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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

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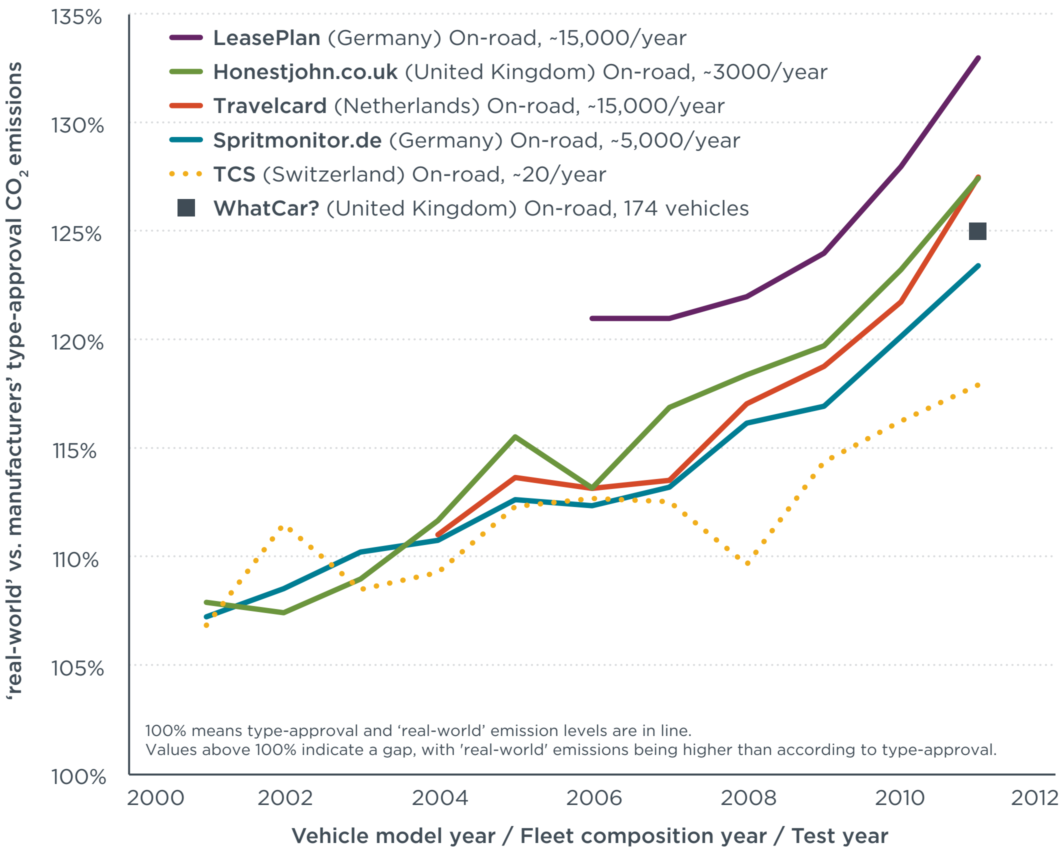
EXECUTIVE SUMMARY

Fuel consumption and carbon dioxide emission values for new cars in Europe today are determined via the so-called type-approval process, which involves testing vehicles under laboratory conditions using the New European Driving Cycle (NEDC). The type-approval values are the basis for consumer information, CO_2 regulation, and CO_2-based vehicle taxation and therefore ought to provide a reliable and stable indication of fuel consumption and emission levels observed—on average—under 'real-world' conditions on the road.

A technically precise definition of real-world driving conditions is elusive because of variations in vehicle design and in the ways that drivers drive. But by aggregating large sets of on-road driving data, clear trends can be observed. This analysis makes use of several such datasets, for both private and company cars, from various European countries. It reveals an overarching trend: while the average discrepancy between type-approval and on-road CO_2 emissions was below 10 percent in 2001, by 2011 it had increased to around 25 percent.

Methods of collecting on-road CO_2 emissions differ from source to source, as do fleet characteristics and driving styles, and therefore the absolute discrepancies found vary from one data source to another as well. But more important than the absolute discrepancy is the *increase over time*, and the annual rate of increase is similar for all sources examined.



Divergence, real-world vs. manufacturers' type-approval CO_2 emissions for various on-road data sources.[1]

1 For spritmonitor.de, Travelcard, and honestjohn.co.uk data are shown by vehicle model year. For TCS and *WhatCar?* data are shown by the year in which vehicles were tested. For LeasePlan the vehicle fleet average for a given year is shown. A detailed description of differences in the datasets is given in the following chapters.

It is reasonable to assume that driving behavior has not changed appreciably over the past ten years. Instead, the observed increase of the gap is most likely due to a combination of these developments:

- » Increasing application of technologies that show a higher benefit in type-approval tests than under real-world driving conditions (for example, start-stop technology)
- » Increasing use of 'flexibilities' (permitted variances) in the type-approval procedure (for example, during coast-down testing)
- » External factors changing over time (for example, increased use of air conditioning)

The underlying data show that the increase in the gap was especially pronounced after 2007–2008, when a number of European Union member states switched to a CO_2-based vehicle taxation system and a mandatory EU CO_2 regulation for new cars was introduced.

