WHITE PAPER

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FROM LABORATORY TO ROAD

A 2017 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 118 g/km in 2016. The rate of reduction in CO_2 emission values increased from roughly 1% per year to more than 3% per year after CO_2 standards were introduced in 2009. Today, car manufacturers are on track to meet the 2021 target of 95 g/km. 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 fifth update of the *From Laboratory to Road* series adds another year of data (2016), one new country (Belgium), one new data source (Cleaner Car Contracts Belgium), and more than 100,000 vehicles to the analysis. **Data on approximately 1.1 million vehicles from 14 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 9% in 2001 to 42% in 2016** (see Figure ES- 1). With the average level virtually unchanged from 2015, 2016 is the first sign of a slowdown in the growth of the gap. 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.

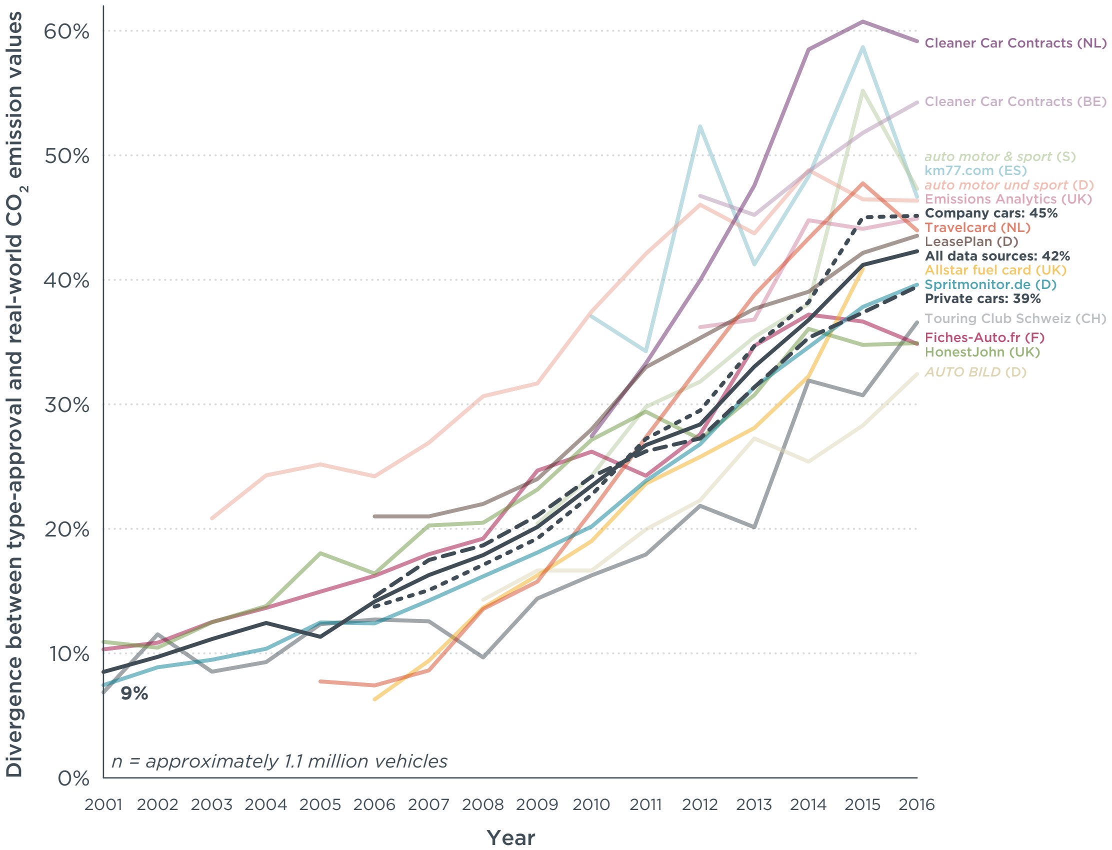

Figure ES- 1. Divergence between real-world and manufacturers' type-approval CO_2 emission values for various on-road data sources, including average estimates for private cars, company cars, and all data sources.

The growing 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 growing 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 increasing 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 Europe-wide web service for tracking on-road fuel consumption and large-scale measurement campaigns using data loggers could furnish this 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 growing 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.

» Better vehicle testing could help close the gap. On-road tests under the Real Driving Emissions (RDE) for pollutant emissions should be extended to CO_2 emissions. Introducing in-use surveillance testing, carried out by independent parties, would ensure compliance with declared CO_2 emission values of production vehicles.

» The European type-approval framework needs to be revised. Key issues to be addressed include ensuring independent surveillance testing of vehicles, increasing data transparency, and breaking financial ties between car manufacturers and testing organizations.

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ABBREVIATIONS

ADIA	Abu Dhabi Investment Authority
B7	diesel with 7% biodiesel
CO_2	carbon dioxide
E5	gasoline with 5% ethanol
E10	gasoline with 10% ethanol
EEA	European Environment Agency
EU	European Union
FCA	Fiat Chrysler Automobiles
g/km	grams per kilometer
GPS	global positioning system
HEV	hybrid electric vehicle
ICCT	International Council on Clean Transportation
IFEU	Institute for Energy and Environmental Research Heidelberg
km	kilometer
km/h	kilometers per hour
MPG	miles per imperial gallon
MPV	multi-purpose vehicle
NEDC	New European Driving Cycle
NO_x	nitrogen oxides
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 2016 (Şenzeybek, Tietge, & Mock, 2017). As a result, car manufacturers met the 2015 CO_2 target of 130 grams per kilometer (g/km) two years in advance and are well on their way to meeting the 2021 target of 95 g/km. Post-2020 targets are scheduled to be set in 2017, as foreseen by the European Commission's (2016a) strategy for low-emission mobility.

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 2016. 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 will be gradually 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 growing 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 fifth 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 2017 update comprises 14 data sources, including one new data source (Cleaner Car Contracts Belgium), that together cover approximately 1.1 million cars from eight countries (see Figure 1). The data were gathered from online fuel tracking services, automobile magazines and associations, fuel card services, and company fleets.

	SOURCE	NUMBER OF ENTRIES
Belgium	Cleaner Car Contracts	835
Germany	Spritmonitor.de	148,304
	LeasePlan	~250,000
	AUTO BILD	2,490
	auto motor und sport	2,395
United Kingdom	Allstar card	242,353
	HonestJohn.co.uk	124,829
	Emissions Analytics	752
Netherlands	Travelcard	308,020
	Cleaner Car Contracts Netherlands	22,601
France	Fiches-Auto.fr	27,001
Spain	km77.com	346
Sweden	*auto motor & sport*	762
Switzerland	Touring Club Schweiz	285

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.

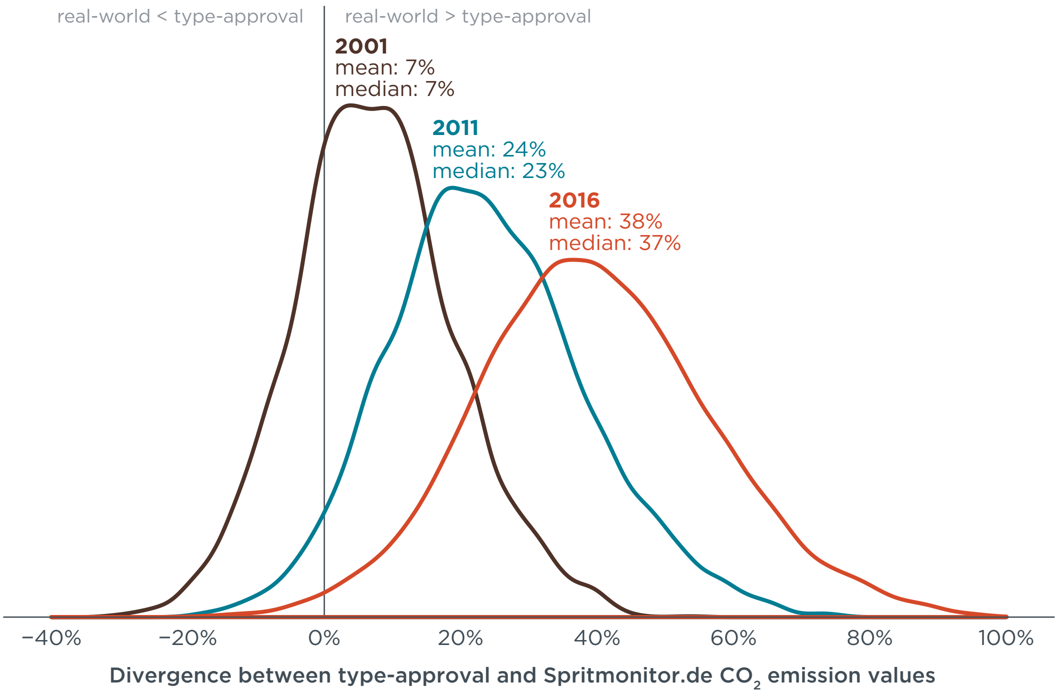

Figure 2. Distribution of the divergence between Spritmonitor.de and type-approval CO_2 emission values, comparison for the years 2001, 2011 and 2016.

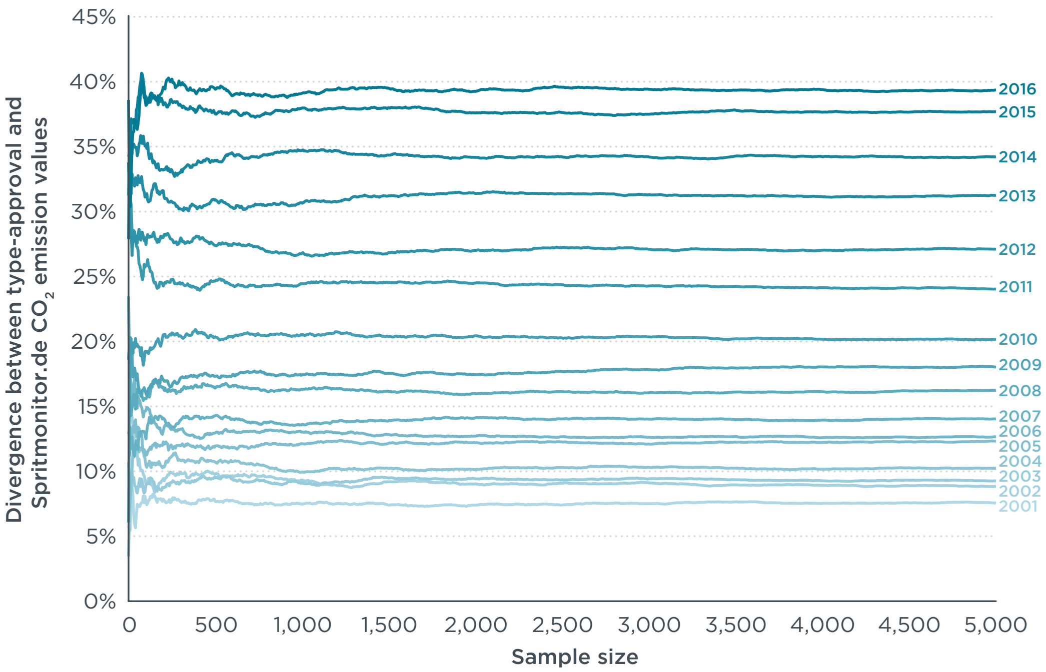

Figure 3. Annual divergence estimates as a function of sample size, based on Spritmonitor.de data.

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 each of the 14 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 growing 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/publications/laboratory-road-2017-update

2. DATA ANALYSIS

2.1 SPRITMONITOR.DE (GERMANY)

Data type	On-road, user-submitted
Data availability	2001–2016, more than 9,000 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 more than 400,000 registered users, data on more than 600,000 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 and presents self-reported data on driving behavior.

Methodology

Spritmonitor.de provided anonymized data on approximately 600,000 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 2016 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 148,000 vehicles remained. The model variants included in the analysis cover approximately 90% 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 (see Mock (ed.), 2016), 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

2 See http://www.spritmonitor.de. The complete dataset used for this analysis was acquired in April 2016.
3 For a description of Peirce's criterion and its application, see Ross (2003).

user-submitted type-approval fuel consumption values were used to gauge the accuracy of the joined values.

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 33% of all vehicles within ±1% agreement and 70% of all vehicles within ±5% agreement. The distribution is slightly left-skewed, indicating that, on average, joined type-approval fuel consumption values are somewhat lower than user input.

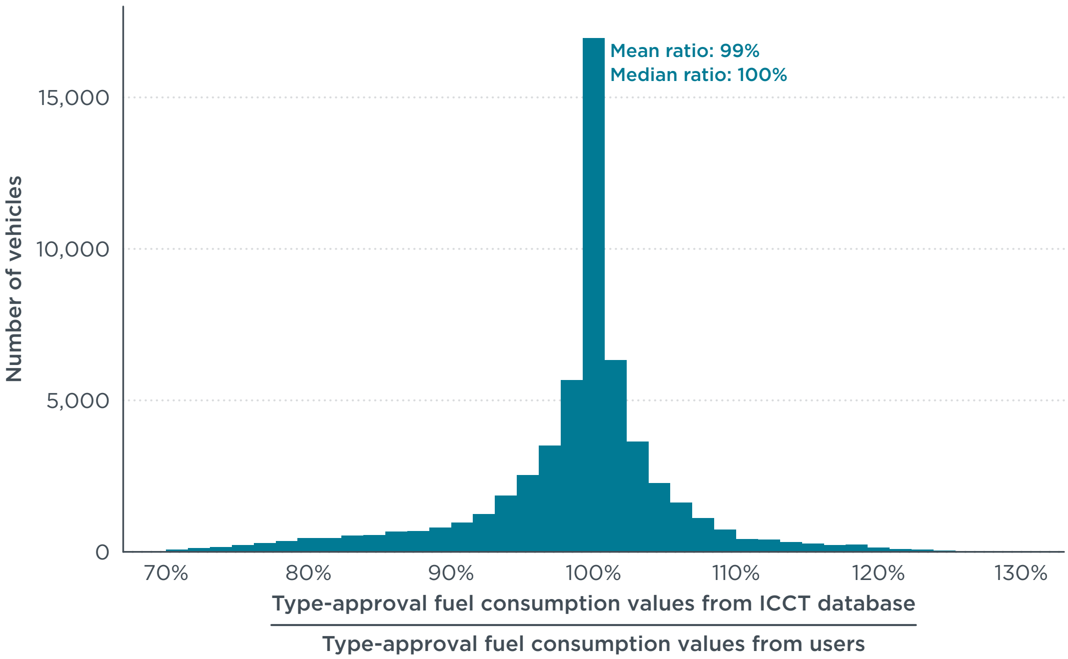

Figure 4. Distribution of the ratio between joined and user-submitted type-approval fuel consumption values for Spritmonitor.de.

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 56,000 vehicles). The graph indicates that the slight differences between joined and user-submitted type-approval fuel consumption values affect annual averages by up to 4 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 (148,000 vehicles vs. 56,000 vehicles), the ICCT joined values were used for the rest of the analysis.

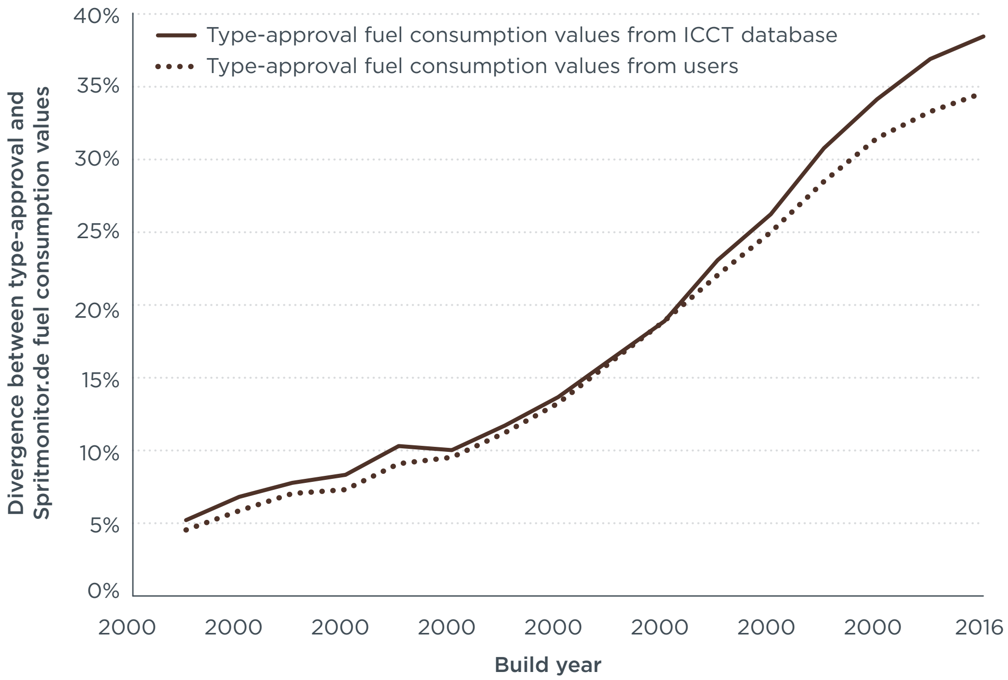

Figure 5. Divergence between type-approval and real-world CO_2 emission values according to ICCT and user-submitted type-approval fuel consumption values, from a subset of the Spritmonitor.de data.

Results presented in this report may differ slightly from those published in previous *From Laboratory to Road* reports, because Spritmonitor.de users continuously add fuel consumption data to the database and new users sign up. Figure 6 shows the development of the average divergence by the year of data analysis (corresponding to ICCT reports from 2012 to 2017). While results from different years largely overlap, results from 2015 and 2016 tended to overestimate the gap in the most recent build years, 2014 and 2015 respectively. For instance, 2016 results for build year 2015 overestimate the gap by almost 2 percentage points compared to results for the same build year presented in this study. This effect persists even when calculating the gap with user-provided type-approval fuel consumption values, so it is not an artifact of joined type-approval fuel consumption values. Similarly, changes in fleet composition (e.g., changes in shares of power trains, transmission types, or vehicle segments) over time do not explain the effect on their own. In order to further explore this effect, we requested anonymized vehicle identifiers from the data proprietor so that possible changes in on-road fuel consumption over vehicle age can be tracked and analyzed in detail in future analyses.

