILD provided fuel consumption data from test drives conducted between 2008 and 2017. Approximately 2,700 vehicles were tested during this time. Official and test fuel consumption values were supplied for each vehicle model.

Results

Excluding PHEVs, the average divergence between type-approval and *AUTO BILD* fuel consumption values reached 32% in test year 2017, which is 5 percentage points higher than in test year 2016. Diesel vehicles consistently exhibited a higher average divergence than gasoline cars. This difference between fuel types was approximately 6 percentage points in test year 2017. Including PHEVs significantly raises the average divergence in 2013–2017, despite their low numbers (17 in total). In 2017, three PHEVs were tested, raising the average divergence by 2 percentage points. On average, PHEVs had gap values exceeding 200%, with a range spanning from 58% to 533%.

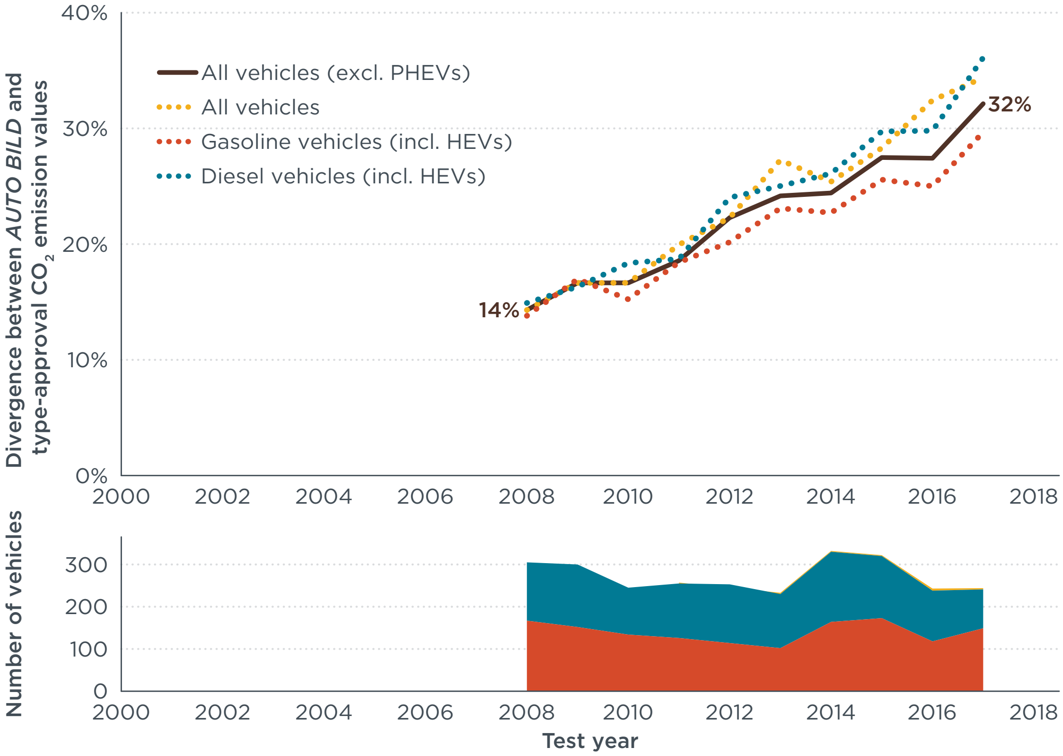

Figure 19. Divergence between *AUTO BILD* and type-approval CO_2 emission values by fuel/power train type. The bottom graph displays the number of vehicles tested per year and fuel/power train type.

2.7 EMISSIONS ANALYTICS (UNITED KINGDOM)

Data type	**On-road, test route**
Data availability	2012–2017, on average 100 vehicles per year
Data collection	Portable emissions measurement system (PEMS) testing on urban and extra-urban roads
Fleet structure, driving behavior	Mixed vehicle fleet; professional drivers always using the same test route

Description

Emissions Analytics is an independent vehicle testing organization specializing in measuring real-world fuel consumption and emissions. Since 2011, the company has conducted on-road tests of more than 2,000 new vehicles using a portable emissions measurement system (PEMS). Of these, more than 1,200 vehicles were tested in Europe, primarily in the United Kingdom and Germany. Fuel economy and emission measurements are published as part of the Emissions Analytics EQUA Index, a rating system developed to inform the public about the on-road performance of vehicles.[12]

The test route used for on-road testing of vehicles combines urban driving (at roughly 28 km/h), extra-urban driving (at roughly 56 km/h), and highway driving (at roughly 97 km/h). The trained test drivers avoid heavy acceleration and unnecessary braking, and tests are not conducted under extreme weather conditions. The test starts after the engine is warmed up. Non-essential auxiliaries are switched off, although the air-conditioning system is used at 50% of the maximum load. The PEMS measures CO_2 emissions as well as carbon monoxide and nitrogen oxides. In addition, a series of sensors attached to the test vehicle collect data on altitude, humidity, and other parameters. These data are used to normalize raw CO_2 emission measurements to ensure that the final figures are as consistent as possible with other test drives.

Methodology

Emissions Analytics provided real-world and type-approval CO_2 emissions data for more than 850 vehicles tested between 2012 and 2017. On average, the company provided data for approximately 100 vehicles per year.

Results

Figure 20 presents the average annual divergence between real-world and official CO_2 emission values by fuel/power train type. Excluding PHEVs, the average divergence decreased from 36% to 34% from 2012 to 2017, peaking at 41% in 2014. PHEVs had a significant impact on the annual average in test years 2014–2016, when up to four PHEVs were tested each year. PHEVs had an average divergence of 263%.