It is important to clarify that nothing in this analysis suggests that manufacturers have done anything illegal. However, the NEDC was not originally designed to measure fuel consumption or CO_2 emissions, and some features of the test procedure can be exploited to influence test results for those values. Manufacturers appear to be taking advantage of permitted tolerances in the NEDC, resulting in unrealistically low CO_2 emission levels. Results from tests that closely resemble type-approval testing, appear to confirm this. In such tests, run using vehicles provided directly by manufacturers and in laboratory settings that are in line with those customary for type approval, the discrepancies between laboratory and real-world results tend to be much smaller and do not show any sign of a marked increase over time. However, these type-approval like laboratory tests do not take into account a number of conditions and behaviors typically found in on-road driving.

The public policy implications of this study are significant. The growing gap between reported efficiencies and actual driving experience cuts in half the expected benefits of Europe's passenger vehicle CO_2 regulations. It creates a risk that consumers will lose faith in type-approval fuel consumption values, which in turn may undermine government efforts to encourage the purchase of fuel-efficient vehicles through labeling and tax policy. For tax authorities, the gap between type-approval and real-world CO_2 values translates into a gap between actual and potential revenues from vehicle taxes. Finally, increasing discrepancies between type-approval and on-road CO_2 emissions can result in a competitive disadvantage for some vehicle manufacturers since it tilts the playing field.

Efforts are being made to address this situation. The United Nations is developing a new vehicle test procedure, the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), which is close to being finalized, as well as a separate test procedure for vehicle air conditioning systems, the Mobile Air-Conditioning Test Procedure (MACTP). The WLTP will feature a more representative driving cycle, more precise road-load testing (to measure rolling and aerodynamic resistance), as well as an improved test procedure generally. Existing tolerances and flexibilities will be reduced, and more realistic CO_2 emission test results are expected. Each of these new test provisions ought to be adopted in the EU as quickly as possible. They will help toward reducing the gap between type-approval and on-road CO_2 emission levels. Nevertheless, it should be acknowledged that the new test procedure will not resolve all the open issues, and may itself have vulnerabilities that are not yet recognized. To contend with these eventualities, the European Commission is investigating the use of additional correction methods at the EU level.

In-service conformity checks for CO_2, similar to those that already exist for air pollutant emissions, should be introduced into EU legislation, to ensure compliance of the on-road vehicle fleet as well as individual test vehicles. In the long run, the EU should resolve the question of whether there are better ways to determine CO_2 emission levels of vehicles than making use of a fixed driving cycle and test procedure. Portable emissions measurement systems (PEMS) could offer a plausible alternative, and that possibility should be actively investigated.

In the final assessment, EU regulation of vehicle CO_2 emissions should discourage investment in technologies that do not perform well under real-world conditions, should minimize the exploitation of flexibilities in testing procedures, and should spur innovations that will lead to CO_2 reductions in reality as well as in the laboratory. Reversing the trend of increasing discrepancies between type-approval and on-road CO_2 emissions, and ultimately closing that gap, is critical to meeting those goals.

1 TABLE OF CONTENTS

2 ABBREVIATIONS

a	Year
ADAC	Allgemeiner Deutscher Automobil-Club
AT	Automatic transmission
BEV	Battery electric vehicle
CD	Charge depleting
CS	Charge sustaining
CO_2	Carbon dioxide
DOE	U.S. Department of Energy
EC	European Commission
EEA	European Environment Agency
EPA	Environmental Protection Agency
EU	European Union
g/km	Grams per kilometer
GHG	Greenhouse gas
GM	General Motors
HEV	Hybrid electric vehicle
ICCT	International Council on Clean Transportation
IFEU	Institut für Energie- und Umweltforschung Heidelberg
km/h	Kilometers per hour
MACTP	Mobile air conditioning test procedure
MPG	Miles per gallon
mph	Miles per hour
MT	Manual transmission
NEDC	New European driving cycle
NO_x	Nitrogen oxide
PEMS	Portable emissions measurement system
RN	Renault-Nissan
SoC	State of charge
TCS	Touring Club Schweiz
TNO	Netherlands Organisation for Applied Scientific Research
U.K.	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
U.S.	United States
VW	Volkswagen
WLTC	Worldwide harmonized light vehicles test cycle
WLTP	Worldwide harmonized light vehicles test procedure

3 INTRODUCTION

In order to limit the negative effects of climate change and to reduce dependence on oil imports, the European Union (EU) needs to reduce its greenhouse gas (GHG) emissions to 80–95 percent below 1990 levels by 2050. A reduction of at least 60 percent by 2050 with respect to 1990 (70 percent with respect to 2008) is required from the transport sector, the only sector in which GHG emissions have increased since 2005 (up 30 percent, compared with a 7 percent decline for all sectors) (EC 2011a, 2011b).