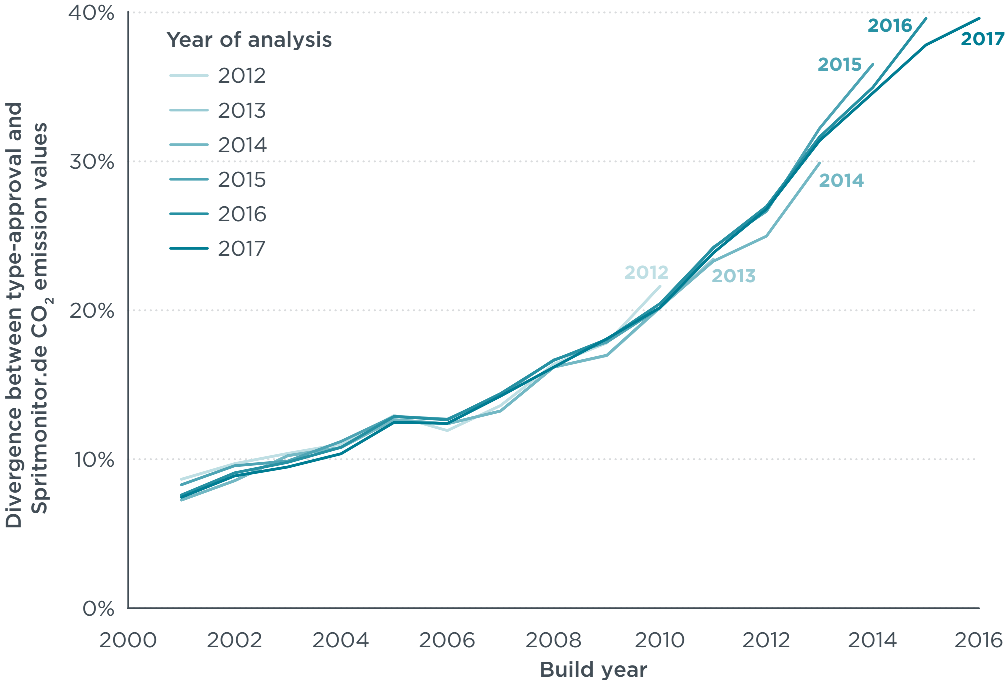

Figure 6. Divergence between type-approval and Spritmonitor.de CO_2 emission values by year of data analysis.

Results

Figure 7 plots the divergence between type-approval and Spritmonitor.de fuel consumption values by fuel type. The gap reached 40% in 2016, more than five 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 down. The difference between the average divergence of diesel and gasoline cars has been gradually increasing since 2010, with the gap for diesel vehicles reaching 43% in 2016, almost 8 percentage points higher than the gap for gasoline cars. 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 trains, and increased from 23% to 51%. However, HEVs and conventional power trains converged in recent years.

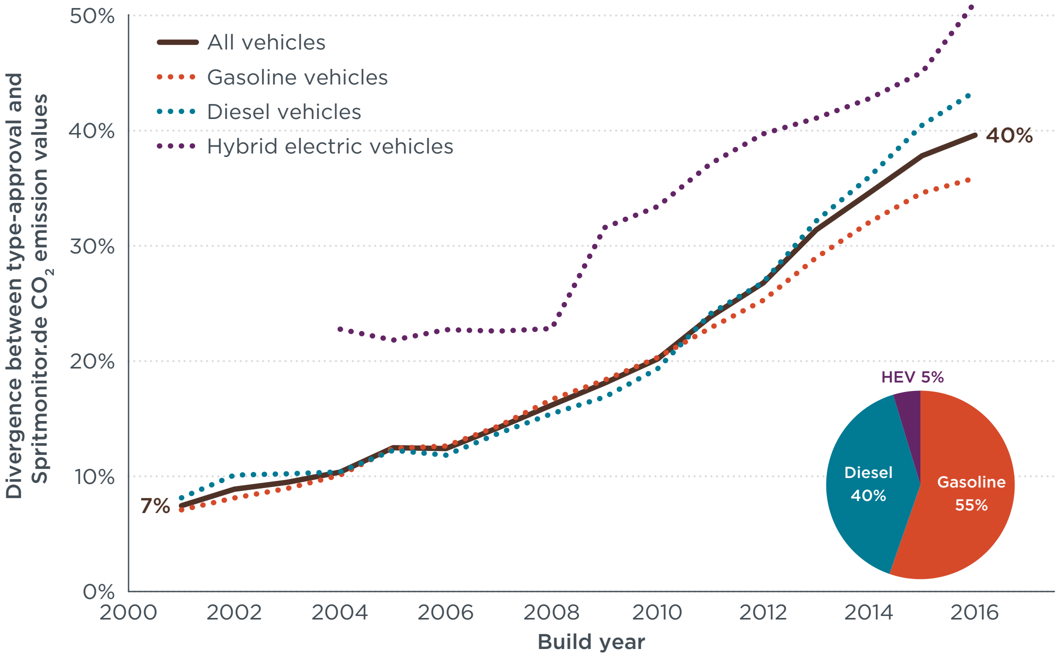

Figure 7. Divergence between type-approval and Spritmonitor.de CO_2 emission values by fuel type. Pie chart indicates the share of vehicles per fuel type in the dataset for build year 2016.

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 8. 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 2016 at 8 percentage points. The share of cars with automatic transitions steadily increased over time. Vehicles with automatic transmissions accounted for roughly 14% of the Spritmonitor.de vehicles built in 2001 and grew to approximately half of the sample in build year 2016.

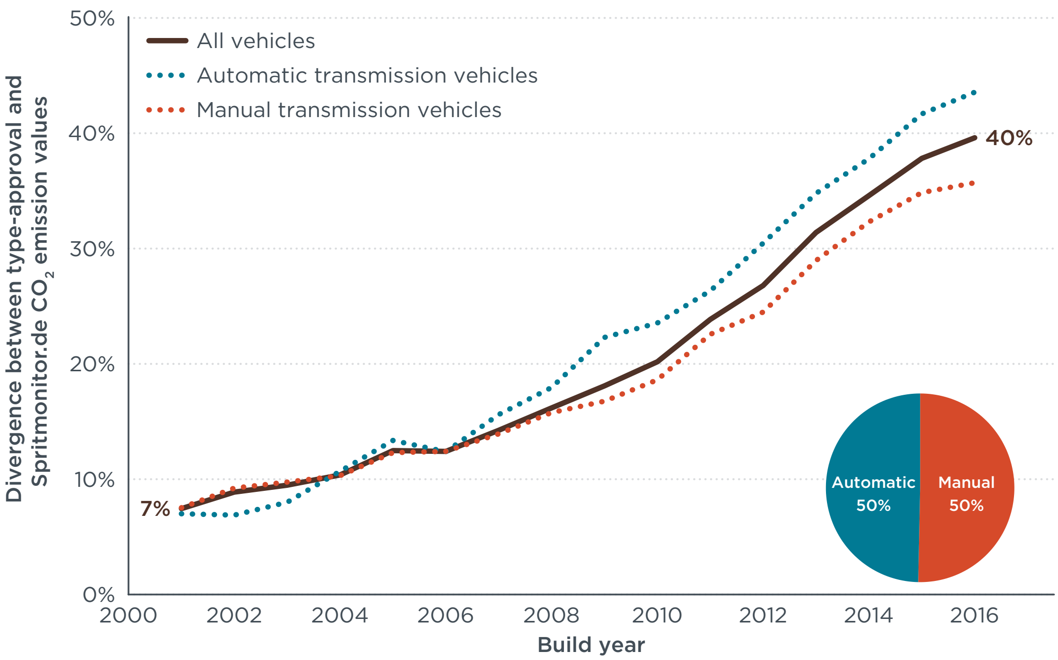

Figure 8. Divergence between type-approval and Spritmonitor.de CO_2 emission values by transmission type. Pie chart indicates the share of vehicles per transmission type in the dataset for build year 2016.

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 9 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 38%). Lower medium vehicles thus follow the market trend closely. The small and medium vehicle segments also make up relatively high annual shares of the Spritmonitor.de sample, around 20% 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. 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 20% in build year 2016. In recent years, average divergence values from the mini segment have also dropped below the market average.

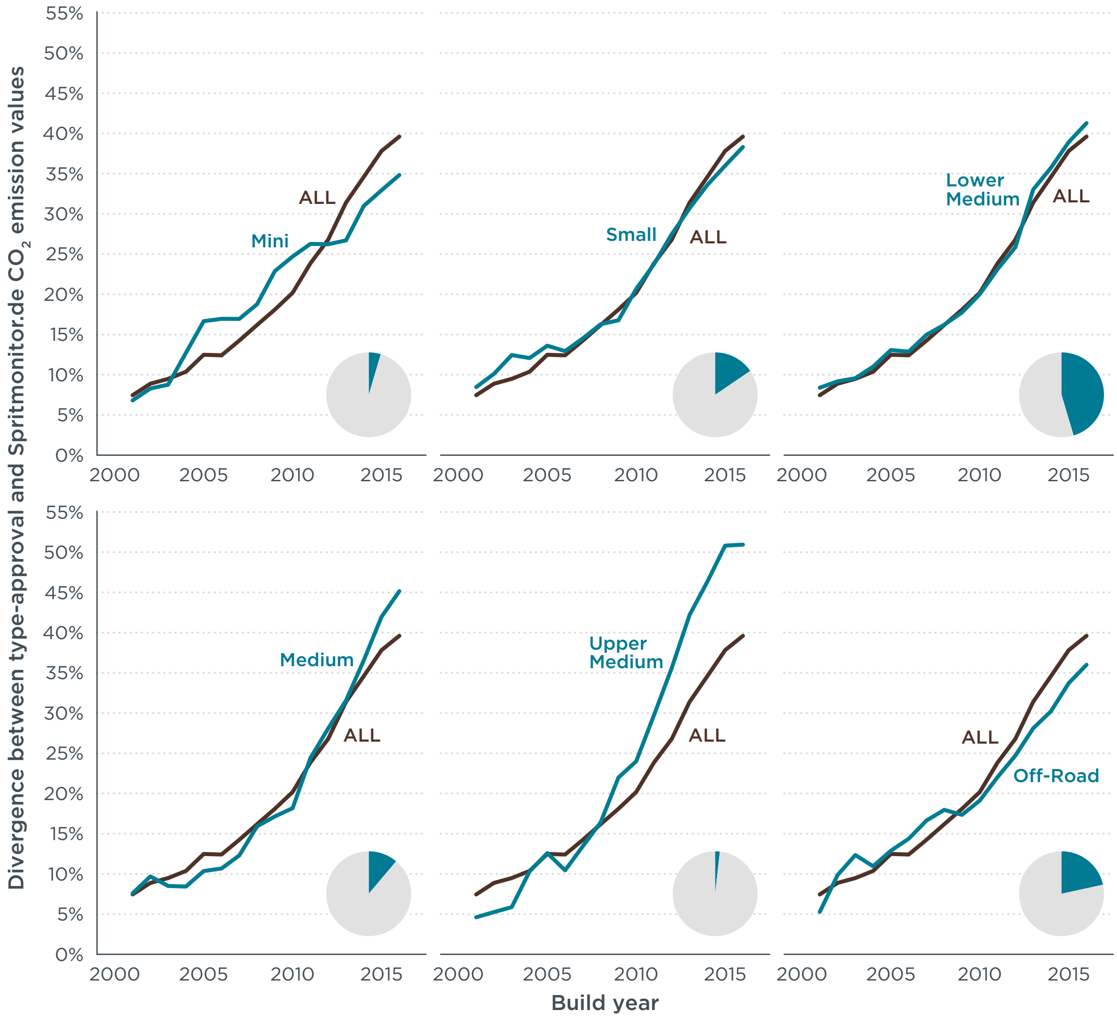

Figure 9. Divergence between type-approval and Spritmonitor.de CO_2 emission values by vehicle segment. Pie charts represent the share of vehicles per segment in the dataset for build year 2016.

4 Vehicle segments 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 10 plots the trend in the divergence between Spritmonitor.de and official CO_2 emission values for a selection of nine 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. While BMW has converged with the market trend since build year 2009, the divergence for Daimler vehicles has grown at a faster pace, reaching 51% in build year 2016.

Toyota also has divergence values above the market average due to the high share of HEVs among Toyota entries in the Spritmonitor.de data (around 77% in build year 2016). As seen in Figure 7, HEVs have average divergence levels significantly higher than those of conventional power trains. Excluding HEVs, Toyota has the lowest average divergence values of all manufacturer groups. In build year 2016, the average divergence from conventional Toyota models was 33%, 7 percentage points below the market average.

Volkswagen and Renault-Nissan historically remained below the market average but have recently converged with the market average. Fiat Chrysler Automobiles (FCA), Ford, and the PSA group have tracked the market average trend closely throughout the years. FCA displays a somewhat erratic trend due to the low number of entries in the Spritmonitor.de sample.

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

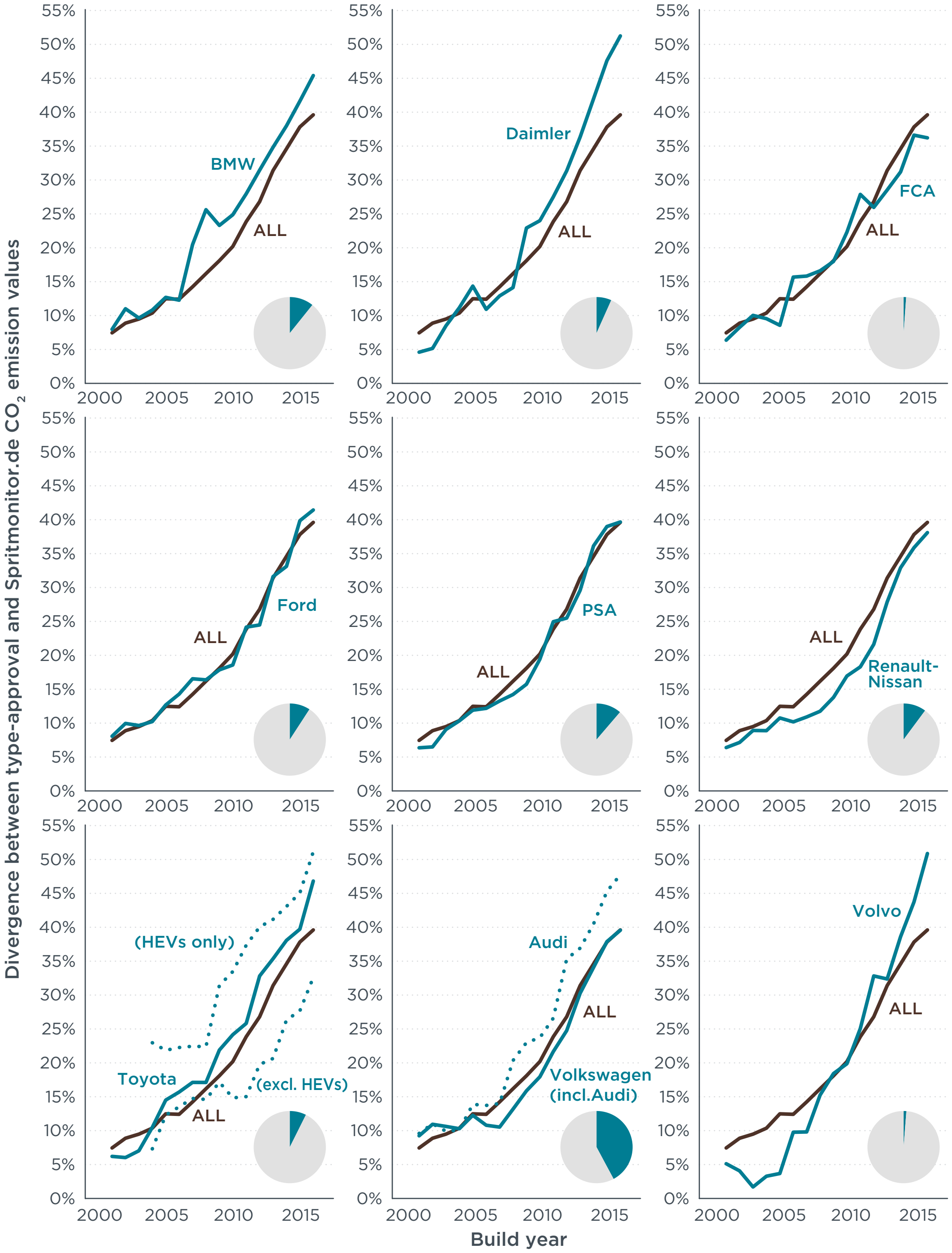

Figure 10. Divergence between type-approval and Spritmonitor.de CO_2 emission values by manufacturer group. Pie charts represent the share of each group in the dataset for fleet year 2016.

Figure 11 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' contribution to their respective 2016 brand sales in Germany is 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 11, 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.

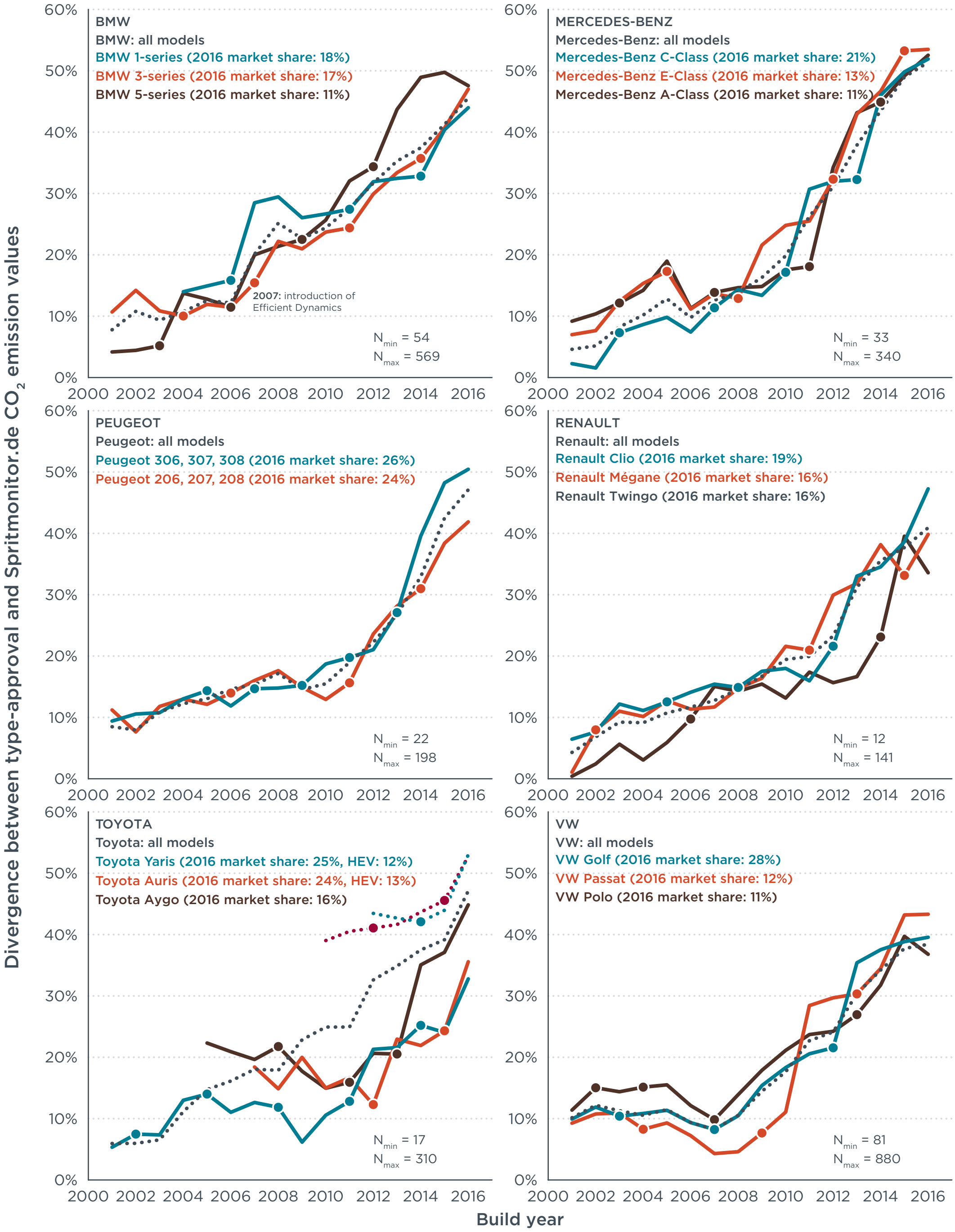

Figure 11. Divergence between type-approval and Spritmonitor.de CO_2 emission values by brand and by top-selling models.[6] Circles indicate the year before a major technical overhaul. Dashed lines represent the brand average.