12 See http://www.equaindex.com/

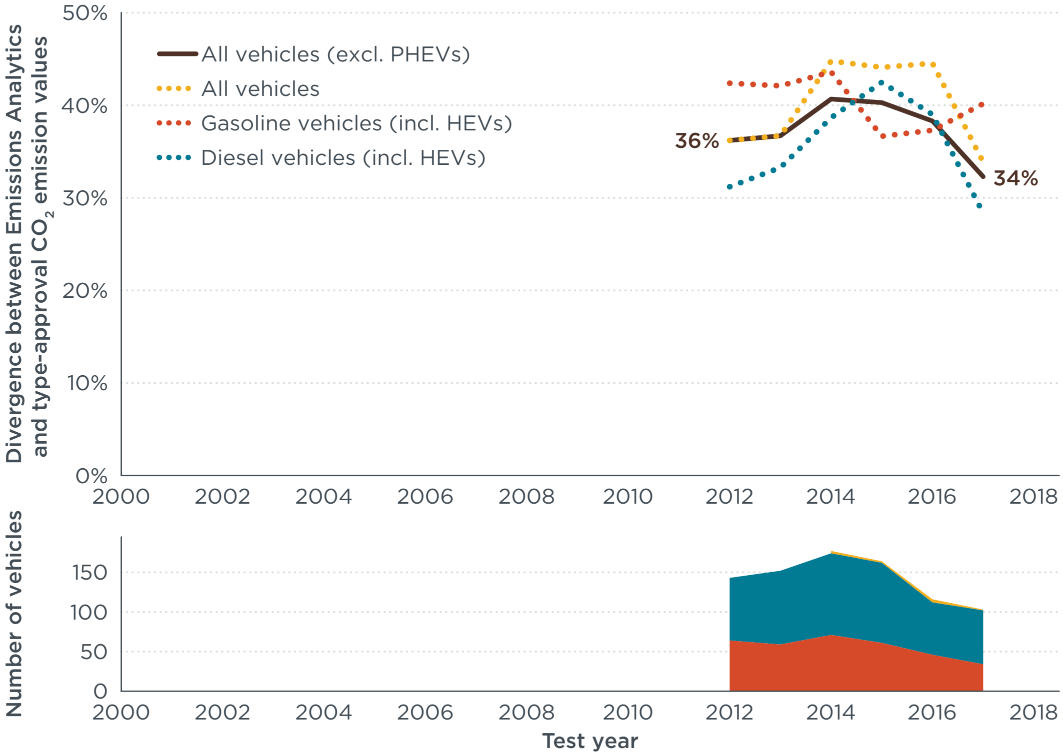

Figure 20. Divergence between type-approval and Emissions Analytics CO_2 emission values by fuel/power train type. The bottom graph displays the number of vehicles tested per year and fuel/power train type.

2.8 *AUTO MOTOR UND SPORT* (GERMANY)

Data type	**On-road, test route**
Data availability	2003–2017, approximately 200 vehicles per year
Data collection	Fuel-consumption data, measured before and after test drives
Fleet structure, driving behavior	Vehicles selected for testing by *auto motor und sport*; urban, extra-urban, and highway driving; professional drivers; adherence to speed limits, low engine speeds

Description

auto motor und sport[13] is a biweekly German automobile magazine first published in 1946. The magazine focuses on car reviews, which usually include on-road vehicle tests.

According to the magazine, *auto motor und sport* fuel consumption tests aim to compensate for shortcomings in the current official type-approval test cycle. Driving patterns and test conditions include driving on the German Autobahn, strong acceleration when overtaking other vehicles, uphill driving, rush-hour driving, use of air conditioning, and driving with additional payload. Since 2015, test results have been broken down by the following driving situations: commute driving, efficient driving, and high-speed highway driving. The overall fuel consumption figure is a weighted average of the test results for the three driving conditions (70% weight for commute driving and 15% for each of the other two driving situations).

Methodology

auto motor und sport provided on-road fuel consumption test results along with type-approval fuel consumption figures for approximately 2,700 vehicles tested between 2003 and 2017.

Results

Figure 21 presents the annual divergence between *auto motor und sport* and type-approval CO_2 emission values. Excluding PHEVs, the average divergence was 44% in test year 2017, down from a peak of 47% in 2015. As in recent years, the average divergence between real-world and official fuel consumption for diesel vehicles (50%) was significantly higher than for gasoline vehicles (40%) in test year 2017. Due to their high gaps, including the 18 PHEVs tested in 2017 raises the average by 6 percentage points.

13 http://www.auto-motor-und-sport.de/

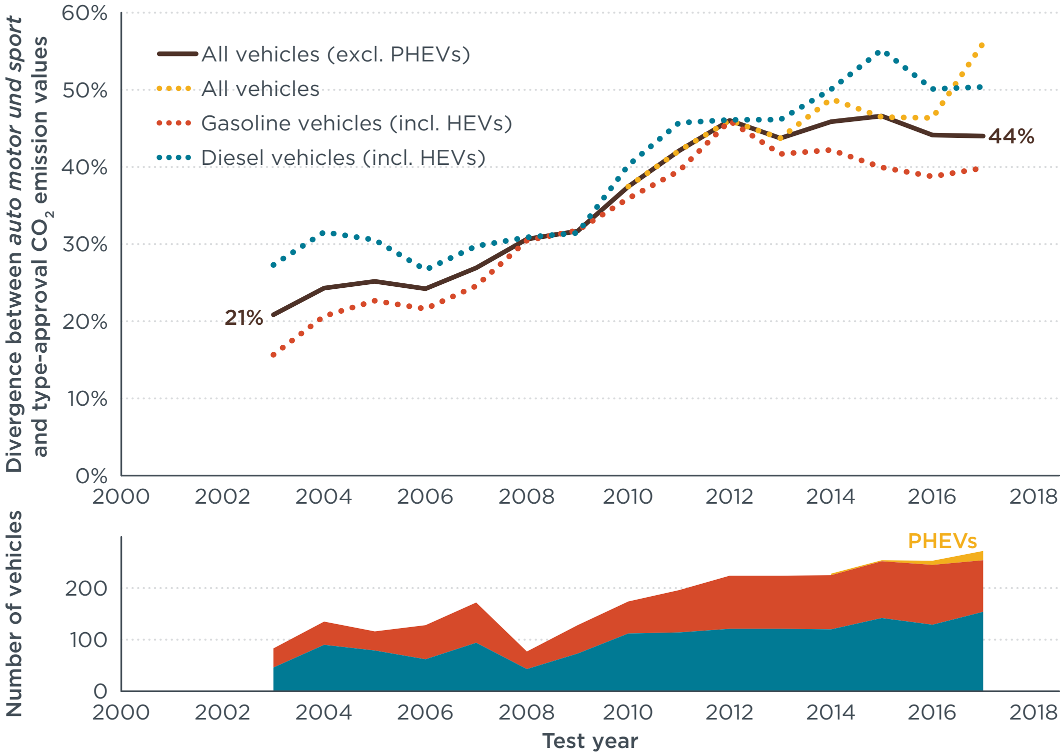

Figure 21. Divergence between *auto motor und sport* and type-approval CO_2 emission values by fuel/power train type. The bottom graph displays the number of vehicles per fuel/power train type and test year.

2.9 *AUTO MOTOR & SPORT* (SWEDEN)

Data type	**On-road, test route**
Data availability	2009–2017, approximately 90 vehicles per year
Data collection	Fuel consumption data, measured before and after test drives (250–350 km)
Fleet structure, driving behavior	Vehicles selected for testing by *auto motor & sport*; speeds typically ranging from 30 to 120 km/h; vehicles driven in convoy during testing

Description

auto motor & sport[14] is a Swedish automobile magazine launched in 1995. As part of the magazine's coverage of the vehicle market, *auto motor & sport* conducts vehicle tests that include measurements of on-road fuel consumption.

Vehicles are tested on a number of routes ranging from 250 to 350 km in length and cover all typical speeds on Swedish roads (30 to 120 km/h). Fuel consumption is estimated by filling the fuel tank to its capacity before and after the test, ensuring that the vehicle is level during refueling. PHEVs are fully charged and soak at a temperature of 20 °C before testing begins. They are then driven in electric drive as far as possible before completing the test route in hybrid mode (primarily using the combustion engine, but energy recovered through regenerative breaking is used in the electric motor). Because *auto motor & sport* tests vehicles year-round, driving conditions and outdoor temperatures vary among tests. When multiple vehicles are tested, cars are driven in a convoy to achieve similar speed and acceleration profiles. In addition, drivers regularly switch vehicles to level out the impact of driving style differences.