For passenger cars, accounting for two-thirds of the GHG emissions from the EU's transport sector, a voluntary commitment by the automotive industry to reduce the level of emissions for new vehicles was reached in 1998–99. However, the annual rate of reduction between 1998 and 2006, as measured by the New European Driving Cycle (NEDC), ranged only between 0.6 percent and 2.2 percent, and the target of 140 grams of carbon dioxide (CO_2) emitted per kilometer traveled (g/km) for 2008 was missed (EC 2010). In 2007, a decision was taken to introduce mandatory regulatory measures, and in early 2009, the first mandatory CO_2 performance standards for passenger cars in the EU were adopted, setting a target of 130 g/km for 2015 and 95 g/km for 2020 (EU 2009). In the course of applying mandatory standards, the annual rate of reduction of the average level of CO_2 emissions from new passenger cars has accelerated from 1.6 percent in 2007 to about 4 percent in the past few years (Mock 2012a). The (preliminary) European average CO_2 emission level in 2012 was 132.2 g/km, compared to 158.7 g/km in 2007 (EEA 2013).

In July 2012, the European Commission put forward a regulatory proposal confirming the 2020 CO_2 target of 95 g/km for new passenger cars (EC 2012). This proposal is currently being discussed in the European Parliament and European Council, and it is expected that it will be adopted later in 2013.

It is important to understand that the performance standards set by the EU only affect the type-approval value for individual vehicles. The term "type approval" refers to laboratory measurements of emission values according to a clearly defined test cycle and test procedure (currently, in the EU, the NEDC is used for this purpose) in a reproducible way to certify that manufacturers are in compliance. In order to achieve real CO_2 emission reductions, it is of great importance to ensure that reductions in the level of CO_2 emissions registered in the laboratory during the type-approval test are also realized under "real-world" driving conditions. The term "real-world" (or, similarly, "on-road") refers here to the practical experience of car owners in their everyday driving. It is acknowledged that every driver has a distinct way of driving, and hence a technically clear definition of real-world driving is elusive. Still, as will be discussed in more detail later, in aggregating a large amount of driving data, clear trends can be observed and analyzed.

In 2012, the International Council on Clean Transportation (ICCT) carried out the first attempt to quantify more precisely the historical divergence of type-approval versus real-world CO_2 values of light-duty vehicles (Mock et al. 2012). At that time, 28,000 user entries from the vehicle database spritmonitor.de were analyzed. The database collects real-world driving fuel consumption data in Germany for most vehicle models available and allows consumers to compare their own figures with those of other users. The fuel consumption information can be converted into CO_2 emissions numbers, and these data were then compared to the type-approval data provided for each vehicle. It was found that there was a discrepancy between the two values and that this discrepancy had increased from about 8 percent in 2001 to 21 percent in 2010, with a particularly pronounced increase since 2007. In addition, laboratory data for 1,200 vehicle models tested by Europe's largest automobile club, Germany's Allgemeiner Deutscher Automobil-Club

(ADAC), were analyzed for the same time period, helping to pinpoint the underlying reasons for the variance found in the analysis.

CO_2 emissions and fuel consumption are directly linked.[2] Therefore, the trend found in the 2012 analysis has implications not only for the reduction of CO_2 emission levels in the atmosphere but also, from a consumer's perspective, for the fuel consumption of their vehicles. Most drivers are aware that there is a gap between the fuel consumption rates they experience during everyday driving and the corresponding values that they obtain from their local car dealer, the Internet, or other media sources. As this gap widens, an ever percentage of the advertised fuel consumption reductions does not result in actual cost savings for consumers. This could lead to a situation whereby consumers lose faith in the official type-approval values provided by the vehicle manufacturers, sapping the public's willingness to invest into new vehicle technologies to cut fuel consumption and CO_2 emissions. This concern has been highlighted recently by an open letter by three EU consumer organizations asking the European Commission to act accordingly (Mock 2012b).

The main objective of this report is to carry out additional analyses with updated and supplemental data in order to see whether they confirm the pattern of growing discrepancies between type-approval and real-world CO_2 values found by ICCT researchers in 2012. For this, the ICCT, in collaboration with the Netherlands Organisation for Applied Scientific Research (TNO) and the Institute for Energy and Environmental Research Heidelberg (IFEU), collected and analyzed various datasets, including those from car magazines and leasing company driving data.

The report is divided into two parts. In the first, a number of different data sources are analyzed in detail, focusing on real-world vs. type-approval CO_2 emission values for various vehicle fleets, in some instances also differentiated by vehicle segment and manufacturers/brands. The second part aims to put the findings into a larger policy context. The United Nations is currently developing a worldwide harmonized test procedure for light-duty vehicles, the so-called WLTP. How the WLTP might affect the discrepancies will be discussed, as well as the implications of persistent gaps between laboratory results and on-road experience from the perspectives of customers, manufacturers, and society as a whole.

2 For reasons of clarity, in this paper only CO_2 values are reported, with CO_2 being an excellent proxy for fuel consumption.

4 DATA ANALYSIS

This chapter discusses various sources of the CO_2 emission levels of light-duty vehicles. Section 4.1 focuses on on-road driving data for Europe, that is, data gathered while driving on normal roads under real-world driving conditions. Section 4.2 looks at data generated in vehicle laboratories under various test conditions. In each case, wherever possible, both current and historical data are analyzed to identify trends over time. Section 4.3 compares the various European data sources to each other. Section 4.4 evaluates data from the United States, which is presented to illustrate differences in vehicles, driving, and testing in the two different regions.