6 2016 market share: models' contribution to their respective brands in Germany in 2016; $N_{min/max}$: minimum and maximum annual number of data entries for vehicle models.

Figure 12 shows how the average CO_2 divergence evolved between build years 2001 and 2016 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 11, the contribution of each model to its brand's 2016 sales in Germany is provided in the top left of each graph, while 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.

As already shown in Figure 9, 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 only caught up with the segment average trend 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 is also 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.

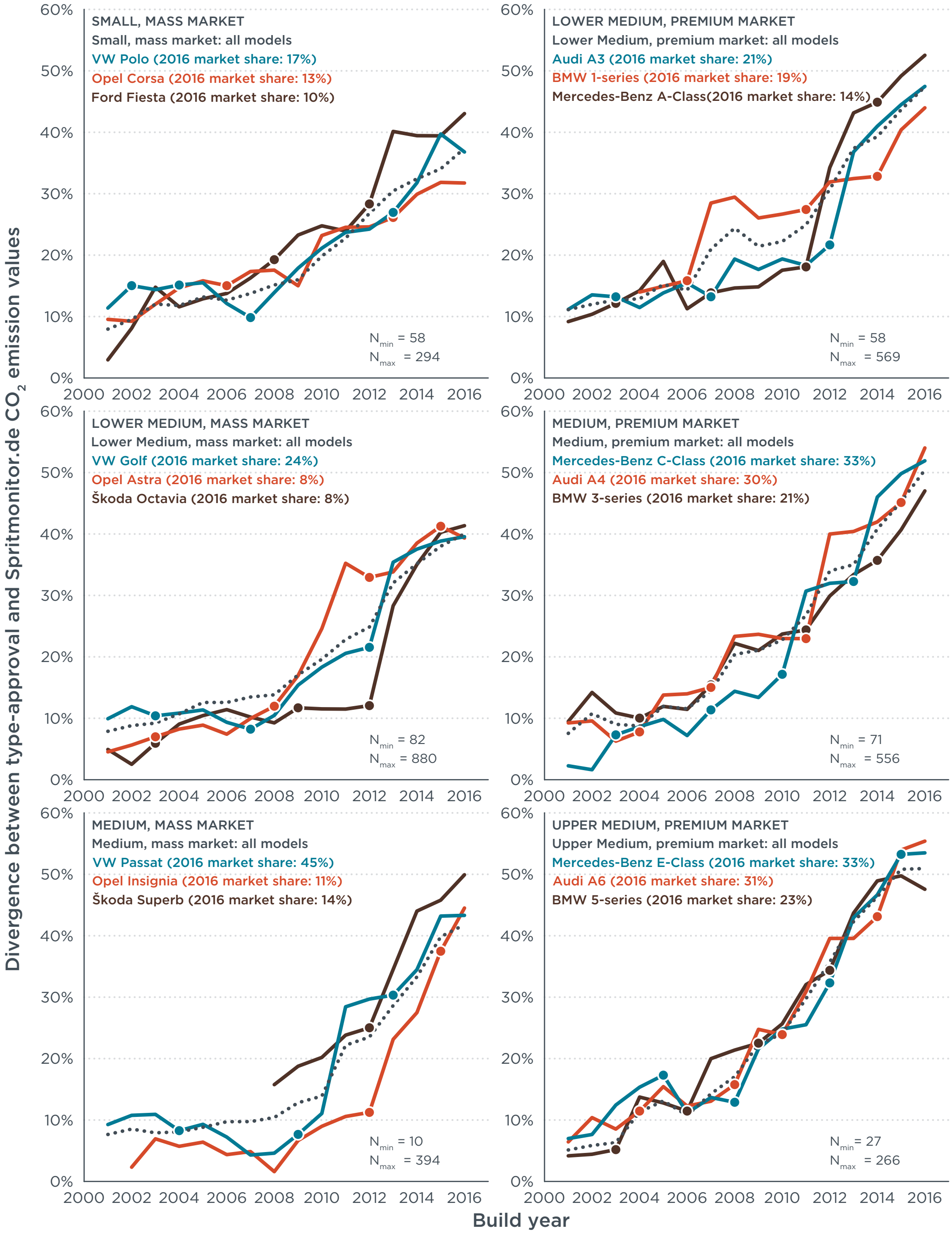

Figure 12. Divergence between type-approval and Spritmonitor.de CO_2 emission values by vehicle segment and their top-selling mass market (left) and premium market (right) models.[7] Circles indicate the year before a major technical overhaul. Dashed lines represent the segment/market average.

The analysis of the average divergence between Spritmonitor.de and type-approval CO_2 emission values at the vehicle model level (Figure 11 and Figure 12) 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

7 2016 market share: models' contribution to their respective brands in Germany in 2016; $N_{min/max}$: minimum and maximum annual number of data entries for vehicle models

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).

2.2 TRAVELCARD (NETHERLANDS)

Data type	On-road, fuel card
Data availability	2005–2016, approximately 26,000 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 company currently serves more than 200,000 vehicles registered in the Netherlands.

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.

For this study, TNO analyzed fuel consumption data from a sample collected in May 2017 of more than 300,000 common vehicles with build years ranging from 2005 to 2016. 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 does not include those vehicles from last year's sample that have exited Travelcard's fleet since then, so divergence estimates may vary slightly compared with previous findings.

Results

Figure 13 plots the divergence between type-approval and Travelcard CO_2 emission values from build year 2005 to 2016. The divergence between real-world and official CO_2 emission values increased steeply following the introduction of CO_2 emission standards in the EU around 2009. In 2016, the average divergence was 44%, down 5 percentage points from build year 2015. 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 14 and TNO regularly publishes analyses of PHEVs in the Travelcard fleet (see Ligterink & Smokers, 2016).

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

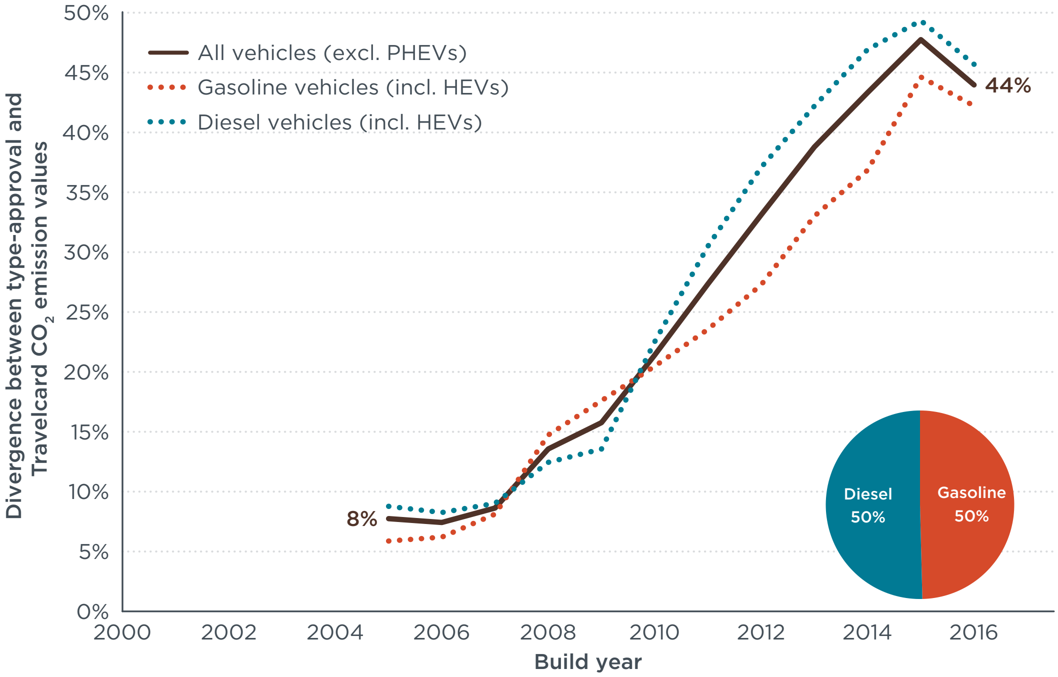

Figure 13. Divergence between type-approval and Travelcard Nederland BV CO_2 emission values. Pie chart indicates the share of vehicles per fuel type in the dataset for build year 2016.

Figure 14 plots the average divergence between type-approval and Travelcard CO_2 emission values by power train type in 2016. Although vehicles with conventional power trains and HEVs on average exceed type-approval CO_2 values by 45%, PHEVs stand out with a gap of 242%. This difference was observed in all build years, with PHEVs consistently exceeding the other power train types by more than 150 percentage points.

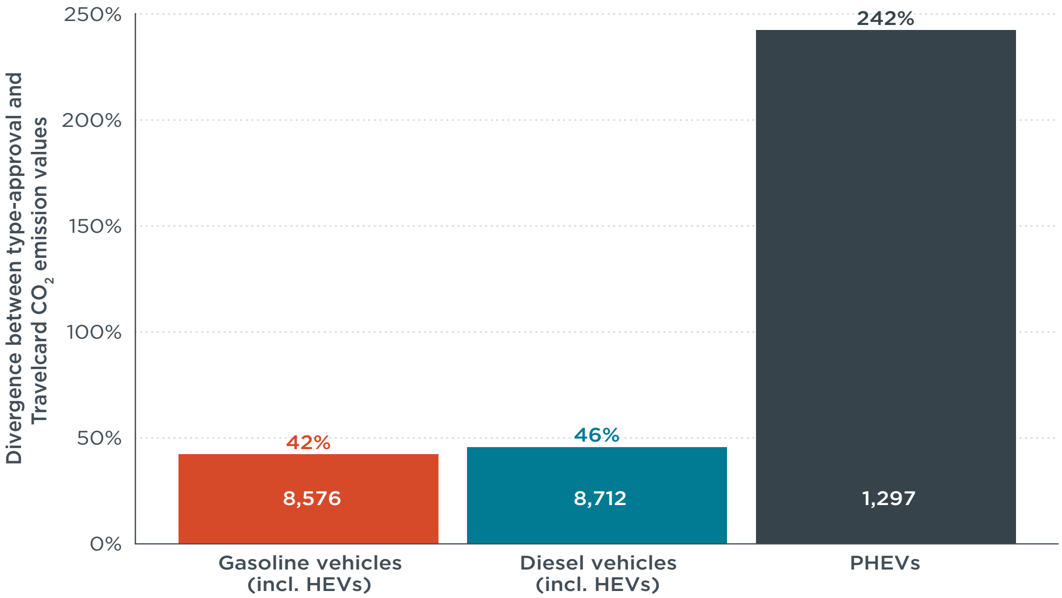

Figure 14. Divergence between type-approval and Travelcard Nederland BV CO_2 emission values by power train type in build year 2016. Number of vehicles per category presented at the base of each bar.

Figure 15 shows how the shares of Travelcard vehicles, grouped by 10 g/km type-approval CO_2 emission bins, evolved between build years 2005 and 2016. The color gradient indicates the average divergence between on-road and official CO_2 emission values.

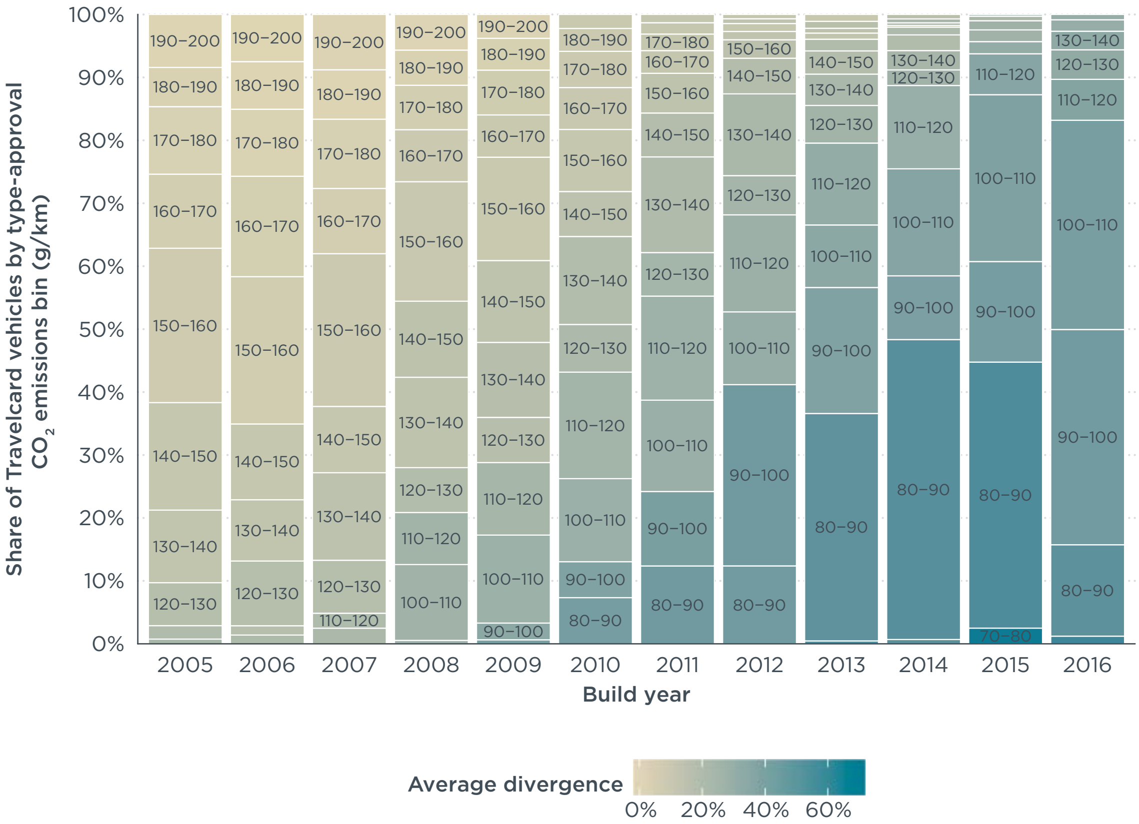

Figure 15. Share of Travelcard Nederland BV vehicles by type-approval CO_2 emissions bin. The color scale indicates the average divergence between real-world and type-approval CO_2 emissions per bin.

Figure 15 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). Vehicles with low CO_2 emission values have the highest divergence, thus undermining the benefits of the tax incentives. For example, in 2016, the average divergence of vehicles with type-approval values between 130 and 140 g/km was about 33%, while the average CO_2 gap of vehicles with official CO_2 emission values between 80 and 90 g/km was 20 percentage points higher (53%). The figure also shows that the gap increased in all type-approval CO_2 bins over time.

Figure 15 offers an explanation for the 5-percentage-point decline in the gap from build year 2015 to 2016 (see Figure 13). 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. This development likely contributed to the decrease in the share of vehicles with comparatively low type-approval CO_2 values in 2016. For example, vehicles with type-approval CO_2 values of 80–90 g/km were popular in the Travelcard fleet in 2015 and had a comparatively high gap. The share of this bin decreased steeply from 42% in 2015 to 15% in 2016, while the gap remained relatively stable in this bin (58% in 2015, 53% in 2016). Because the share of bins with low official CO_2 values and high gaps declined from 2015 to 2016, the average gap displayed in Figure 13 declined as well.

2.3 LEASEPLAN (GERMANY)

Data type	On-road, fuel card
Data availability	2006–2016, approximately 25,000 new vehicles per year
Data collection	Fuel consumption data, automatically recorded using a fuel card when refueling at gas stations
Fleet structure, driving behavior	Company cars; mostly extra-urban and highway driving; fuel is usually paid for by the employer

Description

LeasePlan is a financial service provider founded in the Netherlands in 1963 and specializes in vehicle leasing operations and fleet management. The LP Group B.V. is a consortium composed of a group of long-term responsible investors and includes leading Dutch pension fund service provider PGGM, Denmark's largest pension fund ATP, GIC, Luxinva S.A., a wholly owned subsidiary of the Abu Dhabi Investment Authority (ADIA) and investment funds managed by TDR Capital LLP. LeasePlan currently operates in 32 countries.

This analysis covers real-world and type-approval fuel consumption data from the German subsidiary of LeasePlan. LeasePlan Germany was founded in 1973 and operates a fleet of more than 108,000 company cars for a total of 800 clients.[9] Like the Travelcard sample, LeasePlan real-world fuel consumption data were automatically collected by means of fuel cards. The data were provided for the entire fleet; breaking down the data by vehicle age was not possible. We refer to the year of measurement as fleet year. Considering that LeasePlan vehicles have an average holding period of about three years, the annual estimates of the divergence presented below can be seen as three-year rolling averages of new company cars.

Similar to other company car fleets, the LeasePlan fleet has a particularly high share of diesel vehicles (97% of the analyzed vehicles were diesel powered). Four manufacturer groups (BMW, Daimler, Ford, and Volkswagen) dominate the LeasePlan fleet, which together account for around 88% of the sample. A detailed comparison of LeasePlan data and average German market characteristics can be found in the 2013 update of the *From Laboratory to Road* series (Mock et al., 2013).

LeasePlan cars are less likely than privately owned vehicles to be driven in a fuel-conserving manner. For one, employers normally cover fuel expenses for LeasePlan drivers. In addition, according to LeasePlan, their vehicles are typically used to cover long distances on the German Autobahn, which has no universal speed limit. LeasePlan drivers often exceed 130 km/h, at which speed CO_2 emissions drastically increase. While LeasePlan data is not representative of privately owned vehicles, given the considerable sample size, there is no reason to suspect the sample is unrepresentative of German company cars. Furthermore, any sources of bias are expected to be consistent over time and thus do not affect the trends presented here.

Methodology

LeasePlan provided data for approximately 83,000 company cars for fleet year 2016, out of which approximately 52,000 vehicles had valid real-world and official fuel consumption values. On-road fuel consumption figures were calculated as the sum of the fuel consumed by each vehicle divided by its mileage. Data on vehicle model, body type, and fuel type were also provided. To analyze the divergence by manufacturer group, vehicle brands were grouped as follows: BMW (BMW, Mini), Daimler (Mercedes-Benz, Smart), FCA (Alfa-Romeo, Chrysler, Dodge, Fiat, Jeep, Maserati), Ford, PSA (Citröen,

9 See www.leaseplan.de

Opel, Peugeot), Renault-Nissan (Dacia, Infiniti, Mitsubishi, Nissan, Renault), Toyota (Daihatsu, Lexus, Toyota), and Volkswagen (Audi, Porsche, Seat, Škoda, VW).

From 2006 to 2010, data were provided in aggregated form and thus cannot be disaggregated by vehicle segment or manufacturer.[10] Values for 2012 were not available to the ICCT.

Results

Figure 16 plots the average divergence between LeasePlan and type-approval CO_2 emission values from 2006 to 2016. In 2016, the average divergence was 44%, 1 percentage point higher than in 2015, and more than double the 2006 estimate. The growth of the divergence slowed after 2011 but increased again between 2014 and 2015. This change in trend is related to model facelifts. As noted in Section 2.1, facelifts are usually followed by an increase in divergence. Some of the most popular LeasePlan vehicle models—the VW Passat, the Audi A6, and the Ford Mondeo—underwent facelifts around 2014. These models account for roughly one-quarter of the 2015 fleet and experienced significant increases in the divergence after the facelift.