Methodology

Fuel consumption data from test drives conducted on roughly 850 vehicles between 2009 and 2017 were provided by *auto motor & sport*. The data included both official and test fuel consumption values.

Results

Figure 22 shows the trend in the divergence between type-approval and *auto motor & sport* CO_2 emission values by fuel/power train type. The average gap between real-world and type-approval CO_2 emissions, excluding PHEVs, increased from 20% in test year 2009 to 38% in test year 2017. The divergence plateaued in 2015 to 2017. Including PHEVs inflates the average gap because PHEVs typically have particularly high divergence values, on average approximately 255%.

14 http://www.automotorsport.se/

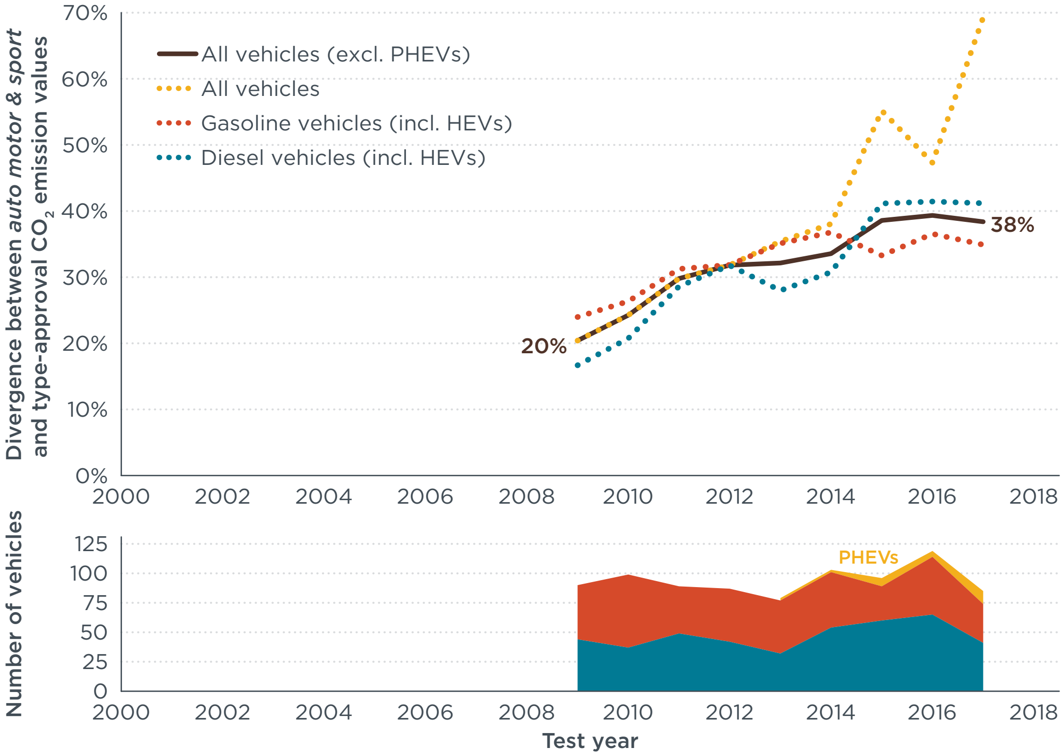

Figure 22. Divergence between *auto motor & sport* and type-approval CO_2 emission values by fuel/power train type. The bottom graph displays the number of vehicles per fuel/power train type and test year.

2.10 KM77.COM (SPAIN)

Data type	**On-road, test route**
Data availability	2010–2017, approximately 40 vehicles per year
Data collection	Fuel consumption data, measured before and after a 500 km test drive
Fleet structure, driving behavior	Vehicles with more than 52 kW of power and 170 km/h maximum speed; extra-urban and highway driving; always the same driver

Description

km77.com is a Spanish automobile website launched in 1999. The site aims to provide consumers with thorough vehicle reviews, including detailed vehicle fact sheets and real-world fuel consumption data from test drives. Arturo de Andrés, a journalist specializing in the automobile industry and a long-standing member of the Car of The Year jury, has conducted the on-road fuel consumption tests from the outset.

The km77.com test route has remained largely unchanged over the years, as the magazine aims to produce comparable real-world fuel consumption results. Test drives always take place in the early morning to avoid traffic and cover a distance of about 500 km of motorways and high-speed country roads around the metropolitan area of Madrid. Each test drive starts and finishes at the same gas station, where the vehicle tank is filled to capacity before and after the test to estimate the real-world fuel consumption. Vehicles are driven at a specific speed for each part of the route so that results are comparable for different vehicles. The total distance traveled and average speeds are recorded using the global positioning system.

Test vehicles are selected from manufacturers' press test pools and must have a minimum engine power of 52 kW and over 170 km/h maximum speed in order to fulfill the km77.com test requirements. Selected cars typically have odometer readings between 2,000 and 10,000 km before testing starts. During the test, all non-essential onboard systems, such as air conditioning, are switched off.

In early 2016, the maximum speed of the km77.com test procedure was lowered to 120 km/h on the highway and 100 km/h on extra-urban roads according to Spanish generic speed limits for these types of road. Furthermore, test drives started approximately 90 minutes later in the day to encounter heavier traffic than in preceding years. With its new approach, km77.com aims to better reflect the average vehicle usage. The test route has remained unchanged. Some of the vehicles have been tested following both the old and the new procedure. The measurements using a maximum speed of 120 km/h are marked as "new test method" in the results.

Methodology

The data provided by km77.com ranged from test year 2010 to test year 2017 and included real-world fuel consumption figures from approximately 380 vehicles. The official type-approval fuel consumption values were retrieved from the km77.com website.

Results

Figure 23 plots the divergence between km77.com measurements and type-approval fuel consumption values as well as the number of measurements by model year. The divergence increased from 37% in 2010 to 48% in 2017. The sample includes a small share of PHEVs (about 1%) with model years between 2013 and 2015 which exhibit a significantly higher divergence than conventional vehicles, typically exceeding 300%. PHEVs consequently have a large impact on the average gap despite their low numbers. For model years 2016 and 2017, results for the new and old methodologies (maximum speed of 120 km/h and 170 km/h, respectively) are presented separately. In model year 2017, the divergence between fuel consumption measurements following the new procedure and official values was approximately 24%. On average, the new methodology reduced the gap by approximately 24 percentage points in model year 2017. Comparing the average gap of vehicles that were measured using the old and new procedures (16 vehicles in model year 2016 and four in model year 2017), the new procedure yields an average gap reduction of 18 percentage points.