4.1 ON-ROAD DRIVING DATA (EUROPE)

4.1.1 Spritmonitor.de (Germany)

Data type	**On-road**
Data availability	2001–11, approx. 5,000 entries per year
Data collection	Fuel-consumption data, entered by vehicle drivers into publicly available online database
Fleet structure, driving behavior	Mostly private cars, urban and extra-urban driving, no details on driving style known

DESCRIPTION

Spritmonitor.de[3] is an online database with more than 250,000 registered users that provides on-road fuel consumption figures for cars in Germany. Anyone can register for free, choose a vehicle model and exact configuration, and then enter the fuel consumption data that one observes in daily driving. The reported values are freely accessible to everyone, for each vehicle individually or aggregated to compile average fuel consumption for a specific vehicle model configuration. In contrast to some other websites, spritmonitor.de does not ask users to estimate the fuel consumption rate directly but instead asks them to enter the amount of fuel purchased (in liters) and the odometer reading after each refueling stop. The resulting specific fuel consumption is then calculated automatically.

For this study, all entries for the years 2001–11 were analyzed for the following manufacturers/brands: BMW (BMW, Mini), Daimler (Mercedes-Benz, smart), Fiat, Ford, General Motors (Opel), PSA (Peugeot, Citroën), Renault-Nissan (Renault, Nissan), Toyota, Volkswagen (Audi, Seat, Skoda, VW), Volvo. Collectively, the vehicle models covered account for about 75 percent of annual sales in Germany. Each vehicle model is differentiated by type of fuel, transmission, engine power, and model year. In total, more than 69,000 user entries were analyzed. It was found that the spritmonitor.de data provides a good representation of the German car market (see Figure 1). The respective market share of diesel and automatic transmission vehicles is similar to that of the overall German market. Similarly, the distribution by segment and manufacturer is in line with the actual market characteristics. The average (type-approval) CO_2 emission level of the spritmonitor.de fleet was 145 g/km in 2011, very close to the 146 g/km reported for the entire German new car fleet in 2011 (Figure 2).

3 See http://www.spritmonitor.de. The data used for this analysis were accessed in October/November 2012.

Figure 1. Characteristics of the spritmonitor.de data analyzed in comparison with the German new car market.[4]

4 Market data taken from Mock (2012c).

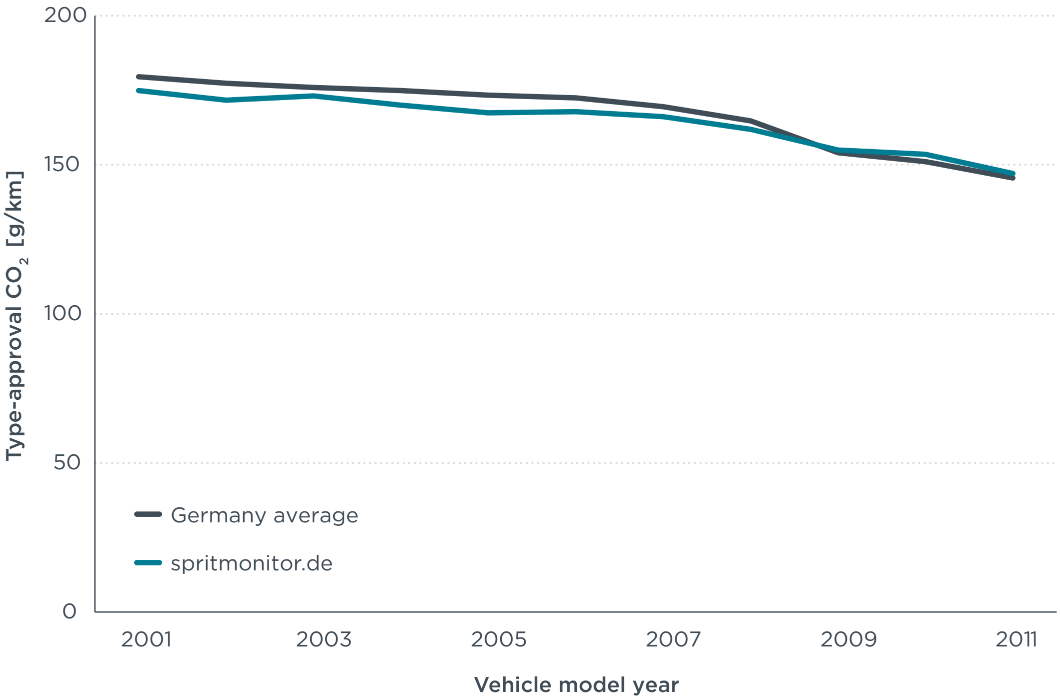


Figure 2. CO_2 type-approval data for spritmonitor.de fleet and German new car market.

METHODOLOGY

To aggregate the detailed data from spritmonitor.de, for every vehicle variant the average fuel consumption was determined and divided by the respective type-approval number to obtain a relative value. The relative differences were then weighted according to the respective German market sales numbers for the vehicle variant in a given year.