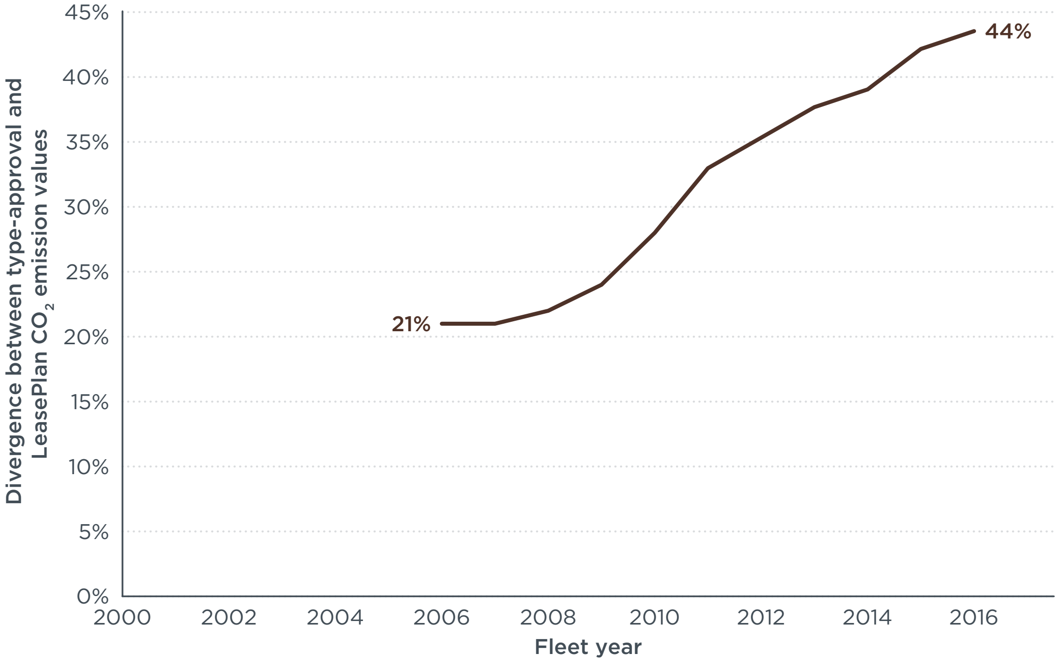

Figure 16. Divergence between type-approval and LeasePlan CO_2 emission values.[11]

10 Because these data were provided directly by LeasePlan, they could not be verified by the ICCT.

11 The data point for 2012 was linearly interpolated from the 2011 and 2013 data points.

Figure 17 shows the trend in the divergence between real-world and official CO_2 emission values for the most popular vehicle segments. From 2011 to 2016, the divergence increased in all vehicle segments. The lower medium and medium segments follow the fleet average closely, as they respectively accounted for about 28% and 43% of the sample. The divergence for the small and upper medium segment lies notably above the fleet average, while the opposite is true for off-road vehicles and multi-purpose vehicles (MPVs).

Figure 17. Divergence between type-approval and LeasePlan CO_2 emission values by vehicle segment. Pie charts represent the share of each segment in the dataset for fleet year 2016.

Similar to Figure 17, Figure 18 shows the trend in the divergence between real-world and official CO_2 emission values, this time by manufacturer group. Over that period, the divergence increased for all manufacturer groups. Daimler, PSA, and Volvo stand out with average divergence values that consistently exceed the fleet average. In the 2016 update of the *From Laboratory to Road*, PSA was the manufacturer group with the lowest gap; however, PSA's acquisition of Opel in 2017 increased the gap averaged over all years from 37% to 42%. Volkswagen models, which account for almost 50% of the sample, lie marginally below the fleet average.

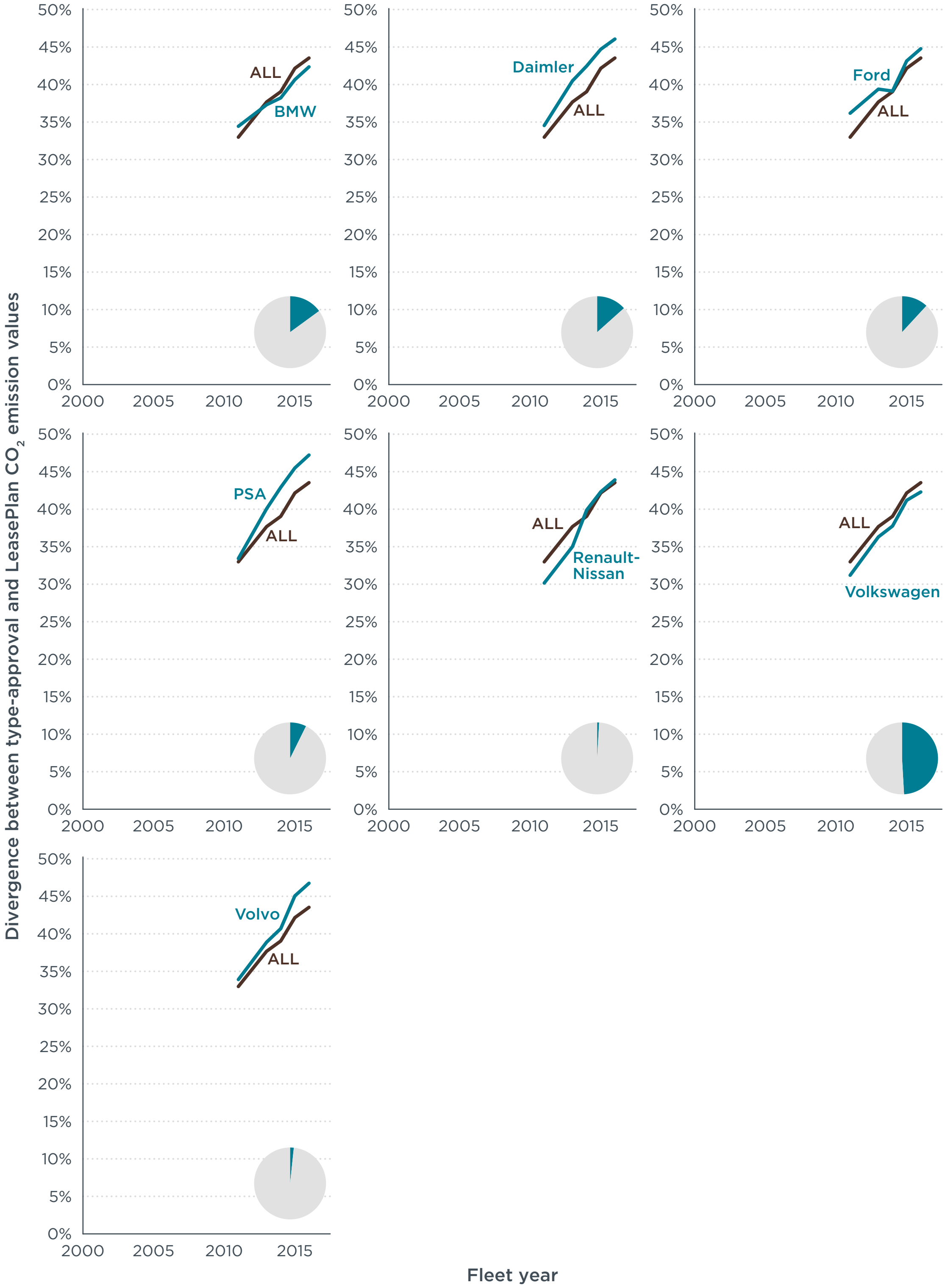

Figure 18. Divergence between type-approval and LeasePlan CO_2 emission values by manufacturer group. Pie charts represent the share of each group in the dataset for fleet year 2016.

2.4 HONESTJOHN.CO.UK (UNITED KINGDOM)

Data type	On-road, user-submitted
Data availability	2001–2016, approximately 8,000 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[12] 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 (the year the model was introduced to the market) is used to date vehicles.

Approximately 130,000 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 125,000 vehicles with most of the vehicles ranging from model years 2001 to 2016. 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 type-approval and HonestJohn.co.uk CO_2 emission values is presented in Figure 19. The divergence increased from 11% in 2001 to 35% in 2016. There is no persistent difference between diesel and gasoline vehicles. PHEVs accounted for less than 1% of the vehicles in model year 2016 and had no appreciable effect on the average divergence.

12 See HonestJohn.co.uk

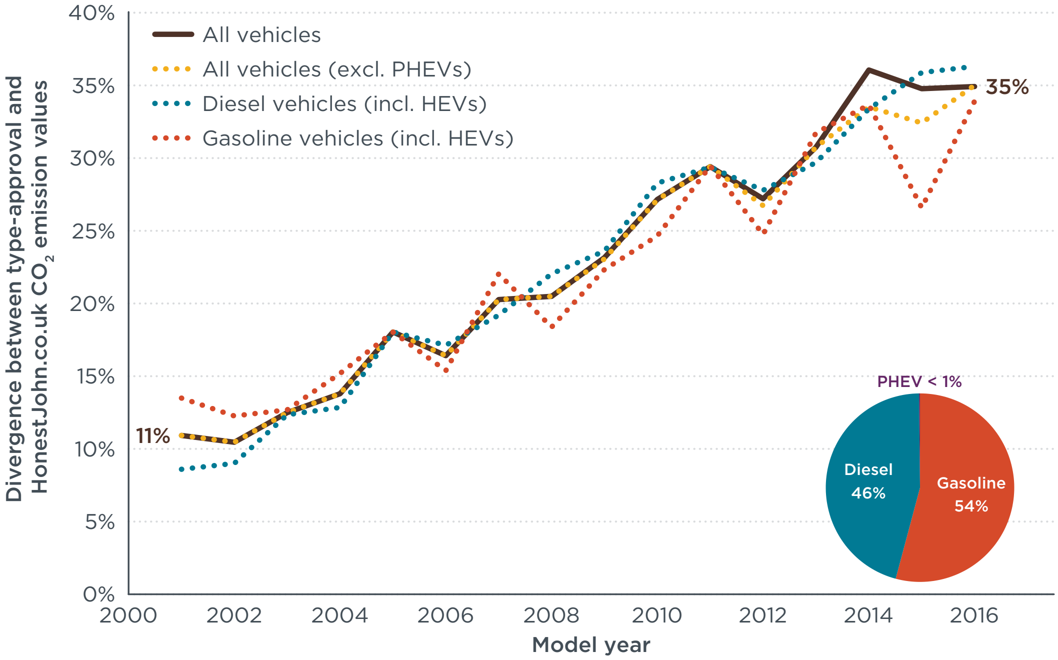

Figure 19. Divergence between type-approval and HonestJohn.co.uk CO_2 emission values by power train type. Pie chart indicates share of vehicles per fuel type in the dataset in model year 2016.

2.5 ALLSTAR FUEL CARD (UNITED KINGDOM)

Data type	On-road
Data availability	2006–2015, approximately 2,000 to 48,000 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

Allstar is a British fuel card provider owned by the FLEETCOR group. Allstar card users can fill up their vehicles at any fuel station on the company's fuel station network, which comprises more than 7,600 filling stations in the United Kingdom. In addition, some cards give access to discounted diesel at approximately 1,800 filling stations.

Element Energy, a U.K. energy consultancy, and the Committee on Climate Change provided anonymized data for the analysis, with type-approval fuel consumption data and other vehicle information provided by the U.K. Department for Transport. On-road fuel consumption data are based on the quantity of fuel purchased at gas stations, which is recorded electronically by the Allstar card system, as well as odometer readings, which are manually recorded by the driver.

Methodology

Data from more than 390,000 passenger cars, most of which were manufactured between 2001 and 2015, were analyzed in the 2016 *From Laboratory to Road* update. The data have not been updated since then. For each vehicle, type-approval CO_2 emission values and common vehicle characteristics such as build year and vehicle segment were provided. Data on total mileage and total fuel consumption were also supplied and were used to calculate the real-world CO_2 emission figures.

A large number of outliers were identified in the Allstar data. The following data points were removed:

» approximately 10,000 vehicles due to missing information
» nearly 50,000 vehicles due to unrealistic on-road fuel consumption figures
» 30,000 vehicles with less than 1,500 km logged driven distance
» 10,000 vehicles with unrealistic divergence estimates (below -50% or higher than 100% for conventional power trains)
» 500 outliers identified using Peirce's criterion
» 7,000 cars constructed before 2006, since it was determined that data from before 2006 was insufficient to calculate reliable annual estimates (less than 2,000 entries per year)

After the removal of these vehicles, approximately 290,000 cars remained in the sample.

Despite this process, a subset of gasoline vehicles still exhibited unusually low divergence estimates. Figure 20 plots the distribution of divergence estimates for gasoline vehicles by build year. The figure shows that, in contrast to other large real-world fuel consumption data sources, the divergence values were not normally distributed. The source of the bias is likely due to a portion of users using the Allstar fuel card irregularly, for example paying using a normal credit card and being reimbursed by their company. Because the Allstar fuel card gives access to discounted diesel at a large number of filling stations, drivers of diesel vehicles may be under pressure by the company paying for fuel expenses to consistently use the fuel card, whereas drivers of gasoline vehicles may use the card less regularly, explaining why this bias only affects gasoline vehicles. The bias underestimates real-world fuel consumption, because not all of the fuel consumed during on-road driving was captured in the data. Due to the prevalence of invalid data for gasoline vehicles, gasoline vehicles were removed from the analysis. Gasoline vehicles accounted for 22% (roughly 83,000 entries) of the raw data.

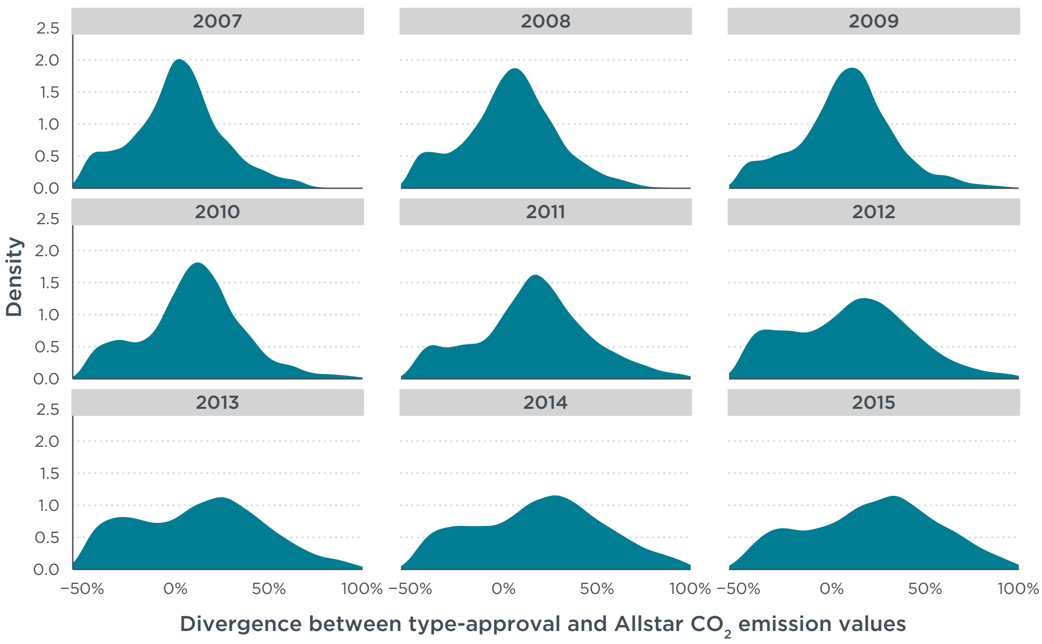

Figure 20. Distribution of Allstar divergence estimates of gasoline vehicles by vehicle build year.

Results

Figure 21 plots average divergence between type-approval and Allstar CO_2 emission values. The gap increased from approximately 6% in 2006 to 41% in 2015. Diesel vehicles, which account for 97% of the vehicles after gasoline vehicles were removed, consistently exhibit a lower divergence than HEVs, although the difference decreased over time. By 2015, the difference between the two power trains decreased to about 9 percentage points.

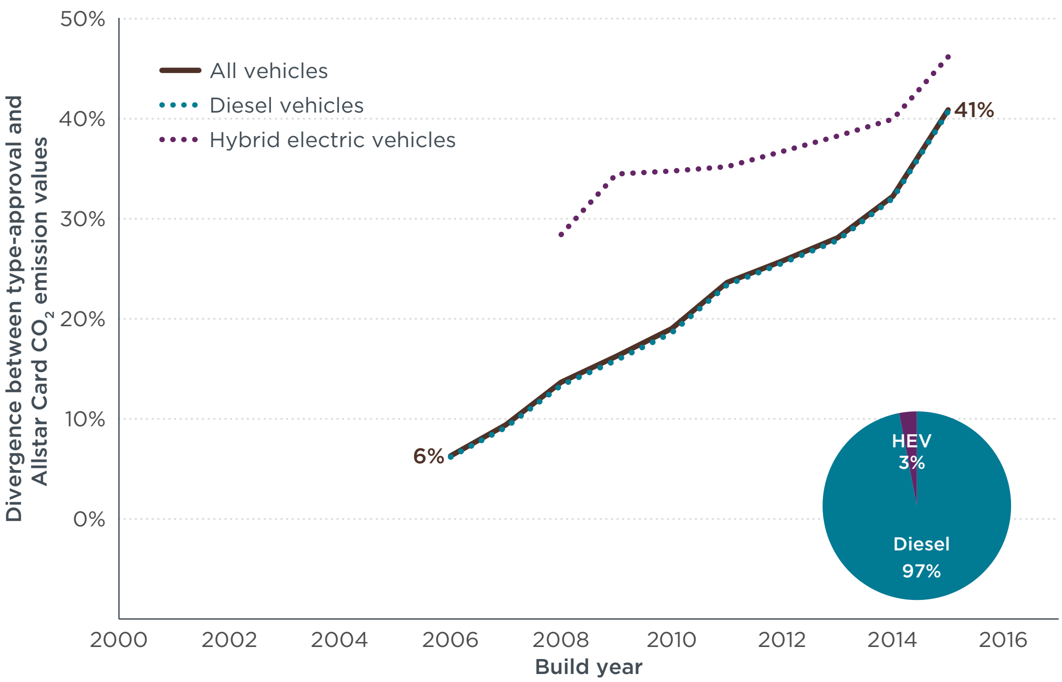

Figure 21. Divergence between type-approval and Allstar CO_2 emission values by fuel type. Pie chart indicates the share of vehicles per power train type in the dataset for 2015.

Figure 22 plots the Allstar divergence estimates by vehicle segment. Small, lower medium, and upper medium vehicles account for roughly 80% of the Allstar dataset and therefore follow the average trend closely. MPVs and the sport segment lie below the average, whereas small vehicles exhibit higher than average gaps until 2014.