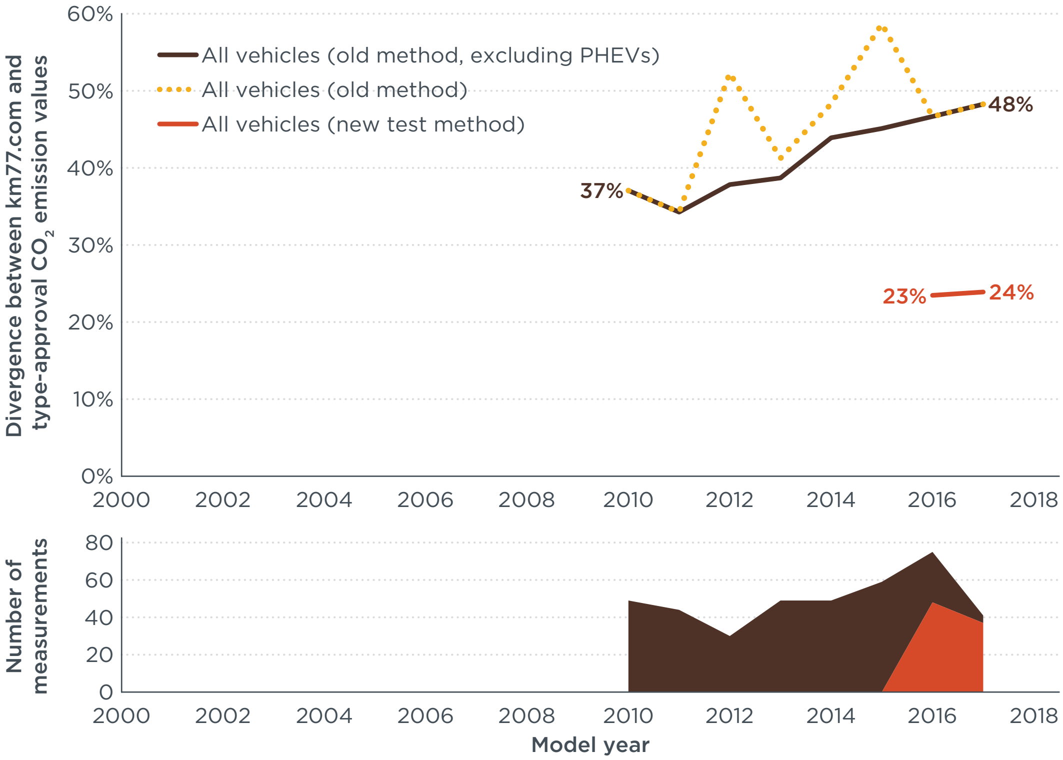

Figure 23. Divergence between km77.com and type-approval CO_2 emission values by power train and test method. The bottom graph displays the number of measurements per year and test method.

2.11 TOURING CLUB SCHWEIZ (SWITZERLAND)

Data type	**On-road**
Data availability	1996–2017, approximately 20 vehicles per year
Data collection	On-road driving, roughly 3,000 km for each vehicle
Fleet structure, driving behavior	Most popular vehicle models in Switzerland; professional drivers

Description

Touring Club Schweiz (TCS) is a Swiss motoring association founded in 1896 and currently has 1.5 million members. Since 1996, TCS has conducted vehicle tests to compare real-world and type-approval fuel consumption values. About 20 of the most popular vehicle models in the Swiss market are selected for testing each year. In 2017, the sample consisted of 10 gasoline and two diesel vehicles. The vehicles are provided directly by manufacturers.

During on-road tests, vehicles are driven for about 3,000 km and fuel consumption is recorded. According to TCS, the driver and driving behavior have not changed over the years. In addition to the on-road tests, TCS conducts laboratory tests on a chassis dynamometer. These values were not analyzed in this study as this analysis focuses on on-road fuel consumption and CO_2 values rather than laboratory measurements.

Methodology

The dataset provided by TCS includes type-approval values as well as on-road test results for each vehicle. Due to the low number of entries, the data were not analyzed by fuel type.

Results

Figure 24 shows the trend in the divergence between real-world and type-approval fuel consumption from test years 1996 to 2017. Despite the somewhat erratic movement of the graph due to the small sample size, an upward trend in the divergence is clearly discernible. The average divergence has increased by about 35 percentage points over the past two decades.

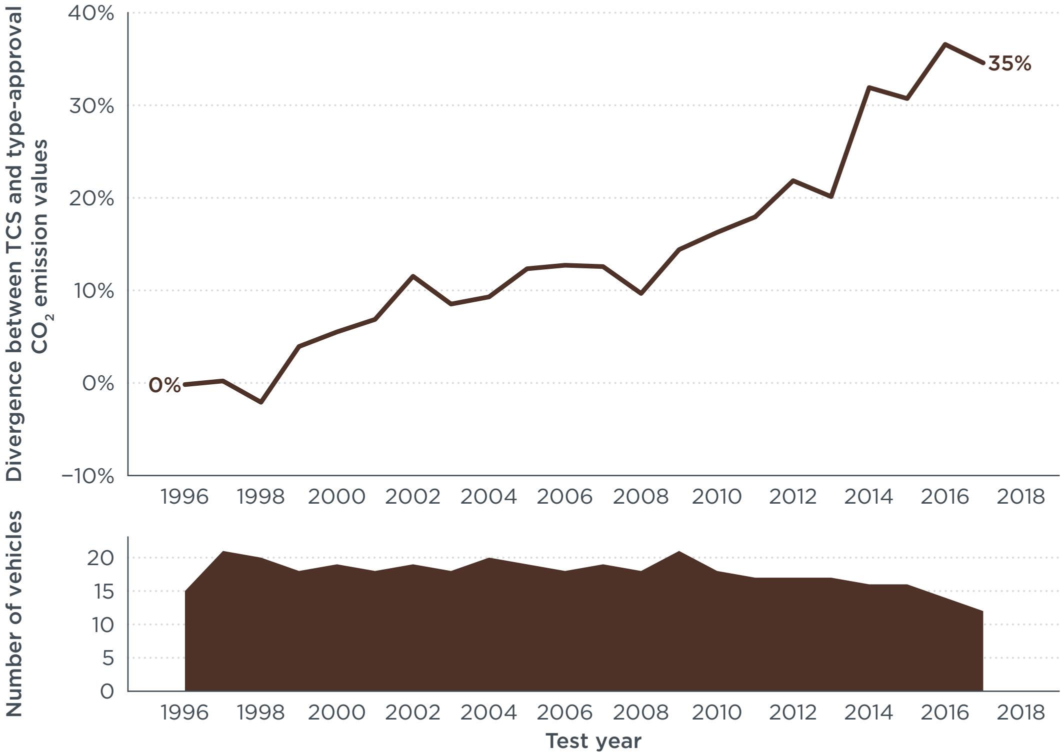

Figure 24. Divergence between TCS and type-approval CO_2 emission values. The bottom graph displays the number of vehicles per year.

3. DATA COMPARISON

Table 1 provides an overview of the 11 data sources presented in this study and the four data sources that were not updated in this 2018 update. The analysis covered a total of 15 sources from eight European countries, which together provided real-world CO_2 emission values for approximately 1.3 million passenger cars.

Table 1. Summary of data sources used in this analysis.