In contrast to the type-approval data, fuel consumption rates reported by spritmonitor.de are not based on laboratory measurements and are not subject to any process of standardization; rather, they reflect how drivers experience fuel consumption in practice. For the analysis, the values obtained from spritmonitor.de are therefore considered to be a good representation of real-world CO_2 values. A breakdown of the spritmonitor.de data in terms of driving situations (for example urban, extra-urban, highway) is not feasible within the scope of this analysis.

Considering that those consumers reporting their experiences to spritmonitor.de are likely to pay more attention to the fuel efficiency of their vehicles and to drive in a more fuel-conserving manner than others, one might posit that the difference between real-world CO_2 and type-approval values is actually higher than what is suggested by the spritmonitor.de analysis. The gap between type-approval and spritmonitor.de fuel consumption rates may thus be viewed as a conservative estimate. Others might argue that spritmonitor.de users are especially frustrated with their cars consuming more fuel than expected and that this is their main reason for submitting data to the system. In any case, even if there is a bias (no matter in which direction) in the data reported to spritmonitor.de with respect to average in-use fuel consumption, that bias should be consistent over time and should not affect the observed trends in the relationship between the spritmonitor.de data and the type-approval data.

RESULTS

As can be seen from Figure 3, the average discrepancy between fuel consumption (and, by extension, CO_2 emission) values reported in spritmonitor.de and manufacturers' type-approval values increased from 7 percent in 2001 to 13 percent in 2007 and then jumped to 23 percent by 2011. This trend confirms the findings of the previous ICCT analysis (Mock et al. 2012) mentioned in the Introduction, now adding a data point for the year 2011 and including more data entries for 2001–10. A significant difference in results between petrol and diesel vehicles cannot be determined based on the overall data for all years. However, just looking at the years 2007 to 2011, the widening in the discrepancy appears to be less pronounced for petrol than for diesel vehicles (Figure 3).

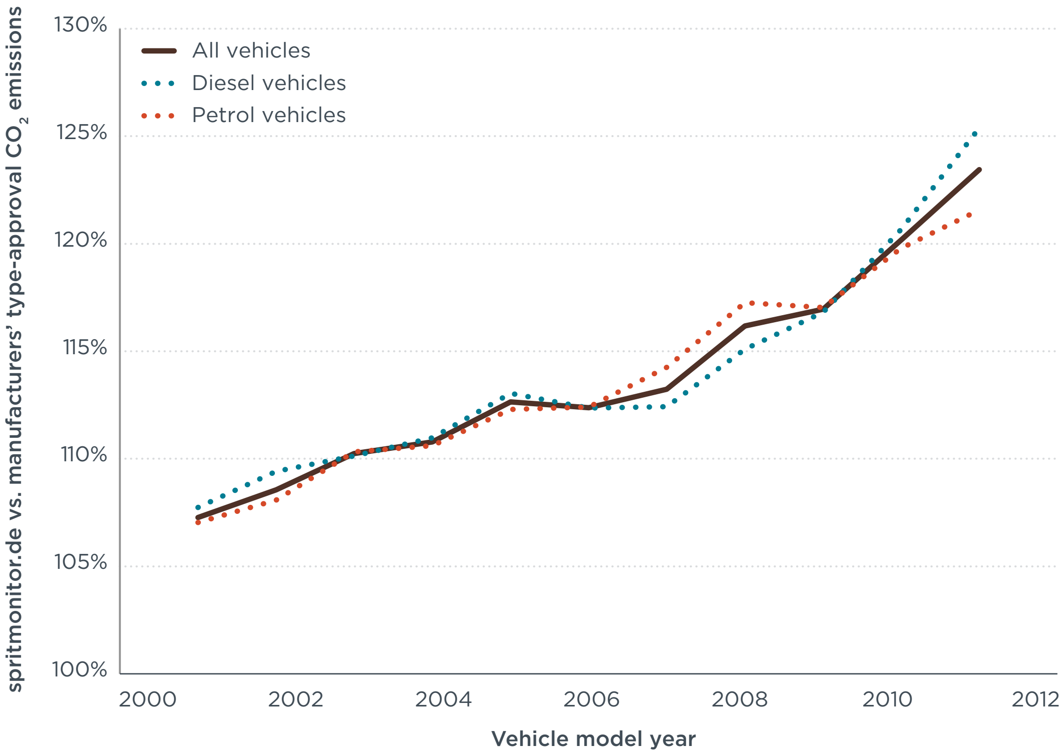


Figure 3. Divergence, spritmonitor.de vs. manufacturers' type-approval CO_2 emissions by fuel.

Figure 4 shows the same analysis by transmission type. According to the data, a greater disparity is observable for vehicles equipped with automatic transmission since 2007, with such vehicles now having a divergence of 26 percent, compared with 22 percent for manual transmission vehicles.