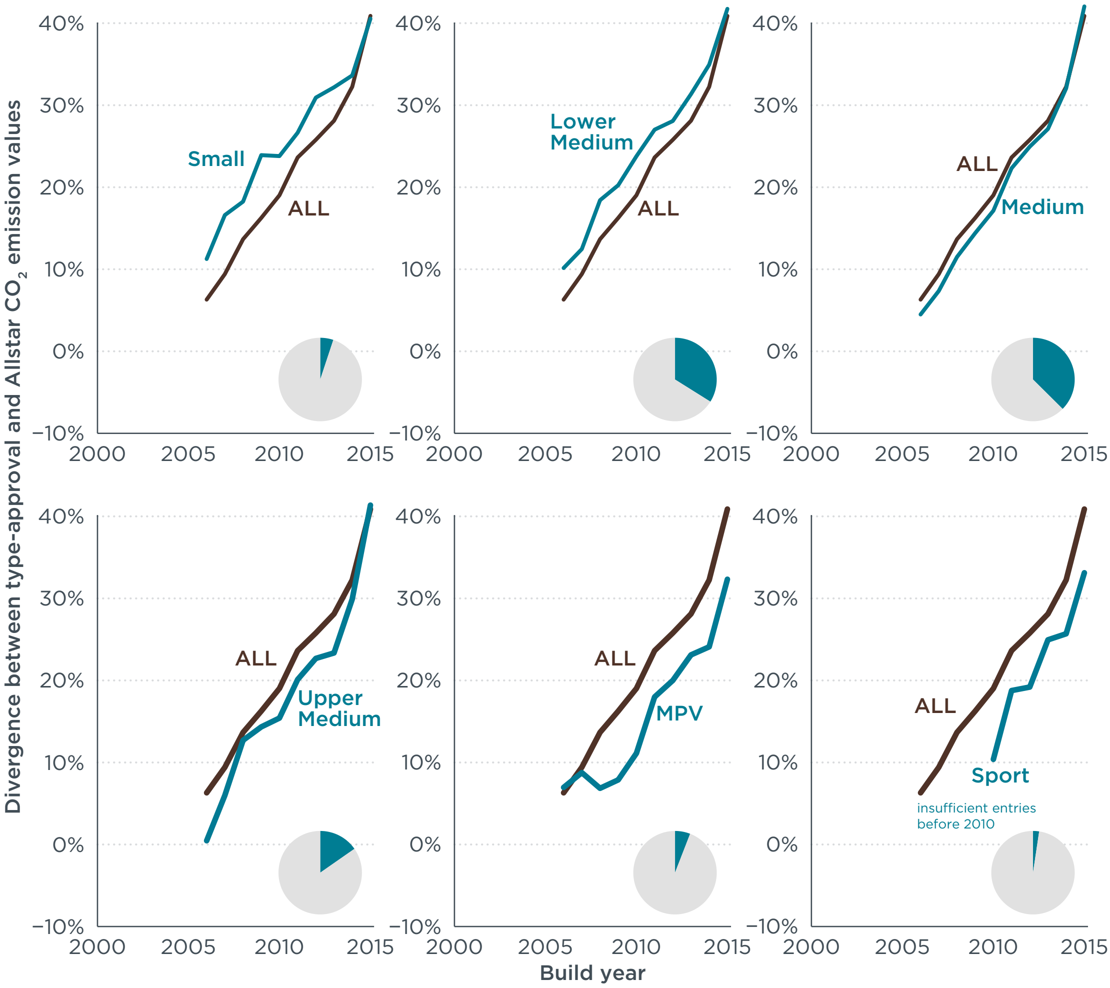

Figure 22. Divergence between type-approval and Allstar fuel card CO_2 emission values by vehicle segment. Pie chart represents the share of vehicles per segment in the dataset for 2015.

2.6 CLEANER CAR CONTRACTS (NETHERLANDS)

Data type	On-road
Data availability	Varies between data sources, typically 2010-2016, roughly 3,300 vehicles per year
Data collection	On-road driving, typically around 30,000 km annual mileage
Fleet structure, driving behavior	Company cars from 16 Dutch fleet owners and leasing companies

Description

The Cleaner Car Contracts initiative was established in 2010 by a number of European NGOs with the objective of introducing more fuel-efficient vehicles in European fleets. It now brings together around 60 leasing companies, fleet owners, and car sharing and rental companies working on fuel-efficient car fleets. Natuur & Milieu,[13] a Dutch environmental organization, and Bond Beter Leefmilieu,[14] a federation of more than 140 environmental associations in Flanders, Belgium, coordinate the initiative. The ICCT has been conducting efficiency benchmarks of Dutch fleets in the Cleaner Car Contracts since 2015 (see Tietge & Backers, 2017).

Methodology

Sixteen member organizations in the Netherlands provided on-road and official fuel consumption values for approximately 39,000 company vehicles, both passenger cars and light commercial vehicles, with model years typically ranging from 2010 to 2016. The 16 datasets were harmonized and merged. Subsequently, anomalous data points were identified using Peirce's criterion.[15] After excluding light commercial vehicles and erroneous or missing data, approximately 23,000 passenger cars were included in this analysis.

Results

Figure 23 shows the average divergence between official and real-world CO_2 emission values for each of the 16 Cleaner Car Contracts fleets, including and excluding PHEVs. The average divergence for the entire fleet reached approximately 54%, 11 percentage points higher than the average divergence excluding PHEVs. The estimates for individual companies, including PHEVs, range from 26% (company C15) to 207% (company C09). Companies with comparatively high divergence values generally have high shares of PHEVs in their fleets. Company C09 stands out with a 207% gap and a 69% PHEV share. In total, PHEVs accounted for roughly 5% of the Cleaner Car Contracts sample.

13 http://www.natuurenmilieu.nl
14 http://www.bondbeterleefmilieu.be/
15 For a description of Peirce's criterion and its application, see Ross (2003).

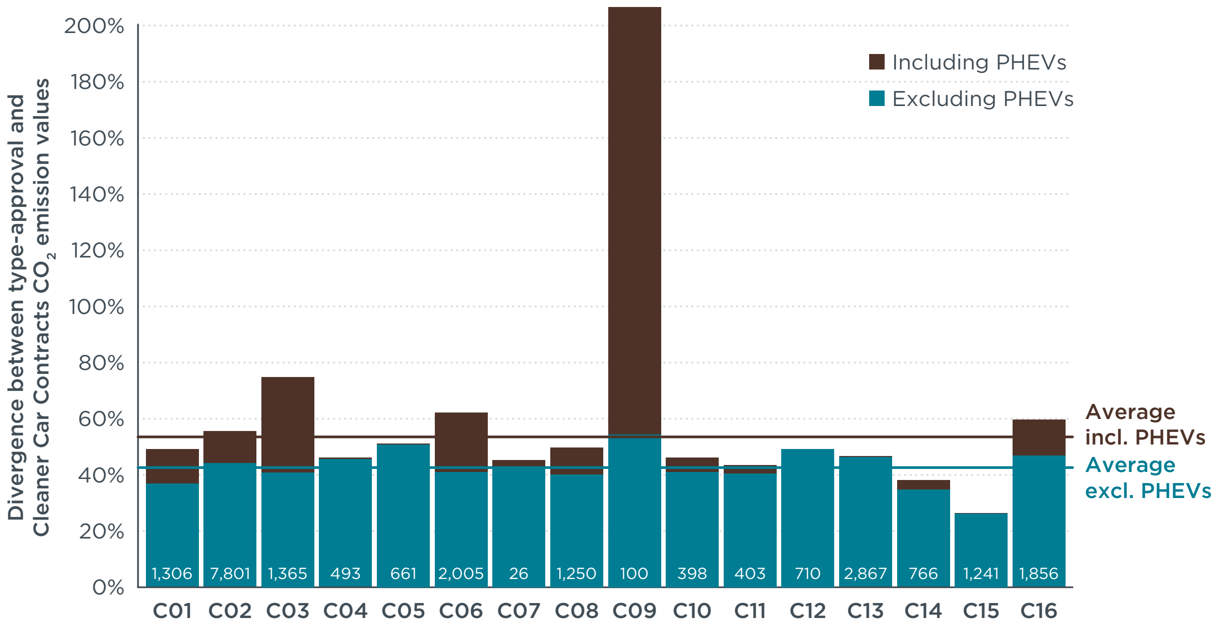

Figure 23. Divergence between type-approval and Cleaner Car Contracts CO_2 emission values. The number of vehicles for each company is at the base of each column.

Figure 24 plots the average divergence for different power trains in the Cleaner Car Contracts sample. Conventional gasoline vehicles exhibit the lowest gap with 29%. Conventional diesel vehicles and HEVs respectively have a gap of roughly 47% and 50%, while PHEVs stand out with an average divergence exceeding 200%. Despite the relatively small share of PHEVs in the fleet, approximately 5%, their high divergence increases the fleet-wide gap by 11 percentage points, from 43% to 54%.

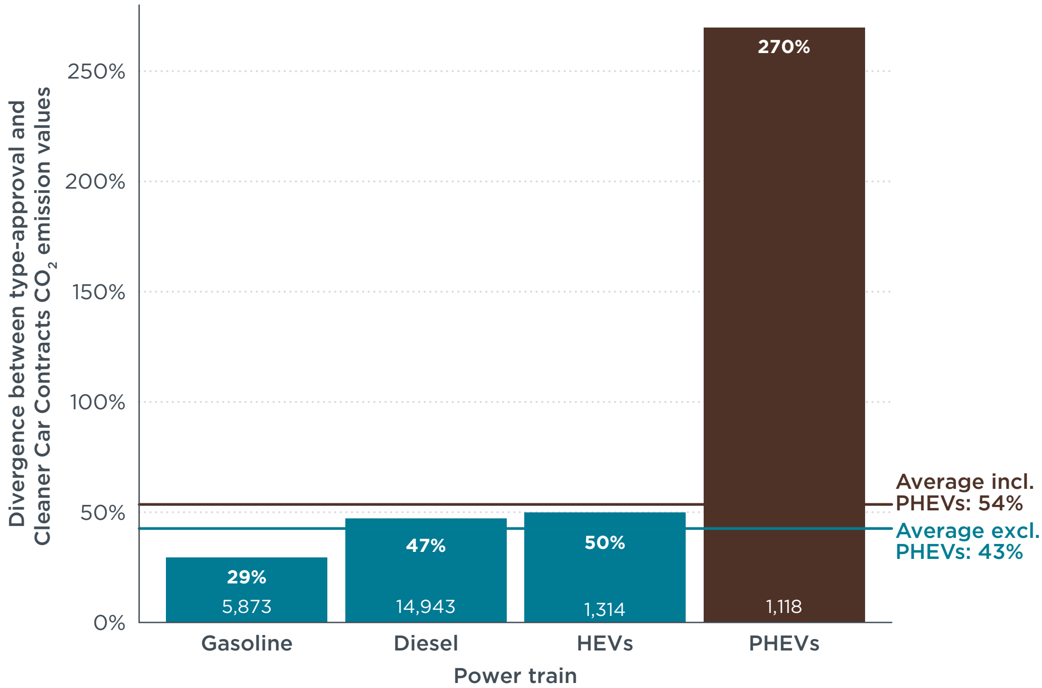

Figure 24. Average divergence between real-world and type-approval CO_2 emission values by vehicle power train for the Cleaner Car Contracts fleet. The number of vehicles per power train is presented at the base of each column.

Figure 25 plots the divergence between type-approval and real-world CO_2 emission values by model year and power train type. The average divergence increased from 27% in model year 2010 to 59% in model year 2016. Excluding PHEVs, the estimates of the divergence range from 27% to 47%. Diesel vehicles account for the majority of the Cleaner Car Contracts dataset (64%) and thus lie close to the average trend (excluding PHEVs). Gasoline cars consistently had divergence values below the fleet average. In model year 2016, their average divergence was 33%, 16 percentage points lower than the diesel average.

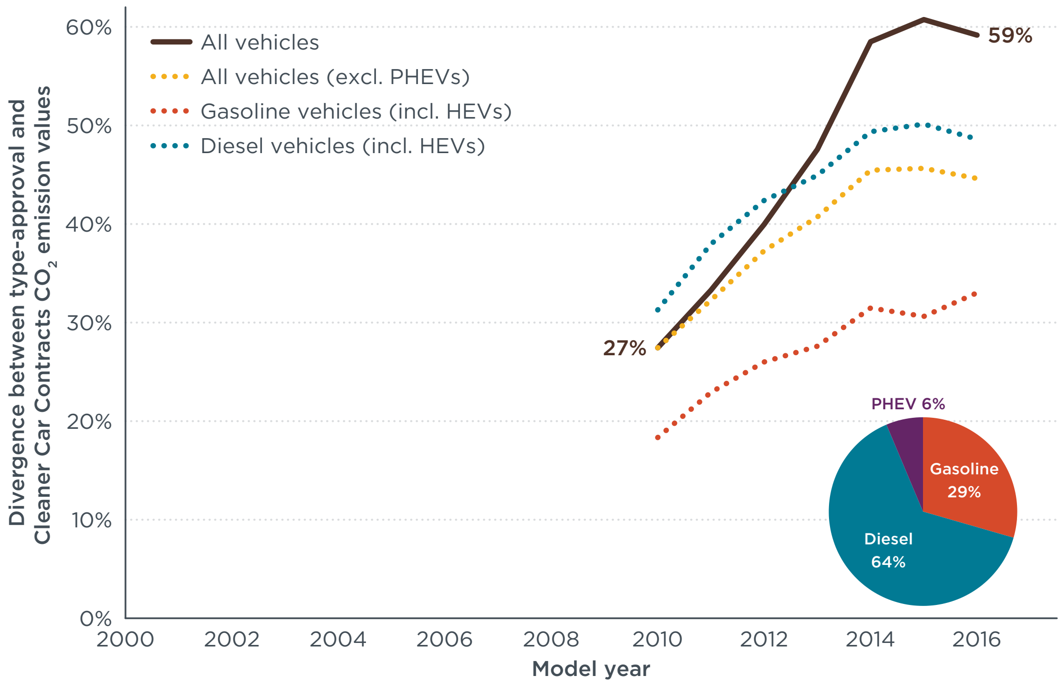

Figure 25. Divergence between type-approval and Cleaner Car Contracts CO_2 emission values by power train type. Pie chart indicates the share of vehicles per power train type in the dataset in 2016.

2.7 CLEANER CAR CONTRACTS (BELGIUM)

Data type	On-road
Data availability	Typically vehicle registration year 2012-2016, roughly 170 vehicles per year
Data collection	On-road driving, typically around 35,000 km annual mileage
Fleet structure, driving behavior	Company cars from two Belgian fleet owners

Description

The ICCT has been conducting fleet efficiency benchmarks for Belgian participants of the Cleaner Car Contracts initiative since 2016. See Section 2.5 for a description of the Cleaner Car Contracts initiative.

Methodology

Two Belgian member organizations of the Cleaner Car Contracts initiative provided on-road and official fuel consumption values for 1,055 company passenger cars. The vehicles were typically first registered between 2012 and 2016. The two datasets were harmonized and merged. Subsequently, anomalous data points were identified using Peirce's criterion.[16] After removing 23 erroneous data points and 197 vehicles with missing data, 835 passenger cars were included in this analysis.

The vast majority (98%) of the Belgian Cleaner Car Contract fleet uses diesel fuel. Vehicles using hybrid electric and plug-in hybrid electric power trains account for the remaining 2% of the fleet. Due to the high share of diesel vehicles, the data were not analyzed by fuel type.

Results

Figure 26 plots the average divergence between Belgian Cleaner Car Contracts and type-approval fuel consumption values for registration years 2012–2016. During this time, the gap increased from 47% to 54%.

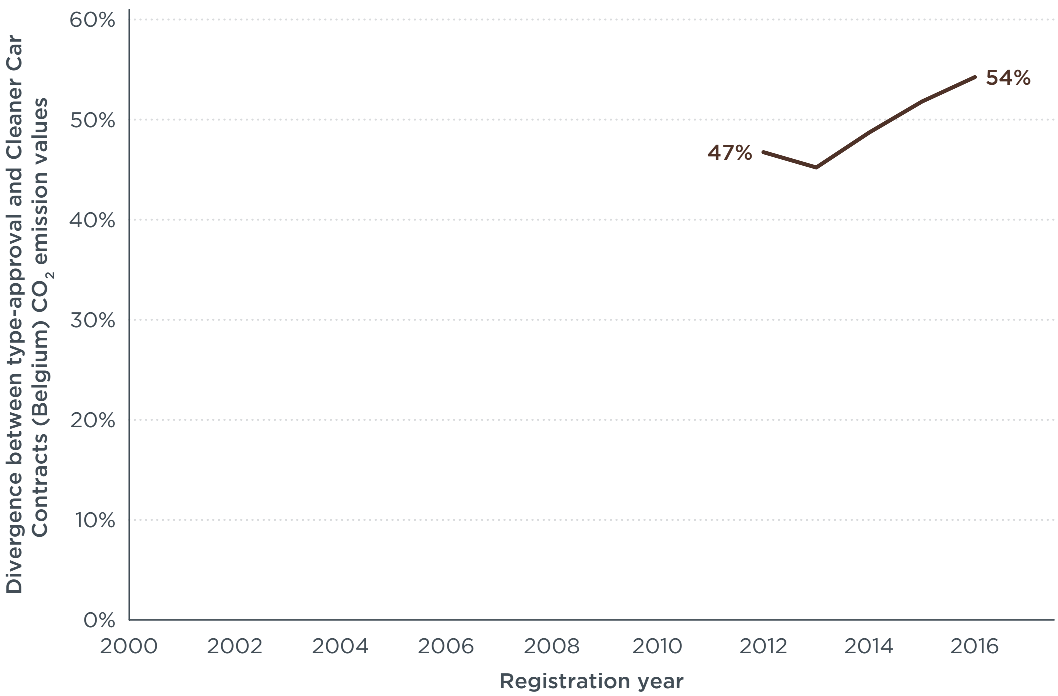

Figure 26. Divergence between type-approval and Cleaner Car Contracts Belgium CO_2 emission values.

16 For a description of Peirce's criterion and its application, see Ross (2003).

2.8 FICHES-AUTO.FR (FRANCE)

Data type	On-road, user-submitted
Data availability	2001-2016, approximately 1,700 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 60,000 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 46,000 user estimates of on-road fuel consumption for more than 400 model variants, with most vehicles ranging from model years 2000 to 2016. 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 (see Mock (ed.), 2016).

After removing entries with missing or inextricable fuel consumption estimates, entries that could not be joined with the ICCT database, and extreme outliers, roughly 27,000 vehicles remained in the sample. The annual number of entries is approximately 1,700 vehicles, though this number drops off to approximately 100 vehicles in model year 2016, as more time needs to 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 27 shows that, while on-road fuel consumption estimates clearly cluster around a central estimate, round numbers tend to be more common than decimal values. This pattern indicates that users estimated or rounded fuel consumption values.