Source	Country	Total vehicles	Vehicles per year (avg.)	Mostly company cars	Years	Dating convention
Spritmonitor.de	Germany	186,940	10,000		2001-2017	Build year
Travelcard	Netherlands	356,032	30,000	X	2005-2017	Build year
Mobilitätspanel	Germany	7,242	400		2001-2017	Build year
HonestJohn	U.K.	152,195	9,000		2001-2017	Model year
Fiches-Auto.fr	France	32,984	2,000		2001-2017	Model year
Auto Bild	Germany	2,717	300		2008-2017	Test date
Emissions Analytics	U.K.	845	100		2012-2017	Test date
auto motor und sport	Germany	2,649	200		2003-2017	Test date
auto motor & sport	Sweden	820	90		2009-2017	Test date
km77.com	Spain	311	40		2010-2017	Test date
Touring Club Schweiz	Switzerland	297	20		2001-2017	Test date
LeasePlan	*Germany*	*250,000*	*20,000*	*X*	*2006-2016*	*Fleet year*
Allstar fuel card	*U.K.*	*242,353*	*20,000*	*X*	*2006-2015*	*Build year*
Cleaner Car Contracts	*Netherlands*	*21,540*	*3,000*	*X*	*2010-2016*	*Model year*
Cleaner Car Contracts	*Belgium*	*835*	*200*	*X*	*2012-2016*	*Registration date*
Total		**1,257,760**	**100,000**			

Annual average divergence

Figure 25 compares the divergence between real-world and official CO_2 emission values for all data sources analyzed in the analysis. As shown in the figure, the CO_2 gap increased over time in all samples. While average estimates of the divergence clustered around 8% in 2001, they ranged from 29% to 48% in 2017. Most data sources had similar growth patterns, but the level of the gap varies by data source.

There are a number of factors that explain the variations in the observed trends. First, company car samples usually exhibit higher average divergence estimates than private car data sources. The reasons for the disparity include weaker incentives for company car drivers to conserve fuel and more driving at highway speeds. In 2017, Travelcard, the only 2017 data source for company cars, furnished an average gap of 42%. In 2016, divergence estimates from company car samples ranged from 41% (Travelcard) to 54% (Cleaner Car Contracts Belgium).

For other cars, a distinction can be drawn between two kinds of data sources: data for private cars that rely on user input and data measured during vehicle tests. Spritmonitor.de (Germany), the German Mobility Panel, HonestJohn.co.uk (U.K.), and Fiches-Auto.fr (France), which belong to the former group, exhibit rather similar trends, despite focusing on different markets. In contrast, average divergence values from test drives show relatively high variability (32% to 48% in year 2017), which is largely due to differing test procedures and small sample sizes. While vehicle tests typically produce internally consistent data thanks to repeatable test procedures, inaccuracies related to changing traffic and weather conditions affect measurements. km77.com, *auto motor und sport* (Germany), and *auto motor & sport* (Sweden) produced some of the higher average divergence values in recent years, probably as a consequence of higher test speeds and more demanding driving patterns and conditions (e.g., uphill driving or use of air conditioning). At the other end of the spectrum, Touring Club Schweiz and *AUTO BILD* provided more conservative estimates of the divergence.

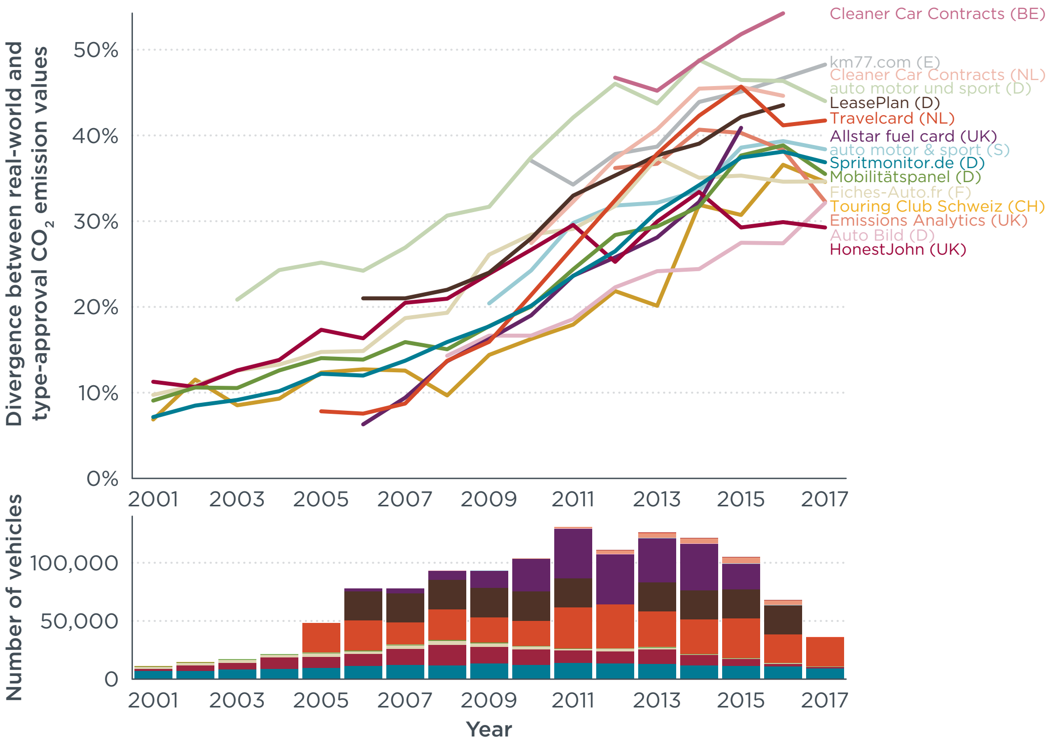

Figure 25. Divergence between real-world and type-approval CO_2 emission values for various on-road data sources.

Dating conventions

Dating conventions vary among data sources. The sources included in this report used five different dating conventions: build year (when a vehicle was manufactured), fleet year (when data for an entire fleet was provided), model year (when a new model generation was introduced), test year (when a vehicle was tested), and registration year (when a vehicle was first registered). Vehicle tests were consistently dated in terms of test year. LeasePlan (see Tietge, Mock, German, et al., 2017) provided data for the entire fleet rather than for individual build years, while Travelcard, another company car source, specified the build year of each vehicle. Spritmonitor.de and the German Mobility Panel also employed vehicle build year, while HonestJohn.co.uk and Fiches-Auto.fr dated vehicles according to their model year, which is the year a new model generation enters the market. The use of model year delivers a less uniform distribution of entries compared with build year, which partly explains the erratic trend from HonestJohn.co.uk estimates. Cleaner Car Contracts Belgium (see Tietge, Mock, German, et al., 2017) was the only data source to employ the time of first registration to date vehicles. The use of different dating conventions renders like-for-like comparisons between individual years difficult. However, the annual increase in the divergence between real-world and official CO_2 emission values for each of the data sources is valid and the general upward trend in the CO_2 gap is unambiguous.

Central estimate

A central estimate of the divergence between real-world and type-approval CO_2 emission values was constructed by combining all data sources analyzed in the report. An average annual divergence estimate for private cars was calculated based on all private car samples and weighted by the number of entries in each sample and year. The same procedure was applied to company car data sources. Private and company car estimates were then combined, assigning equal weights to each, under the assumption that the European new car market consists of private and company cars in equal shares (Næss-Schmidt & Winiarczyk, 2010).

Figure 26 plots the trend in the central estimate of the divergence by private or company car. The trends of the individual data sources are also displayed in the figure for context. The central estimate of the divergence grew from 8% in 2001 to 39% in 2017, just 1 percentage point lower than in 2016. The difference between company and private cars gradually increased in recent years and amounted to about 6 percentage points in 2017.