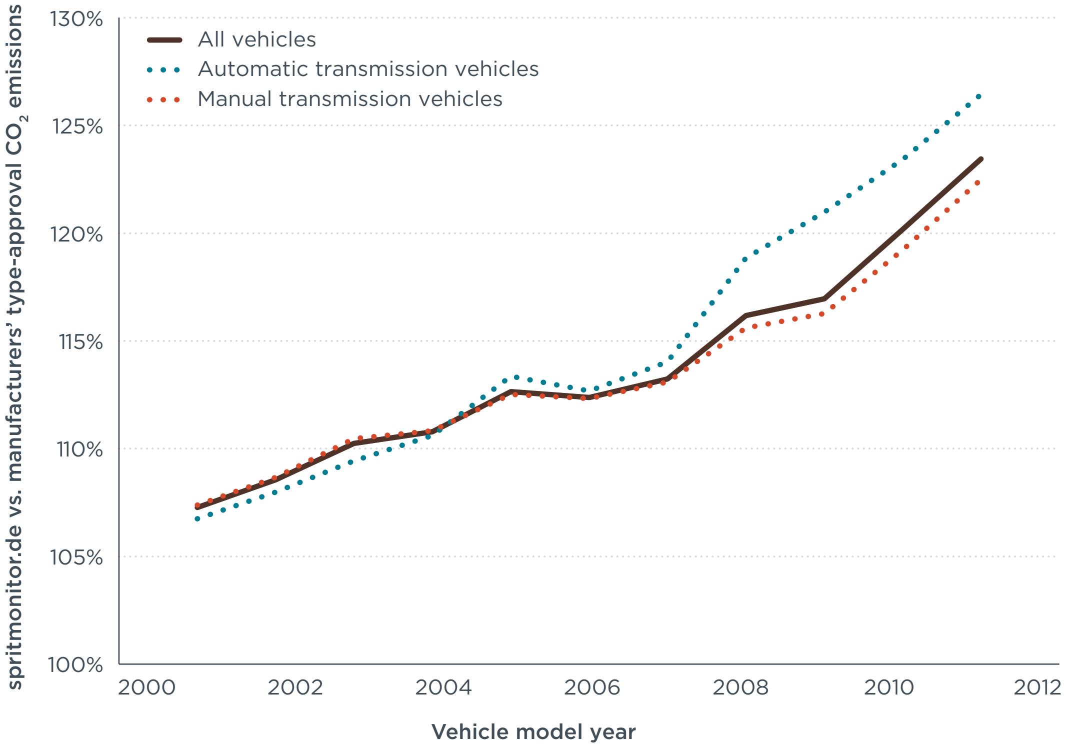


Figure 4. Divergence, spritmonitor.de vs. manufacturers' type-approval CO_2 emissions by transmission type.

An analysis by vehicle class (Figure 5) reveals hardly any differences among them. Most of the vehicle segments mirror closely the overall market trend. Only the divergence for vehicles in the upper-medium-size and sports car category seems to have grown slightly more than for other vehicle segments.

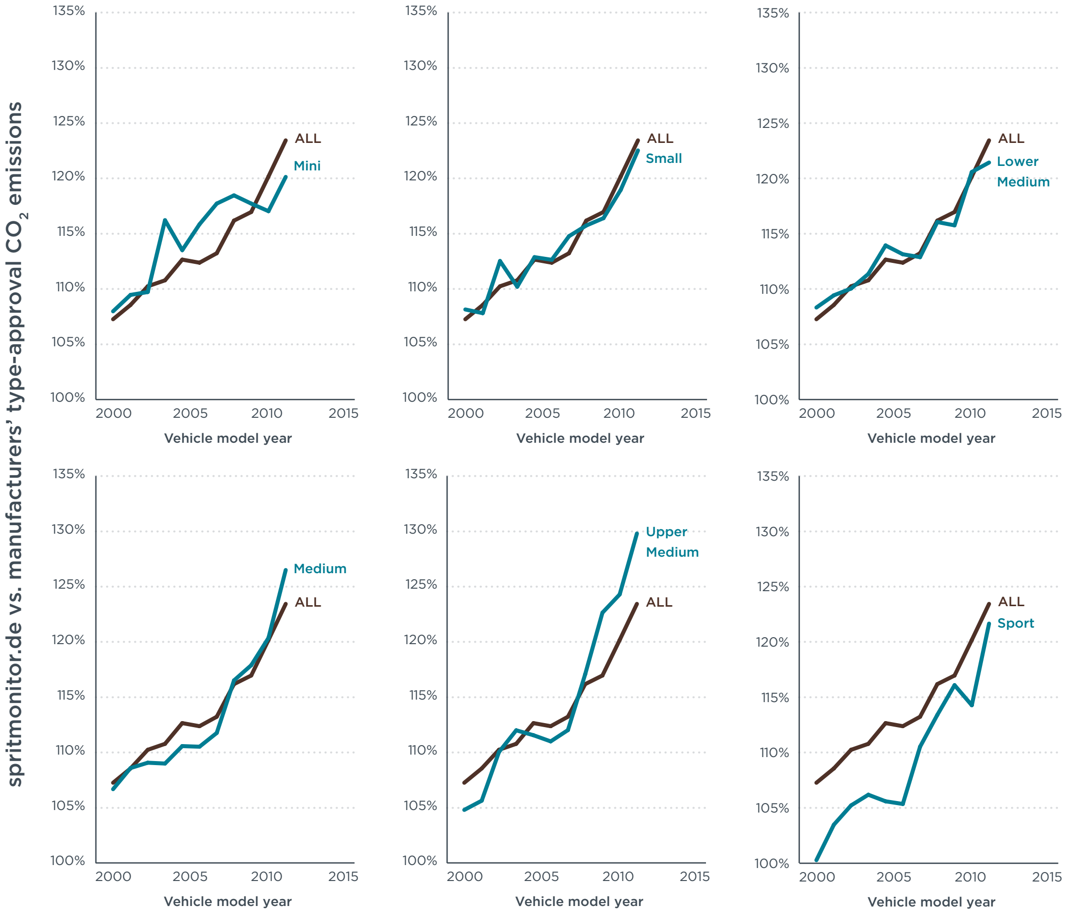


Figure 5. Divergence, spritmonitor.de vs. manufacturers' type-approval CO_2 emissions by vehicle segment.