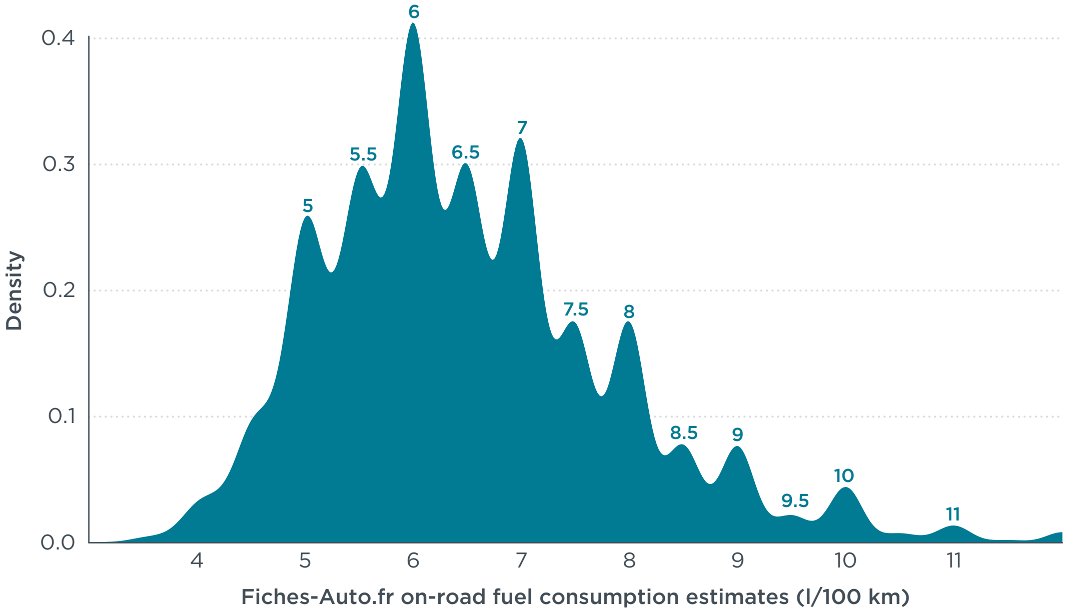

Figure 27. Distribution of on-road fuel consumption estimates by Fiches-Auto.fr users.

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 3 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, though this effect is small compared with the increase in the divergence over time.

Results

Figure 28 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 2016. Due to the comparatively low number of entries for recent models, separate estimates for different power trains are not presented.

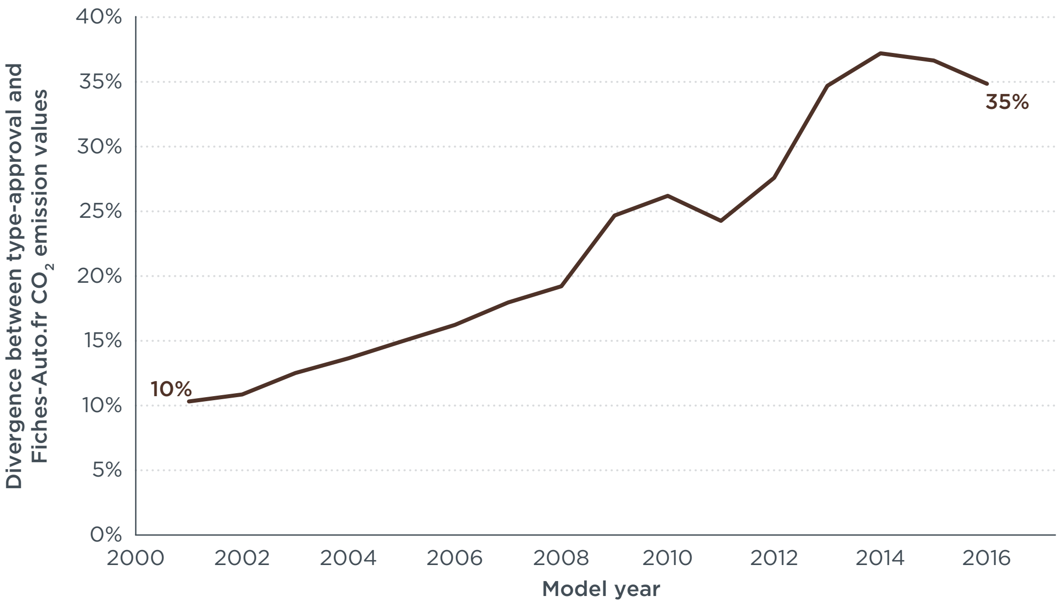

Figure 28. Divergence between type-approval and Fiches-Auto.fr CO_2 emission values.

2.9 *AUTO BILD* (GERMANY)

Data type	On-road, test route
Data availability	2008–2016, approximately 280 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 400,000. 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 2016. Approximately 2,500 vehicles were tested during this time. Official and test fuel consumption values were supplied for each vehicle model.

Results

The average divergence between type-approval and *AUTO BILD* fuel consumption values amounted to 32% in test year 2016. Diesel vehicles consistently exhibited a higher average divergence than gasoline cars. This difference between fuel types approached 5 percentage points in test year 2016. PHEVs significantly raised the average divergence from 2013 to 2016, despite their low numbers (14 in total). This effect was particularly strong in 2016, raising the average by 5 percentage points with five PHEVs tested. On average, PHEVs had gap values exceeding 200%, with a range spanning from 58% to 533%.

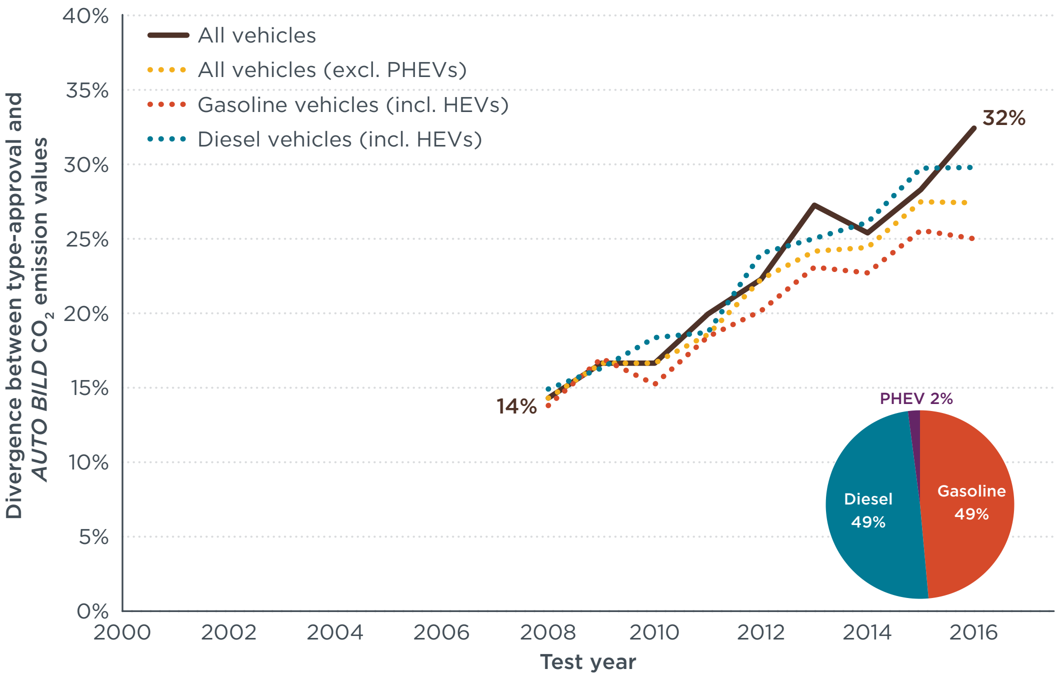

Figure 29. Divergence between type-approval and *AUTO BILD* CO_2 emission values by power train type. Pie chart indicates the share of vehicles per power train type in the dataset for test year 2016.

2.10 EMISSIONS ANALYTICS (UNITED KINGDOM)

Data type	On-road, test route
Data availability	2012–2017, on average 150 vehicles per year, currently testing 200 vehicles or more 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 1,000 new vehicles using a portable emissions measurement system (PEMS). 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.[17]

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 750 vehicles tested between 2012 and 2016. On average, the company tested approximately 150 vehicles per year but is currently testing upwards of 200 vehicles per year.

Results

Figure 30 presents the average annual divergence between real-world and official CO_2 emission values by fuel type. From test year 2012 to 2016, the average divergence increased from 36% to 45%. Excluding PHEVs, the divergence increased from 36% to 39%. PHEVs had a significant impact on the annual average in test years 2014–2016, when up to four PHEVs were tested each year. PHEVs averaged a divergence of 270%.

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

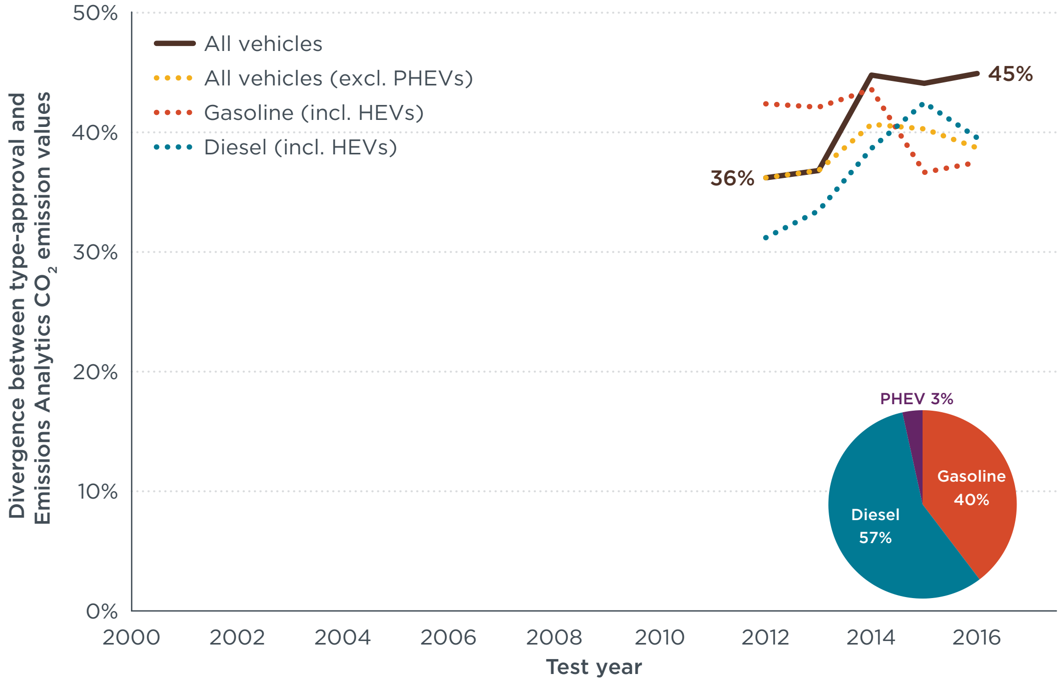

Figure 30. Divergence between type-approval and Emissions Analytics CO_2 emission values by fuel type. Pie chart indicates the share of vehicles per fuel type in the dataset in test year 2016.

2.11 *AUTO MOTOR UND SPORT* (GERMANY)

Data type	On-road, test route
Data availability	2003–2016, approximately 170 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[18] is a bi-weekly, 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 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 2,400 vehicles tested between 2003 and 2016.

Results

Figure 31 presents the annual divergence between *auto motor und sport* and type-approval CO_2 emission values. The average divergence was 46% in test year 2016, virtually unchanged from 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 2016.

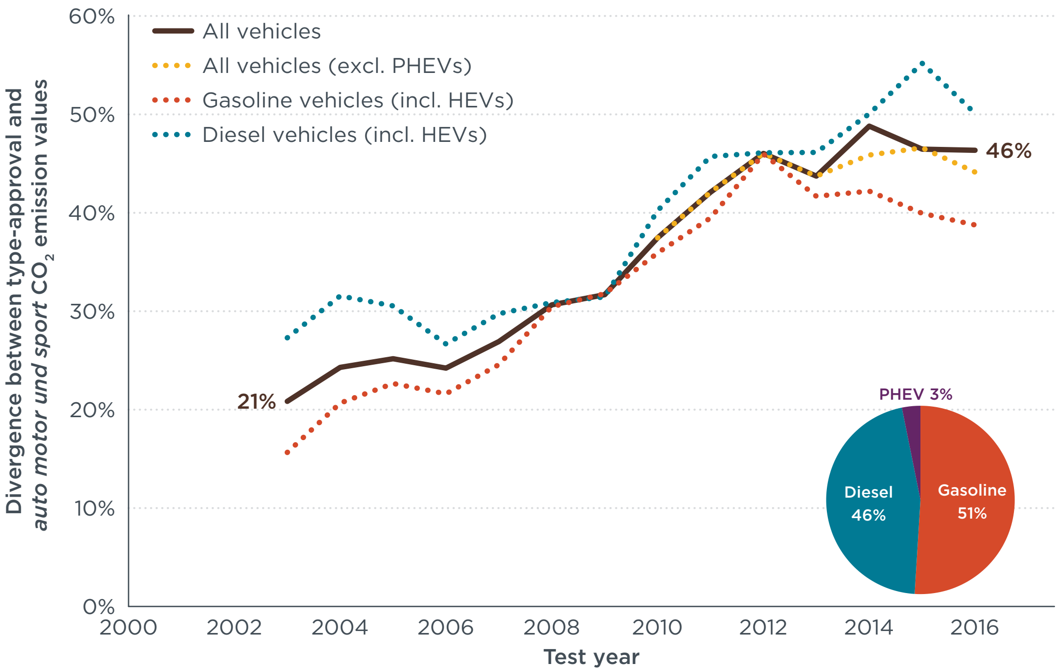

Figure 31. Divergence between type-approval and *auto motor und sport* CO_2 emission values by fuel type. Pie chart indicates the share of vehicles per fuel type in the dataset for test year 2016.

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

2.12 *AUTO MOTOR & SPORT* (SWEDEN)

Data type	On-road, test route
Data availability	2009–2016, 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[19] 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 distance and cover all typical speeds on Swedish roads (30 to 120 km/h). Fuel consumption is estimated by filling up 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 750 vehicles between 2009 and 2016 were provided by *auto motor & sport*. The data included both official and test fuel consumption values.

Results

Figure 32 shows the trend in the divergence between type-approval and *auto motor & sport* CO_2 emission values by power train type. The average gap between real-world and type-approval CO_2 emissions increased from 20% in test year 2009 to 47% in test year 2016. As shown in the figure, the divergence decreased from 2015 to 2016. This decrease is due to PHEVs: In 2015, PHEVs accounted for 7% of all vehicles tested, while this number declined to 4% in 2016. PHEVs typically have particularly high divergence values, approximately 240%. Excluding PHEVs, the average divergence increased from 2015 to 2016 and nearly doubled from 2009 (20%) to 2016 (39%).

19 http://www.automotorsport.se/

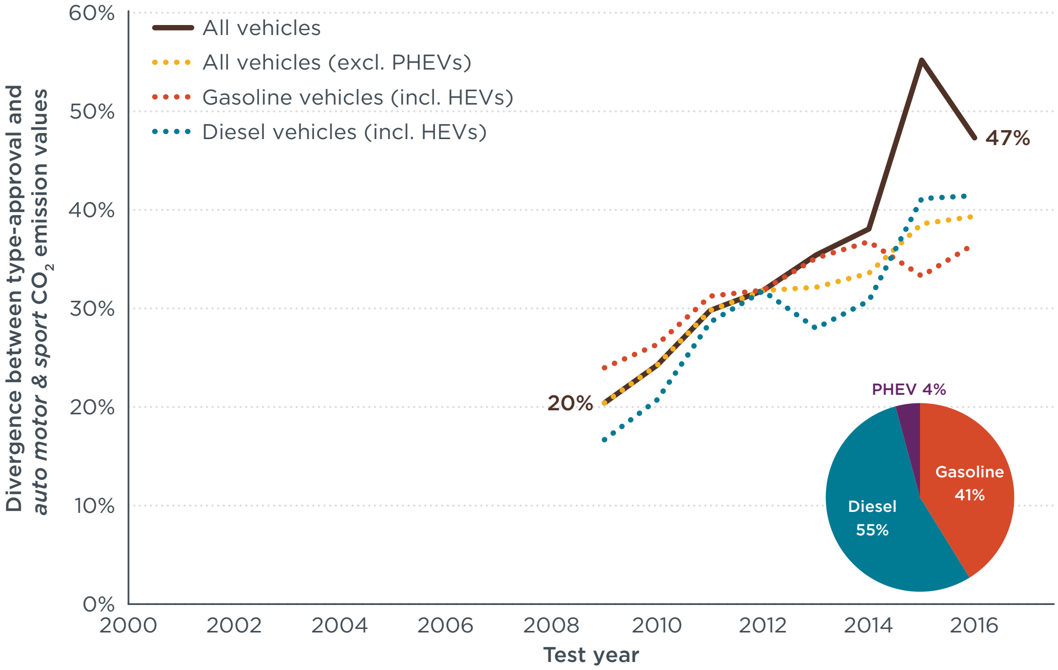

Figure 32. Divergence between type-approval and *auto motor & sport* CO_2 emission values by power train type. Pie chart shows the share of vehicles per power train type in the dataset in test year 2016.

2.13 KM77.COM (SPAIN)

Data type	On-road, test route
Data availability	2010–2016, approximately 50 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 (GPS).

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 100 km/h from the 120 km/h used in preceding years. The measurements using a maximum speed of 100 km/h are marked as "new methodology" in the results.

Methodology

The data provided by km77.com ranged from test year 2010 to test year 2016 and included real-world fuel consumption figures from approximately 350 vehicles. The official type-approval fuel consumption values were retrieved from the km77.com website.

Results

Figure 33 plots the divergence between km77.com measurements and type-approval fuel consumption values. The divergence increased from 37% in 2010 to 47% in 2016. PHEVs, which account for less than 2% of the km77.com sample, exhibit a significantly higher divergence than conventional vehicles, on average exceeding 300%. PHEVs consequently have a large impact on the average gap despite their low numbers.
For model year 2016, results for the new and old methodology (maximum speed of 100 km/h and 120 km/h, respectively) are presented separately. Only vehicles with both measurements were presented for model year 2016, leaving 16 vehicles. On average, the new methodology reduces the gap by 17 percentage points.

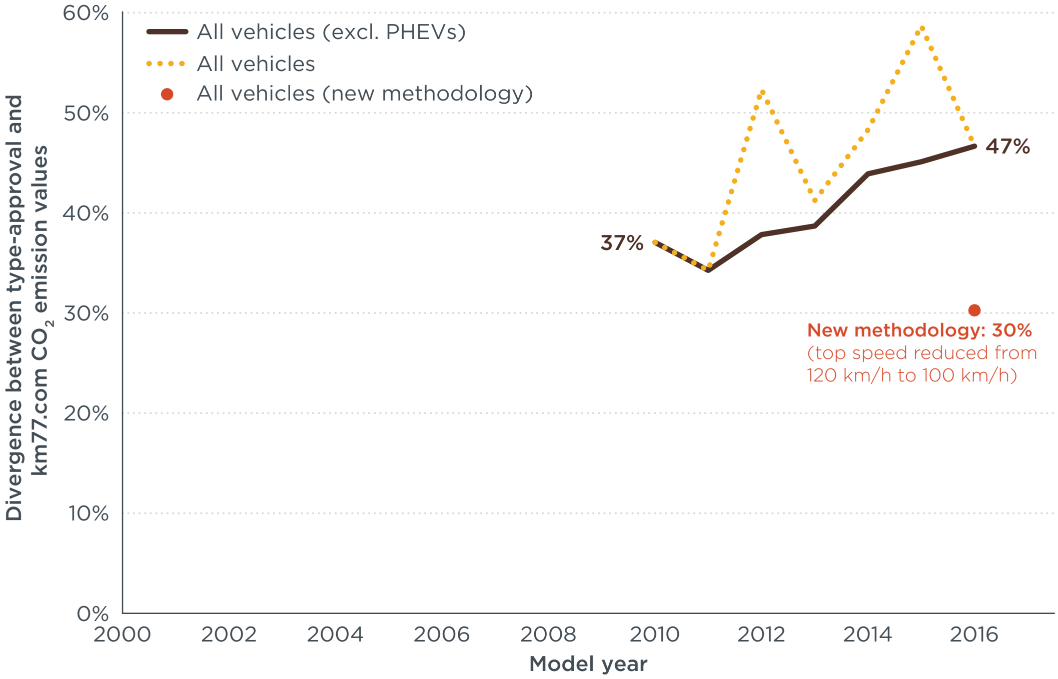

Figure 33. Divergence between type-approval and km77.com CO_2 emission values by fuel type.