Considering that the data sources analyzed in this study cover different European markets, focus on either company or private cars, and are based on a wide variety of measurement procedures, the central estimate of the divergence presented in Figure 26 provides strong evidence that type-approval CO_2 emission values grew increasingly unrepresentative over time, although 2016–2017 data indicate that the gap stabilized around 40%. It should be noted that these estimates refer to newly registered vehicles. Accordingly, the average in-use fleet divergence is lower due to fleet turnover.

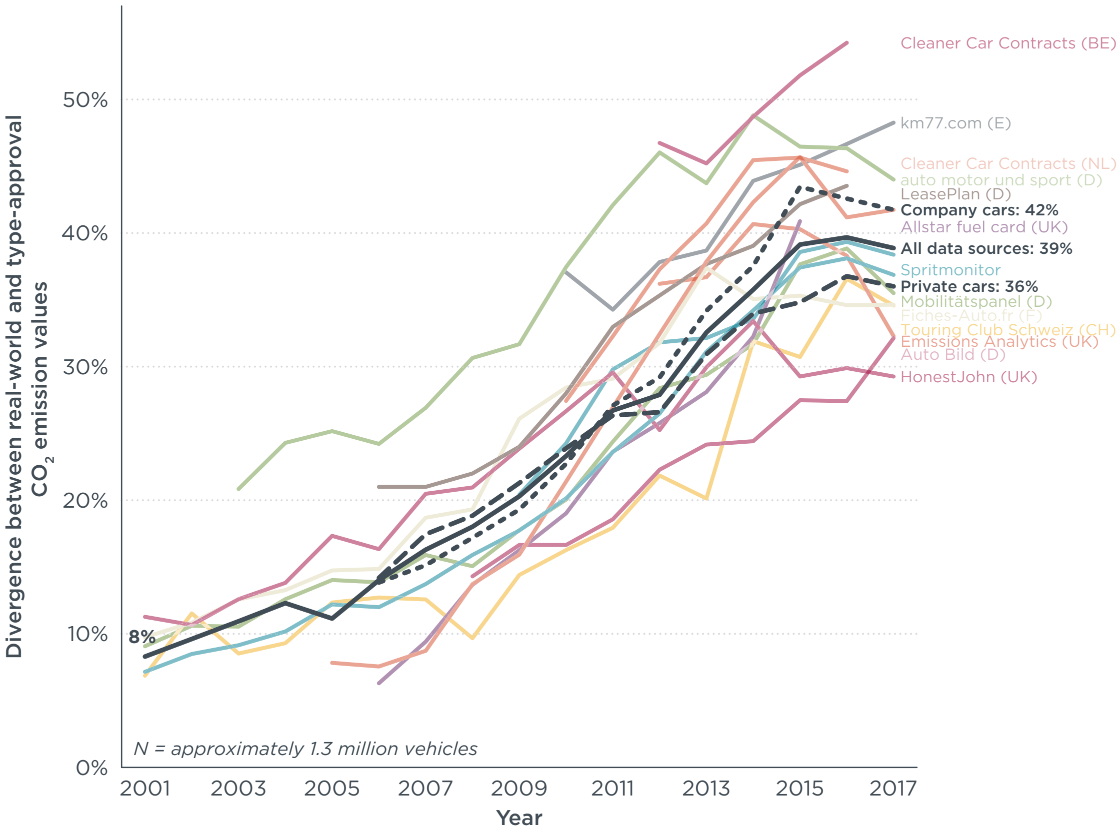

Figure 26. Divergence between real-world and manufacturers' type-approval CO_2 emission values for various on-road data sources, including average estimates for private cars, company cars, and all data sources combined.

4. DISCUSSION OF RESULTS

This 2018 update of the *From Laboratory to Road* series adds another year of data, one new data source, and approximately 200,000 vehicles to the ongoing analysis. The central estimate has more than quadrupled since 2001, but the gap plateaued in 2016–2017. Even though the precise level of the divergence varies from sample to sample, the historical upward trend is consistent across all 15 data sources. Most data sources also confirm that the gap ceased to grow after 2015. The heterogeneity of the data—collected from consumers, company fleets, and vehicle tests—and the considerable regional coverage—spanning eight European countries—indicate that the findings are valid and generalizable. This section discusses reasons for the growth of the divergence over time and for the recent stabilization of the gap. It concludes with an examination of this study's limitations.

Reasons for the gap growth

The divergence between real-world and manufacturers' type-approval CO_2 emission values is well-documented at this point, and some studies explore the reasons for this development. Previous *From Laboratory to Road* studies asserted that driver behavior, the increased use of biofuels, and the decrease in type-approval CO_2 emission values over time—making the gap look proportionately larger—fail to account for the growth in the gap (see Tietge, Mock, German, et al., 2017). Technical and regulatory reasons for the increase in the divergence over time are discussed below.

Many new technologies penetrated the vehicle market during the 2001 to 2017 time frame and some contribute to the growing gap. Air-conditioning systems and elaborate entertainment systems are included in virtually all new vehicles. These systems consume energy during real-world driving, but are turned off during laboratory testing, thereby contributing to the gap. Stop/start systems and hybrid power trains have been shown to be disproportionately effective during type-approval testing vis-à-vis on-road driving (Stewart et al., 2015). Plug-in hybrid electric vehicles typically exhibit a particularly high divergence (see Section 2.1 for example), although it should be noted that real-world CO_2 emissions are strongly affected by charging patterns (see Ligterink & Smokers, 2015).

A number of studies indicate that test cycle optimization and the exploitation of loopholes in the NEDC-based test procedure account for most of the increase in the divergence, which is consistent with the pattern of rapid increases in the gap after the introduction of new model generations or major facelifts (see Section 2.1). Road load coefficients, the values used to simulate driving resistances during laboratory testing, were higher when measured by independent test organizations than when the values were submitted by manufacturers for type-approval tests (Mellios, Hausberger, Keller, Samaras, & Ntziachristos, 2011). Road load coefficients were estimated to account for more than one-third of the divergence between type-approval and real-world CO_2 emission values (Kühlwein, 2016). Tolerances and flexibilities during laboratory testing also contribute to the gap (Kadijk et al., 2012) and were estimated to account for more than half of the divergence (Stewart et al., 2015). Other factors, such as the aforementioned technology developments, were found to account for smaller portions of the divergence.

Reasons for the plateau

This 2018 update of the *From Laboratory to Road* series indicates that the gap between real-world and NEDC CO_2 values stabilized after 2015. A number of reasons may have contributed to this change in the trend:

- After the 2015 targets were met, and with two years before manufacturers had to contend with 2020 CO_2 targets, there was limited regulatory pressure on car makers to reduce CO_2 emission values of new vehicles. The fact that 2017 marked the first year on record in which average CO_2 emissions of new passenger cars in Europe failed to decline (Tietge, 2018a) supports this hypothesis.