To illustrate the differences between low- and high-CO_2-emitting vehicles, in terms of their divergence from the official rates, Figure 6 shows the 2011 data for petrol and diesel cars at 5 g/km CO_2 emission intervals.[5] Looking at the linear regression lines, it can be seen that the spritmonitor.de data for 2011 petrol vehicles ranges between 120 and 125 percent of the type-approval numbers and for diesel vehicles between 125 and 130 percent. Hence, there is little variation between low- and high-CO_2-emitting cars. This is particularly true in focusing on the absolute CO_2 emission levels instead of percentage differences. The absolute difference between type-approval and real-world emissions is about constant over a large CO_2 range, according to the spritmonitor.de dataset.[6]

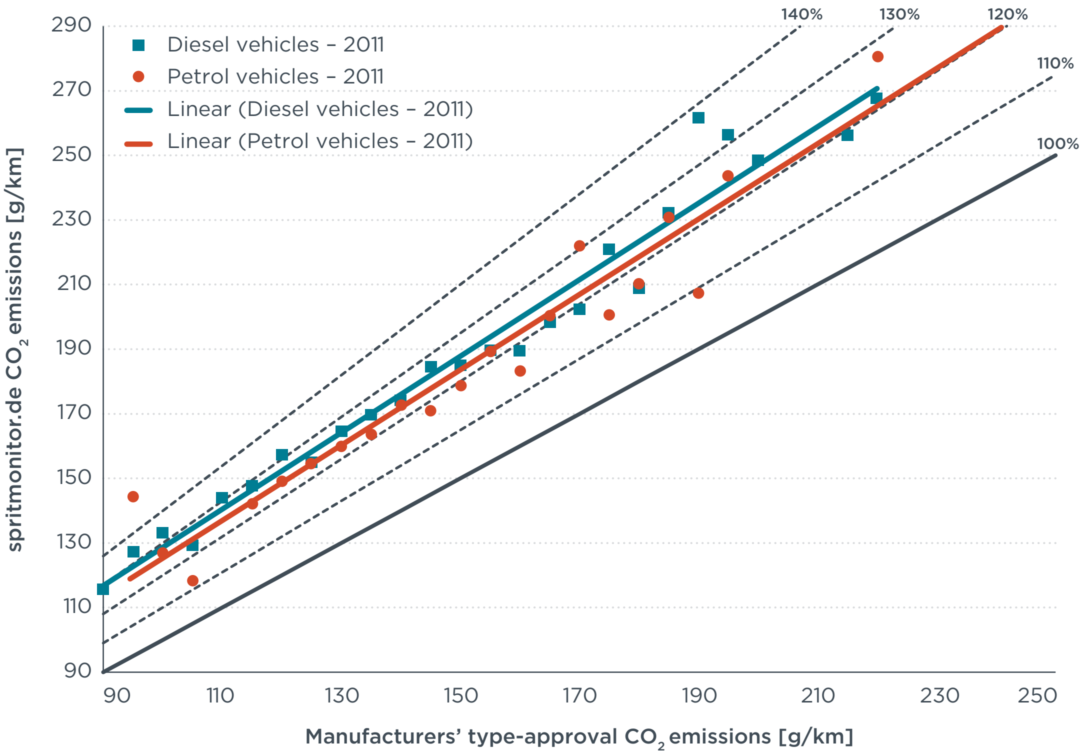


Figure 6. Correlation deviation, spritmonitor.de vs. manufacturers' type-approval CO_2 emissions by CO_2 emission category.

The spritmonitor.de data is detailed enough to allow for a meaningful analysis of individual brands and manufacturers. According to the data, while most manufacturers follow the overall trend line, there are some differences between them that can be seen in Figure 7. It is important to note that for a comparison between manufacturers, differences in framework conditions need to be taken into account.

For example, as will be discussed in further detail in Chapter 5.1.1, differences in driving behavior and vehicle use can explain part of the absolute level of discrepancy between type-approval and real-world CO_2 emissions. Therefore, a direct comparison of vehicles that are mostly driven at high speeds on the highway with other vehicles that are driven more on urban roads or on highways but typically with lower speeds does not allow for any meaningful conclusions. This is of course true as well for the respective manufacturers of these vehicles. More useful is a comparison of manufacturers with a similar customer base, such as, for example, Audi, BMW, and Daimler. On the other hand,

5 For the spritmonitor.de data, a conversion factor of 2.43 kg CO_2 per liter of petrol and 2.65 kg per liter of diesel fuel was used.