2.14 TOURING CLUB SCHWEIZ (SWITZERLAND)

Data type	On-road
Data availability	1996–2016, 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. Approximately 20 of the most popular vehicle models in the Swiss market are selected for testing each year. In 2016, the sample consisted of seven diesel and seven gasoline 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 34 shows the trend in the divergence between real-world and type-approval fuel consumption from test years 1996 to 2016. 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 almost 40 percentage points over the past two decades.

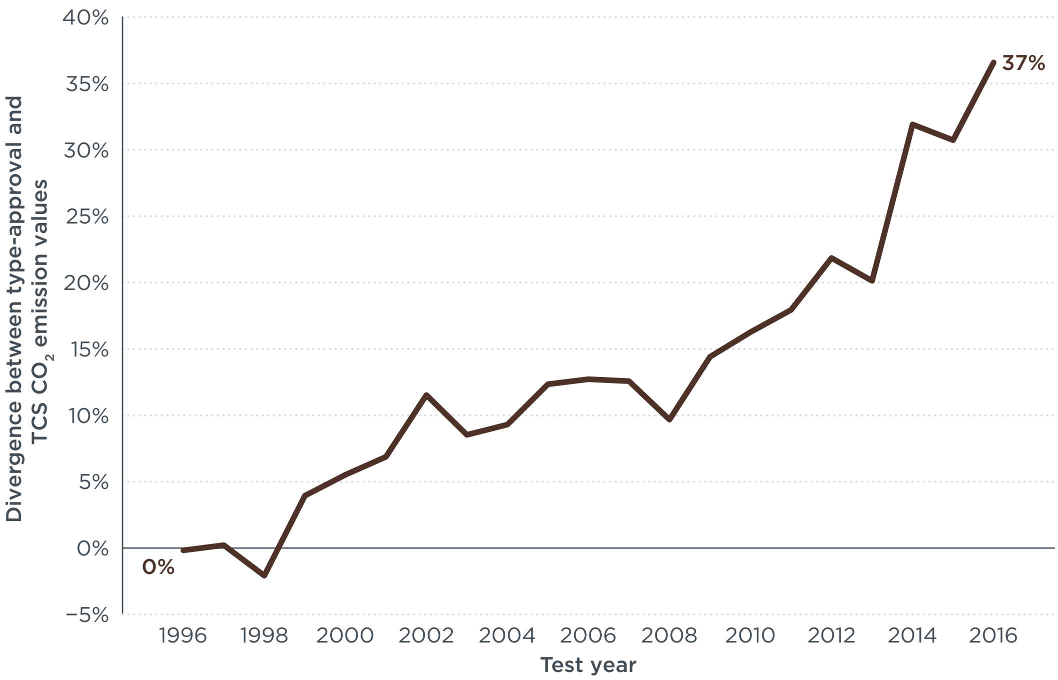

Figure 34. Divergence between type-approval and TCS CO_2 emission values.

3. DATA COMPARISON

Table 1 provides an overview of the data sources used in this study. The analysis covered a total of 14 sources from eight European countries, which together provided real-world CO_2 emission values for more than 1.1 million passenger cars.

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

Source	Country	Total vehicles	Vehicles per year (avg.)	Mostly company cars	Dating convention
Spritmonitor.de	Germany	148,304	~9,000		Build year
Travelcard	Netherlands	308,020	~26,000	X	Build year
LeasePlan	Germany	~250,000	~25,000	X	Fleet year
Allstar card	U.K.	242,353	~24,000	X	Build year
HonestJohn.co.uk	U.K.	124,829	~8,000		Model year
Cleaner Car Contracts	Netherlands	22,601	~3,300	X	Model year
Fiches-Auto.fr	France	27,001	~1,700		Model year
AUTO BILD	Germany	2,490	~280		Test date
auto motor und sport	Germany	2,395	~170		Test date
Cleaner Car Contracts	Belgium	835	~170	X	Registration date
Emissions Analytics	U.K.	752	~150		Test date
auto motor & sport	Sweden	762	~90		Test date
km77.com	Spain	346	~50		Test date
TCS	Switzerland	285	~20		Test date
Total	**-**	**1,130,973**	**~71,000**		**-**

Annual average divergence

Figure 35 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 9% in 2001, they ranged from 32% to 59% in 2016. 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 2016, divergence estimates from company car samples ranged from 44% (LeasePlan) to 59% (Cleaner Car Contracts Netherlands). The Cleaner Car Contracts Netherlands sample delivered the highest divergence estimates in recent years due to comparatively high shares of PHEVs. Together, company cars account for about 71% of the vehicles analyzed in the report.

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), 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 47% in year 2016), 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 the highest 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.

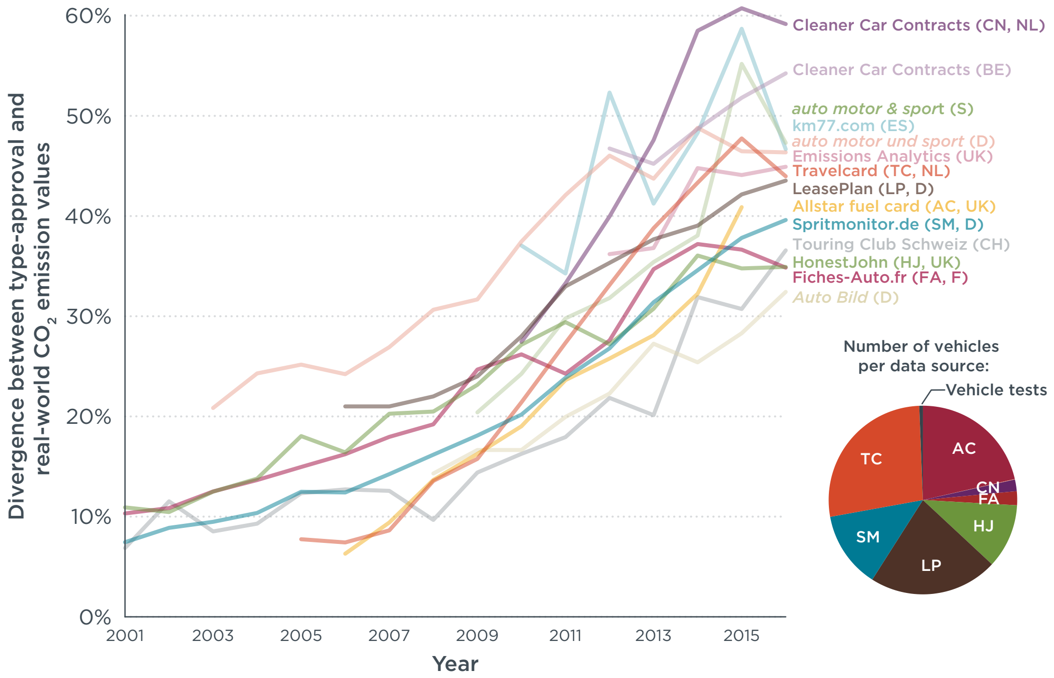

Figure 35. Divergence between type-approval and real-world CO_2 emission values for various on-road data sources.

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 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 also employed vehicle build year, while HonestJohn.co.uk, Cleaner Car Contracts Netherlands, 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 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 36 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 9% in 2001 to 42% in 2016, virtually unchanged from the 2016 *From Laboratory to Road* study. The difference between company and private cars gradually increased in recent years and amounted to about 6 percentage points in 2016.

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 36 provides strong evidence that type-approval CO_2 emission values grew increasingly unrepresentative over time, although 2016 data indicates that the growth in the gap may be leveling off. 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.

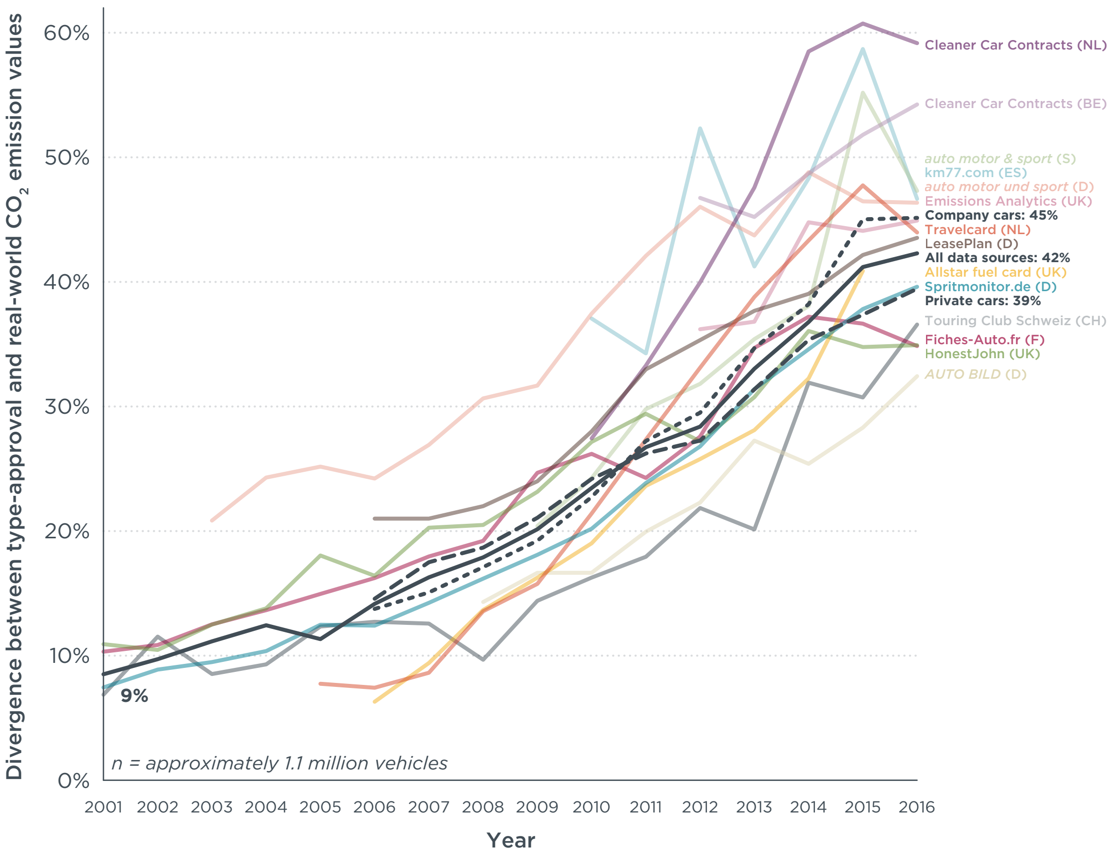

Figure 36. Divergence between real-world and manufacturers' type-approval CO_2 emission values for various on-road data sources, including average estimates for private cars, company cars, and all data sources combined.

4. DISCUSSION OF RESULTS

This 2017 update of the *From Laboratory to Road* series adds another year of data, one new data source, and more than 100,000 vehicles to the ongoing analysis. The central estimate has more than quadrupled since 2001, but 2016 indicates that the growth of the gap may be slowing. Even though the precise level of the divergence varies from sample to sample, the historical upward trend is consistent across all 14 data sources. The heterogeneity of the data—collected from consumers, company fleets, and vehicle tests—and the considerable regional coverage—spanning eight European countries—indicates that the findings are valid and generalizable.

The growing divergence is well-documented at this point, and some studies explore the reasons for this development. Although a detailed discussion of the reasons is outside the scope of this study, the following sections briefly discuss several contributing factors.

Decreasing type-approval values

A common misconception is that the increase of the divergence is primarily due to the reduction of type-approval CO_2 values over time, which makes any difference between real-world and type-approval values appear proportionally larger. This argument presupposes that at least part of the gap consists of some constant offset, which remains stable as type-approval values decrease. However, Figure 37 shows that the average difference between type-approval and real-world CO_2 values has not remained constant over time but increased from 12 to 49 g/km according to Spritmonitor.de data. This increase implies that, even if type-approval CO_2 emission values had remained constant from 2001, the gap would still have increased significantly, from 7% in 2001 to 29% in 2016 (see Figure 38).

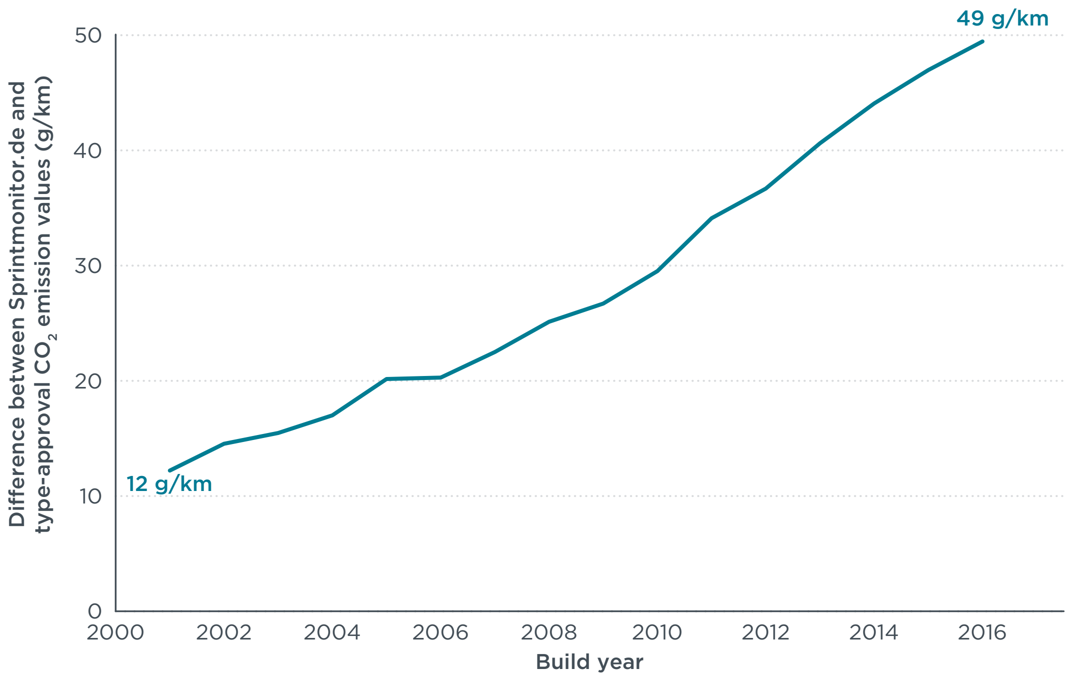

Figure 37. Average difference between real-world and type-approval CO_2 emission values observed in Spritmonitor.de data.

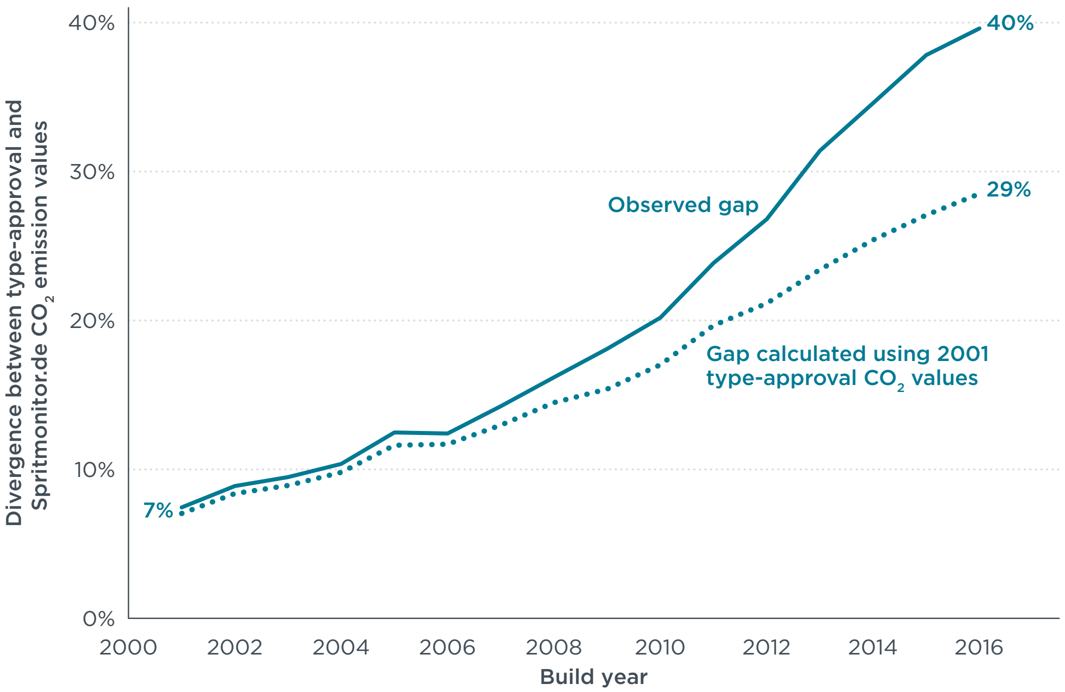

Figure 38. Divergence between real-world and type-approval CO_2 emission values holding constant type-approval CO_2 values.

Driving Behavior

Driving behavior is also purported to be a reason for the growing divergence, but the data do not support this claim. Figure 39 plots the divergence for different driving styles, including economical, balanced, and speedy driving, according to Spritmonitor.de data. The driving styles are based on self-reported information from users of the web service. The figure indicates that driving behavior indeed affects the divergence: economical driving on average reduces the gap by 7 percentage points compared with balanced driving, while speedy driving increases the gap by 9 percentage points, on average. However, all driving styles saw an *increase* in the gap over time, and shares of the different driving styles remained fairly constant. The Spritmonitor.de data thus provides no evidence for the claim that driving behavior is the leading cause of the growing divergence, although it is conceivable that exogenous factors (e.g., increased speed limits, increased vehicle performance, increased opportunity costs of driving) could contribute to the gap.