» WLTP-based certification is required for all new passenger cars since September 2018. On-road real-driving emissions (RDE) tests of nitrogen oxides emissions is mandatory for most new passenger cars after September 2019. In the buildup to these regulatory changes, manufacturers may have marketed fewer new models and model generations. As demonstrated in section 2.1, the divergence tends to increase after technical overhauls, so slower marketing of new model generations would slow down the growth of the gap.

» It is conceivable that most flexibilities in the NEDC-based type-approval procedure have been exhausted. Alternatively, increased scrutiny on the real-world performance of vehicles may have acted as a deterrent to further test optimization.

» Fleet composition plays a role in the stabilization of the gap. Diesel shares of new car registrations declined in the European market in the wake of dieselgate (Tietge, 2018a, 2018b). Because diesel vehicles tend to exhibit a higher gap than gasoline vehicles, this shift reduces the gap (see section 2.1).

» The data for this year's analysis were collected later during the year than in previous *From Laboratory to Road* studies. The time of data collection can affect the gap estimate due to seasonal fluctuations in weather (van Gijlswijk & Ligterink, 2018). While this bias could affect continuously updated data sources like Spritmonitor.de, the stabilization of the gap was also observed in data sources that are impervious to this bias.

In short, it is likely that a combination of reasons contributed to the stabilization of the gap. Changes in fleet composition were shown to affect the average gap level, but do not alone explain the plateau. More research is needed to determine the cause of the slowdown and to determine whether the gap may once again increase in time for the 2020 EU CO_2 targets.

Limitations

This study summarizes data from 15 different sources, and each comes with some limitations. First, self-reported data from web services may suffer from self-selection bias. However, previous analyses show that large user-reported samples, such as Spritmonitor.de, generally provide good representations of national new car fleets (see Mock et al., 2013). Moreover, results from Spritmonitor.de are congruent with data from the German Mobility Panel (see Figure 27), a sample that is designed to be representative of the German population. This finding indicates that any bias in the Spritmonitor.de data has a limited effect on the gap estimates. Second, samples based on fuel card data generally consist of company cars, and produce higher divergence estimates than web services. However, this difference is likely due to how company cars are driven (e.g., higher shares of speedy driving) and does not imply a sampling bias, but rather indicates that company and private cars perform differently under real-world conditions. Lastly, data sources that rely on vehicle tests suffer from small sample sizes. Nevertheless, combining 15 heterogeneous samples from eight European countries paints a clear picture of a growing gap between type-approval and real-world CO_2 emission values from 2001 to 2015 and a recent stabilization of the gap.

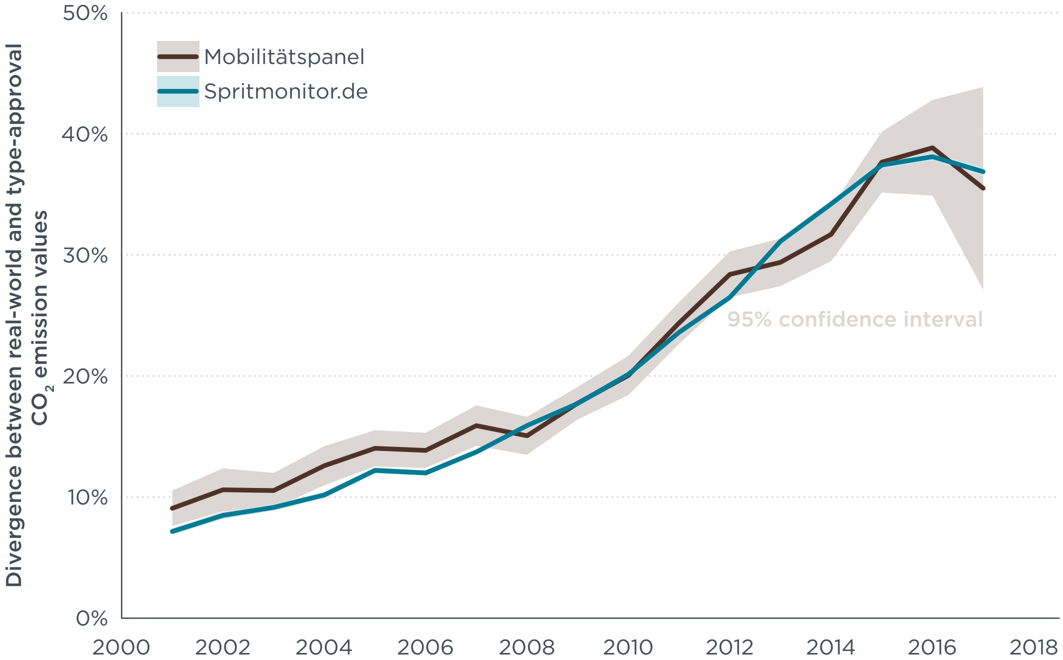

Figure 27. Comparison of annual average divergence estimates from the German Mobility Panel and Spritmonitor.de. The shaded areas represent 95% confidence interval of the mean.

5. POLICY IMPLICATIONS

Implications for Stakeholders

EU CO_2 standards are successful at driving down CO_2 emission values of new passenger cars, at least on paper. Type-approval values decreased by approximately 30% in the last 17 years, from 170 g/km of CO_2 in 2001 to 119 g/km in 2017. The evidence presented in this study indicates that this progress was undermined by an increasing divergence between the on-paper and on-road performance of new cars. The gap has important implications for all stakeholders.

From a **government's perspective**, the divergence undermines the efficacy of vehicle taxation schemes. Many EU member states base vehicle taxes on type-approval CO_2 emission values. Because the divergence between real-world and type-approval CO_2 emission values grew over time, governments incurred increasing losses in tax revenue. Lost tax revenues amounted to approximately 10 billion euros across 11 European countries in 2016 (Runkel & Mahler, 2018). Fiscal incentives for low-carbon vehicles also may not deliver the desired results, because the real-world performance of low-carbon vehicles can differ dramatically from on-paper values, leading to a misallocation of public funds.

From a **customer's perspective**, stated fuel consumption values do not serve as a reliable basis for purchasing decisions. For a new vehicle, the divergence translates into unexpected fuel expenses of approximately 400 euros per year.[15]

From a **societal perspective**, the growing divergence undermines the EU's efforts to mitigate climate change and to reduce fossil fuel dependence. Figure 28 plots the development of type-approval CO_2 emission values in the EU and overlays an estimate of real-world values based on Spritmonitor.de divergence estimates. While type-approval figures declined from 170 g/km of CO_2 in 2001 to 119 g/km in 2017, a 30% decrease, the real-world estimate decreased by only 10%.

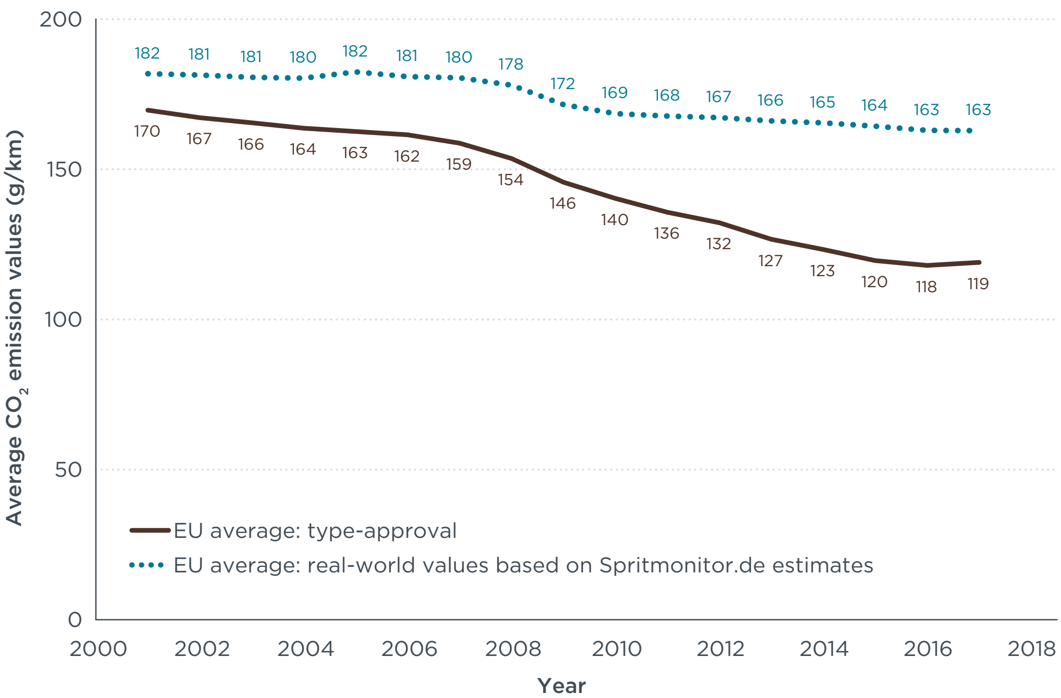

Figure 28. Real-world versus type-approval CO_2 emission values of new European passenger cars based on Spritmonitor.de estimates and type-approval data from the European Environment Agency (EEA, 2018).

15 Assuming a fuel price of 1.3 euros per liter and an annual mileage of 15,000 km.

From a **manufacturer's perspective**, unrealistic claims about vehicle performance undermine public confidence, particularly in the wake of dieselgate. The current situation also penalizes manufacturers that report more realistic CO_2 values, because manufacturers that present less realistic values can achieve their CO_2 emission targets at lower costs. Improved vehicle testing procedures and more rigorous policy enforcement would help level the playing field for car manufacturers.

Recommendations for Policies and Research

This study points to multiple pathways and recommendations for future research and policies, which also are largely reflected in recommendations of the high-level group of scientific advisors of the European Commission, the European Commission Scientific Advice Mechanism (2016). Data availability is a fundamental challenge for policymakers and researchers alike. With data for approximately 1.3 million vehicles, the *From Laboratory to Road* series represents the most exhaustive collection of real-world fuel consumption values in Europe, but no official, large-scale measurement campaigns have been implemented at national or European levels. In the United States, the My MPG service by the U.S. Environmental Protection Agency and U.S. Department of Energy is a national platform for measuring on-road fuel consumption.[16] A similar service could be established in Europe to measure real-world policy impacts.

As a response to the paucity of real-world fuel consumption data, a new type-approval regulation will require future light-duty vehicles to log fuel and electric energy consumption data, and to make the data accessible in a standardized format on the on-board diagnostics port (European Commission, 2018). With fuel consumption meters being introduced by January 1, 2020 for new type approvals and becoming mandatory for all new cars from January 1, 2021 onward, it will for the first time be possible to comprehensively monitor CO_2 emissions under real-world driving conditions. As part of the 2025 and 2030 CO_2 standards for European light-duty vehicles, the European Commission will be required to annually report the gap between official and real-world CO_2 emissions, as measured using fuel consumption meters, from 2021 onwards. With the details of such a monitoring system to be defined in 2019/20, it is important to emphasize that public access to anonymized, detailed fuel and energy consumption data will be paramount for transparent market surveillance.

Measuring real-world CO_2 emissions is a prerequisite for improvements, but policy measures should also directly target closing the gap. The WLTP, introduced for new vehicle types in September 2017, will likely produce more realistic CO_2 emission values, but there are indications that a substantial divergence will remain in future years (Stewart et al., 2015). In response, as part of the 2025 and 2030 CO_2 standards, the European Commission must 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 a mechanism to adjust each manufacturer's average CO_2 emissions for its real-world performance, beginning in 2030.

In-service conformity testing would entail selecting vehicles from the European car fleet and comparing their performance under laboratory testing with declared type-approval values. In-service conformity testing could be an essential building block of improved regulations as it offers opportunities to (a) verify CO_2 emission values declared during type approval, (b) verify the accuracy of fuel consumption meters, and (c) verify road load parameters, which are vital inputs for laboratory testing and otherwise go unchecked.

Modern power trains present new challenges for policies and research on real-world CO_2 emissions. PHEVs are growing in popularity, and multiple European governments have

16 http://www.fueleconomy.gov/mpg/MPG.do

implemented policies to incentivize their uptake (Tietge, Mock, Lutsey, & Campestrini, 2016). This study and other research (e.g., Ligterink & Smokers, 2015; Plötz, Funke, & Jochem, 2015) indicate that PHEVs substantially exceed type-approval CO_2 emission values during real-world driving. While data on PHEVs are abundant in the Netherlands, less data are available for other markets. Data from fuel consumption meters offer an opportunity to in the future quantify fuel and electric energy consumption of the PHEVs and to adjust the utility factor—the portion of driving that PHEVs are assumed to conduct in electric mode—in regulations. Policies incentivizing the purchase of PHEVs face the challenge of ensuring that these vehicles are charged in an appropriate manner to increase electric-drive shares.

This study focuses on passenger cars, but other vehicle types also may exhibit a real-world CO_2 emissions gap. While first attempts at measuring real-world CO_2 emission values of light commercial vehicles (e.g., Zacharof, Tietge, Franco, & Mock, 2016) and heavy-duty vehicles (e.g., Sharpe & Muncrief, 2015) have been made, there is little publicly available information on these vehicles' real-world performance. Heavy-duty vehicles currently account for a third of on-road CO_2 emissions, and this share is predicted to grow (Muncrief & Sharpe, 2015). More research on real-world CO_2 emissions of light commercial and heavy-duty vehicles is warranted.

Lastly, communicating realistic CO_2 emission values to consumers presents another policy challenge. European regulators do not present real-world fuel consumption values to consumers. In contrast, the U.S. FuelEconomy.gov website provides a one-stop shop for laboratory measurements, real-world-adjusted fuel consumption values, and on-road measurements by consumers. Some attempts have been made to predict the on-road performance of European cars based on basic vehicle characteristics (Ligterink, Smokers, Spreen, Mock, & Tietge, 2016; Mellios et al., 2011; Ntziachristos et al., 2014; Tietge, Mock, Franco, & Zacharof, 2017) and have generally proven reasonably accurate at predicting average on-road fuel consumption. More customized predictions of real-world fuel consumption can be generated using online tools (e.g., European Commission Joint Research Center, 2017). Data from models, consumers, and fuel consumption meters, packaged in a convenient website with other pertinent vehicle data and displayed at the point of sale, would enable consumers to make informed purchasing decisions.

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