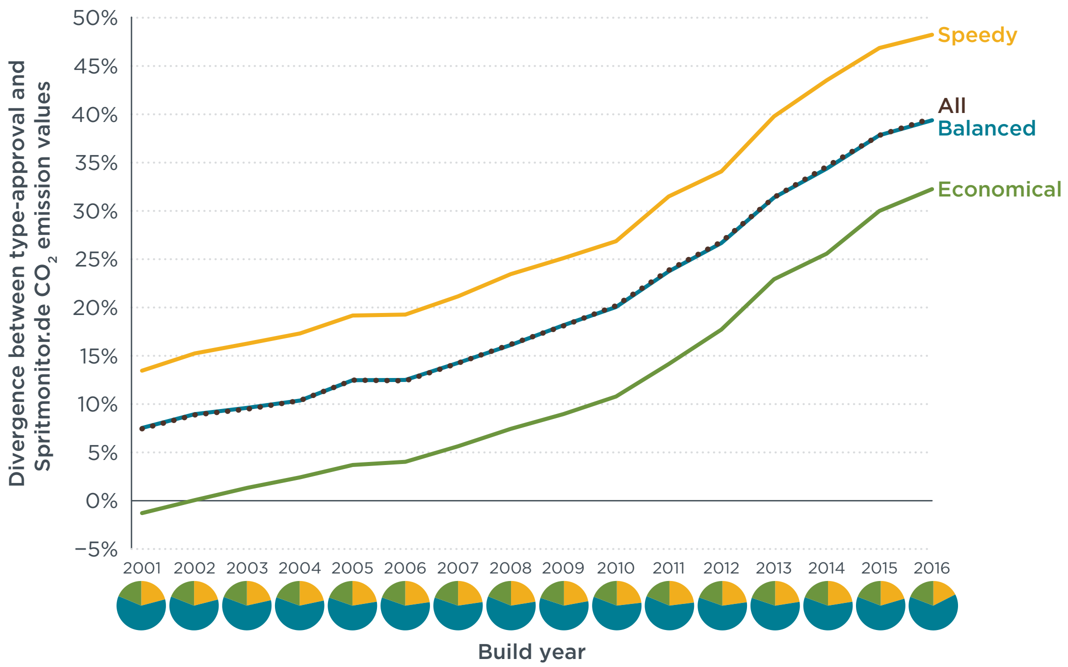

Figure 39. Divergence between Spritmonitor.de and type-approval CO_2 emission values for different driving styles, including economical, balanced, and speedy driving. Pie charts present the user share of driving styles per year.

Vehicle technologies

Many new technologies penetrated the vehicle market during the 2001 to 2016 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 2.5 for example), although it should be noted that real-world CO_2 emissions are strongly affected by charging patterns (see Ligterink & Smokers, 2015).

Another change that contributes to the gap is the increasing use of ethanol blends and biodiesel in vehicles. Ethanol blends E5 and E10 (5% and 10% ethanol share respectively) made up more than 80% of all gasoline sold in the EU in 2014, while B7 (7% biodiesel share) accounted for virtually all diesel sold in the same year (EEA, 2015). These blends have a lower volumetric energy density than conventional fuels, so vehicles consume more fuel as the share of ethanol and biodiesel increases. Since most of the real-world data in this analysis relies on fuel consumption measurements (as opposed to CO_2 emission measurements), this could lead to an inflation of the divergence estimate. However, since modern reference fuels for type approval include common ethanol and biodiesel blends (see European Commission, 2014), only older vehicles should be affected, implying that the estimates presented in this study may underestimate the growth in the divergence.

Vehicle testing and policy framework

A number of studies indicate that test cycle optimization and the exploitation of loopholes in the 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.

Numerous systemic flaws in the European type-approval framework enable the exploitation of loopholes during vehicle testing. For one, road load coefficients are not verified by regulators—and they are not even available to the public (Kühlwein, 2016; Mellios et al., 2011). Second, on-road testing, used to verify air pollutant emissions under the Real Driving Emissions (RDE) procedure, has not been extended to CO_2 emissions. Similarly, European regulators do not conduct in-use tests of production vehicles. Together, on-road and in-use testing could help identify irregularities in stated CO_2 emission values. Third, car manufacturers pay technical service companies to conduct type-approval tests. Technical service companies therefore have an incentive to produce favorable test results to attract business from car manufacturers (Mock & German, 2015). Lastly, European regulators do not have the authority to revoke type-approval certificates and to impose fiscal penalties in case of noncompliance. Taken together, the European type-approval framework provides opportunities for car manufacturers to exploit loopholes in vehicle testing procedures.

Limitations

This study covers 14 data 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, data presented in this study do not indicate that users of web services are prone to extremely economical or speedy driving, but tend to gravitate to balanced driving styles (see Figure 39). Shares of different driving styles also remained stable over time, indicating that any bias in the sample selection remained stable over time, rendering the trend in divergence estimates valid. Nevertheless, data on driving styles and driving conditions was not available for all samples, and the distribution of driving style in the general population is unknown, as is the accuracy of self-reported information on driving styles, so the potential for self-selection bias remains. 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 the 14 samples paints a clear picture of a growing gap between type-approval and real-world CO_2 emission values. The fact that 14 heterogeneous samples from eight European countries all show an increase in the gap over time indicates that this trend is robust.

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 16 years, from 170 g/km of CO_2 in 2001 to 118 g/km in 2016. 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 growing gap has important implications for all stakeholders.

From a **government's perspective**, the growing 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 incur increasing losses in tax revenue. Fiscal incentives for low-carbon vehicles may also 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.[20]

From a **societal perspective**, the growing divergence undermines the EU's efforts to mitigate climate change and to reduce fossil fuel dependence. Figure 40 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 118 g/km in 2016, a 30% decrease, the real-world estimate decreased by less than 10% and has stagnated since 2010.

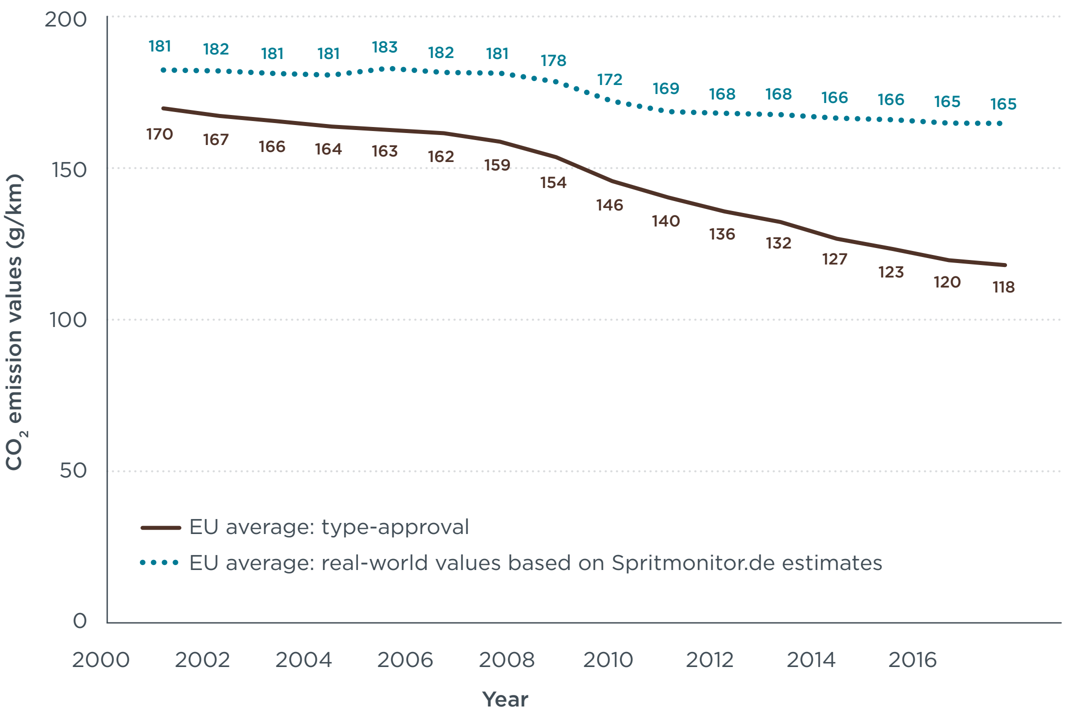

Figure 40. Real-world versus type-approval CO_2 emission values of new European passenger cars based on Spritmonitor.de estimates and type-approval data from the European Environment Agency (EEA, 2016).

20 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 are also largely reflected in a recent statement 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 more than 1.1 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.[21] A similar service could be established in Europe to measure real-world policy impacts. Other methods of data collection, such as the use of data loggers, could also furnish estimates of on-road fuel consumption (see Posada & German, 2013).

This 2017 update of the *From Laboratory to Road* series for the first time indicates that the growth of the gap between real-world and NEDC CO_2 values may be slowing. Future research should establish whether 2016 in fact signaled a change in the trend and, if so, the underlying reasons. Potential reasons include: reduced pressure on vehicle manufacturers to produce low type-approval CO_2 emission values in 2016 after the 2015 CO_2 target was met; vehicle manufacturers shifting focus to the WLTP after its introduction in 2017; changes in the vehicle market that may affect the gap (see Section 2.2); and increasing pressure on vehicle manufacturers to produce more realistic CO_2 emission figures. Empirical data on the divergence between real-world and WLTP CO_2 emission values will also be needed to safeguard regulations from a growing gap under the new type-approval procedure.

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 implemented policies to incentivize their uptake (Tietge, Mock, Lutsey, & Campestrini, 2016). This study and other research (e.g., Ligterink & Smokers, 2015) indicate that PHEVs substantially exceed type-approval CO_2 emission values during real-world driving, with divergence estimates frequently exceeding 200%, predominantly due to low electric-drive shares. While data on PHEVs is abundant in the Netherlands, less data is available for other markets. Future research should focus on collecting real-world fuel consumption data for PHEVs to gauge the extent of the problem. 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 may also 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

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

predicted to grow (Muncrief & Sharpe, 2015). More research on real-world CO_2 emissions of light commercial and heavy-duty vehicles is warranted.

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. Such simple approaches could be used to present more realistic point estimates of fuel consumption figures to consumers.

The real-world gap should be taken into account in research and policies related to road transportation. For instance, because a large portion of the improvements in vehicle efficiency only occur on paper and not in the real world, the growing divergence dilutes the benefits from European CO_2 standards. Although the impact assessment accompanying the 2021 CO_2 standards acknowledges the divergence, it used a comparatively low and outdated adjustment factor of 19.5% to account for the gap (European Commission, 2012a, 2012b). Using a realistic, up-to-date correction factor in future rulemakings—or instituting a mechanism for updating the correction factor as the gap develops—could ensure that CO_2 standards correctly value the costs and benefits associated with target levels.

The foregoing recommendations focus on measuring vehicles' real-world performance, communicating it to consumers, and incorporating it during policy formation, but there are also numerous measures to close 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 and will increase again in future years (Stewart et al., 2015). Additional vehicle testing will be required to ensure real-world compliance of vehicles. For instance, on-road tests for pollutant emissions under the RDE regulation could be extended to CO_2 emissions. Similarly, in-use conformity testing of CO_2 emissions could ensure that production vehicles conform to declared values.

Lastly, a reform of the European type-approval framework is necessary. This reform should provide public access to road load coefficients and resolve other issues of data transparency. Reform should also break financial ties between car manufacturers and the organizations that conduct type-approval tests. Furthermore, more rigorous policy enforcement would act as a deterrent to the exploitation of loopholes in the type-approval process, and European regulators need the power to issue vehicle recalls and impose fiscal penalties for transgressions. A proposal by the European Commission (2016b) addresses some of these issues, but will not in itself be enough to reform the type-approval framework.

The European Commission recognizes the gap between real-world and type-approval CO_2 emission values and the problem that it presents, and its Scientific Advice Mechanism findings (2016) underline the urgent need to reduce real-world CO_2 emissions.

REFERENCES

EEA. (2015). *EU fuel quality monitoring 2014: Summary report* (Publication). European Environment Agency. Retrieved from http://www.eea.europa.eu/publications/eu-fuel-quality-monitoring-2014

EEA. (2016). Monitoring of CO2 emissions from passenger cars - Data — European Environment Agency [Data Table]. Retrieved November 1, 2016, from http://www.eea.europa.eu/data-and-maps/data/co2-cars-emission/monitoring-of-co2-emissions-from

European Commission. (2012a). *Impact assessment accompanying the documents proposal for a regulation of the European Parliament and of the Council amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars - part I*. Retrieved from http://eur-lex.europa.eu/resource.html?uri=cellar:70f46993-3c49-4b61-ba2f-77319c424cbd.0001.02/DOC_2&format=PDF

European Commission. (2012b). *Impact assessment accompanying the documents proposal for a regulation of the European Parliament and of the Council amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars - part II*. Retrieved from http://eur-lex.europa.eu/resource.html?uri=cellar:70f46993-3c49-4b61-ba2f-77319c424cbd.0001.02/DOC_1&format=PDF

European Commission. (2014). *Commission Regulation (EU) No 136/2014*. European Commission. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014R0136&from=EN

European Commission. (2016a). *A European strategy for low-emission mobility*. Brussels: European Commission. Retrieved from https://ec.europa.eu/transport/themes/strategies/news/2016-07-20-decarbonisation_en

European Commission. (2016b). *Proposal for a regulation of the European Parliament and of the Council on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles*. Brussels: European Commission. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1453996101816&uri=COM:2016:31:FIN

European Commission Scientific Advice Mechanism. (2016). *Closing the gap between light-duty vehicle real-world CO2 emissions and laboratory testing.* Retrieved from https://ec.europa.eu/research/sam/pdf/sam_co2_emissions_report.pdf

Greene, D. L., Khattak, A., Liu, J., Hopson, J. L., Wang, X., & Goeltz, R. (2015). *How do motorists' own fuel economy estimates compare with official government ratings? A statistical analysis* (Baker Reports No. 4:15). Knoxville: The Howard H. Baker Jr. Center for Public Policy. Retrieved from http://bakercenter.utk.edu/wp-content/uploads/2015/09/BR_Greene_4-15.pdf

Harrison, P. (2017). *Low-carbon cars in Germany: A summary of socio-economic impacts*. Retrieved from https://www.camecon.com/how/our-work/low-carbon-cars-in-germany/

Kadijk, G., Verbeek, M., Smokers, R., Spreen, J., Patuleia, A., van Ras, M., … Buttigieg, D. (2012). *Supporting analysis regarding test procedure flexibilities and technology deployment for review of the light duty vehicle CO2 regulations* (No. 033.22993). TNO. Retrieved from https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/cars/docs/report_2012_en.pdf

Kok, R. (2011). The effects of CO2-differentiated vehicle tax systems on car choice, CO2 emissions and tax revenues. Presented at the European Transport Conference, Glasgow, United Kingdom: Association for European Transport. Retrieved from http://abstracts.aetransport.org/paper/index/id/3686/confid/17

Kühlwein, J. (2016). *Official vs. real-world road-load parameters in EU vehicle efficiency testing*. Retrieved from The International Council on Clean Transportation, http://www.theicct.org/effect-roadload-coeffs-co2-emissions-eu

Ligterink, N. E., & Smokers, R. T. M. (2015). *Monitoring van plug-in hybride voertuigen (PHEVs) april 2012 t/m maart 2015*. Retrieved from http://repository.tudelft.nl/view/tno/uuid%3A72869589-afaf-41a9-9e1a-2dd0d0f05061/

Ligterink, N. E., & Smokers, R. T. M. (2016). *Monitoring van plug-in hybride voertuigen (PHEVs) april 2012 t/m maart 2016*. TNO. Retrieved from http://publications.tno.nl/publication/34622243/22jtHB/TNO-2016-R10938.pdf

Ligterink, N. E., Smokers, R. T. M., Spreen, J., Mock, P., & Tietge, U. (2016). *Supporting analysis on real-world light-duty vehicle CO2 emissions* (No. TNO 2016 R10419v3). TNO. Retrieved from https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/analysis_ldv_co2_emissions_en.pdf

Mellios, G., Hausberger, S., Keller, M., Samaras, C., & Ntziachristos, L. (2011). *Parametrization of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes.* Joint Research Centre, Luxembourg, European Commission.

Mock (ed.), P. (2016). *European vehicle market statistics – Pocketbook 2016/17*. Retrieved from The International Council on Clean Transportation, http://www.theicct.org/sites/default/files/publications/ICCT_Pocketbook_2016.pdf

Mock, P., & German, J. (2015). *The future of vehicle emissions testing and compliance*. Retrieved from The International Council on Clean Transportation, http://theicct.org/future-of-vehicle-testing

Mock, P., German, J., Bandivadekar, A., Riemersma, I., Ligterink, N., & Lambrecht, U. (2013). *From laboratory to road – A comparison of official and "real-world" fuel consumption and CO_2 values for cars in Europe and the United States*. Retrieved from The International Council on Clean Transportation, http://theicct.org/laboratory-road

Muncrief, R., & Sharpe, B. (2015). *Overview of the heavy-duty vehicle market and CO2 emissions in the European Union*. Retrieved from The International Council on Clean Transportation, http://www.theicct.org/overview-heavy-duty-vehicle-market-and-co2-emissions-european-union

Næss-Schmidt, H. S., & Winiarczyk, M. (2010). *Company car taxation: subsidies, welfare and environment*. Luxembourg: EUR-OP.

Ntziachristos, L., Mellios, G., Tsokolis, D., Keller, M., Hausberger, S., Ligterink, N., & Dilara, P. (2014). In-use vs. type-approval fuel consumption of current passenger cars in Europe. *Energy Policy*, *67*, 403–411. https://doi.org/10.1016/j.enpol.2013.12.013

Posada, F., & German, J. (2013). *Measuring in-use fuel economy: Summary of pilot studies*. Retrieved from The International Council on Clean Transportation, http://www.theicct.org/measuring-in-use-fuel-economy-summary-pilot-studies

Ross, S. M. (2003). Peirce's criterion for the elimination of suspect experimental data. *Journal of Engineering Technology*, *20*(2), 38–41.

Şenzeybek, M., Tietge, U., & Mock, P. (2017). *CO2 emissions from new passenger cars in the EU: Car manufacturers' performance in 2016*. Retrieved from The International Council on Clean Transportation, http://theicct.org/co2-emissions-new-PV-EU-OEM-performance-2016

Sharpe, B., & Muncrief, R. (2015). *Literature review: Real-world fuel consumption of heavy-duty vehicles in the United States, China, and the European Union*. Retrieved from The International Council on Clean Transportation, http://www.theicct.org/literature-review-real-world-fuel-consumption-heavy-duty-vehicles-united-states-china-and-european

Stewart, A., Hope-Morley, A., Mock, P., & Tietge, U. (2015). *Quantifying the impact of real-world driving on total CO2 emissions from UK cars and vans*. Element Energy.

Summerton, P., Pollitt, H., Billington, S., & Ward, T. (2013). *Fueling Europe's future – How auto innovation leads to EU jobs*. Cambridge Econometrics. Retrieved from http://www.camecon.com/EnergyEnvironment/EnergyEnvironmentEurope/FuellingEuropesFuture.aspx

Tietge, U., & Backers, K. (2017). *Cleaner Car Contracts benchmark 2017–Overview of vehicle fleets and efficiency benchmark*. Natuur & Milieu. Retrieved from https://www.natuurenmilieu.nl/wp-content/uploads/2017/05/CCC_benchmark_overview_2017_170501v2-003.pdf

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

Tietge, U., Mock, P., Lutsey, N., & Campestrini, A. (2016). *Comparison of leading electric vehicle policy and deployment in Europe*. Retrieved from The International Council on Clean Transportation, http://www.theicct.org/comparison-ev-policies-europe-2016

van Meerkerk, J., Renes, G., & Ridder, G. (2013). Greening the Dutch car fleet: the role of differentiated purchase taxes. Presented at the European Transport Conference, Frankfurt, Germany: Association for European Transport. Retrieved from https://abstracts.aetransport.org/paper/index/id/218/confid/1

Zacharof, N., Tietge, U., Franco, V., & Mock, P. (2016). Type approval and real-world CO_2 and NO_X emissions from EU light commercial vehicles. *Energy Policy*, *97*, 540–548. https://doi.org/10.1016/j.enpol.2016.08.002