6 Note that the figure does not include any information on the number of vehicles for each data point. For a vehicle number weighted analysis, please see the previous figure examining specific vehicle segments.

differences in driving styles and vehicle use cannot explain the observed *increase* in the level of discrepancy, as again will be discussed in the following chapter.

For a more detailed discussion of the challenges in comparing manufacturers' data, please see section 4.3.3.

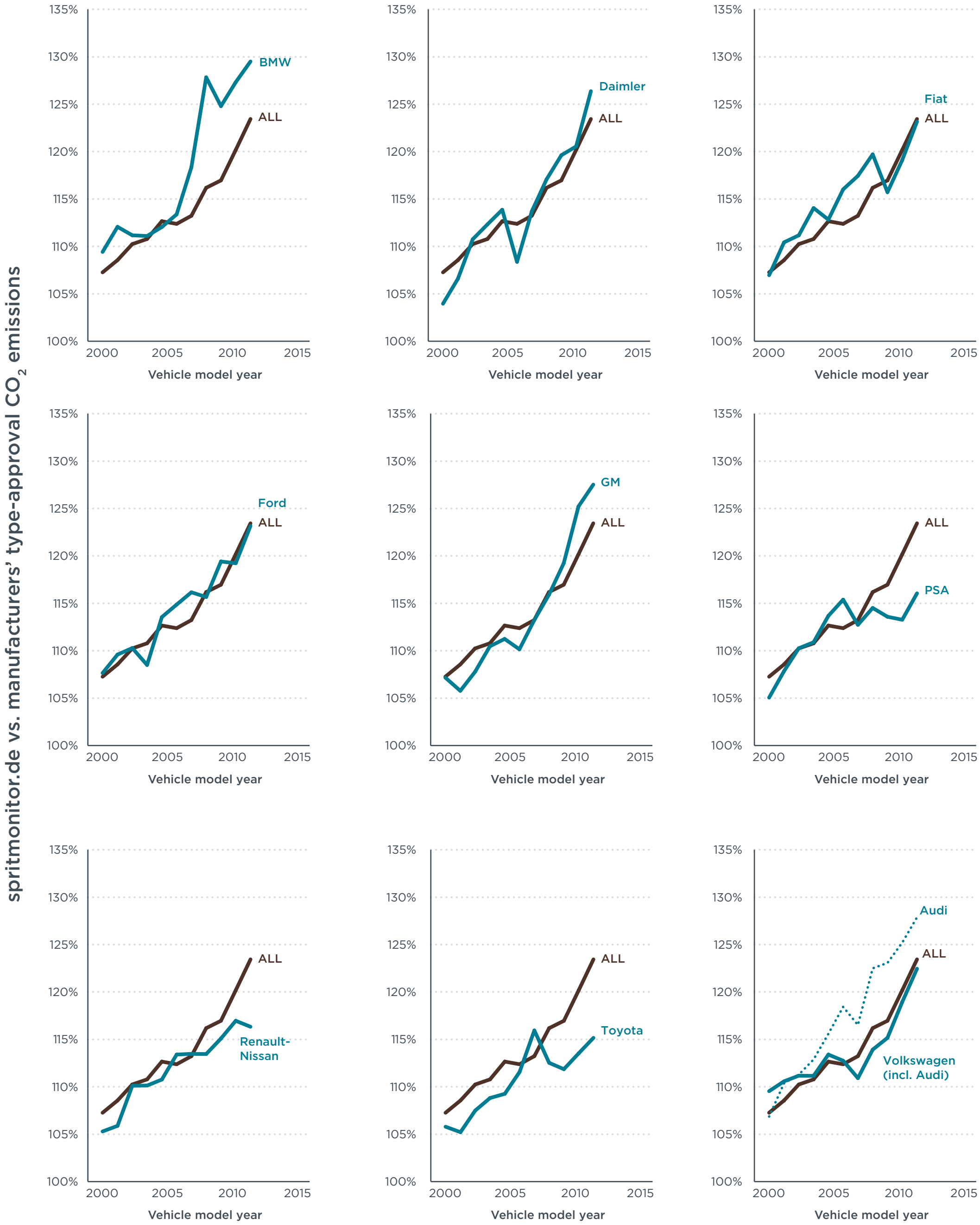


Figure 7. Divergence, spritmonitor.de vs. manufacturers' type-approval CO_2 emissions by brands/manufacturers.[7]

7 BMW (BMW, Mini), Daimler (Mercedes-Benz, smart), Fiat, Ford, GM = General Motors (Opel), PSA (Peugeot, Citroën), Renault-Nissan (Renault, Nissan), Toyota, Volkswagen (Audi, Seat, Skoda, VW).

Figure 8 compares the 2001 situation to 2011 for selected manufacturers and brands. Whereas in 2001 the average CO_2 emission level[8] for new cars in the EU was 168 g/km, and the discrepancy according to spritmonitor.de data was 7 percent, the corresponding figures were 138 g/km and 23 percent in 2011.[9] That is, while in every instance the CO_2 emission level has decreased over the past ten years according to the data examined, the gap for each manufacturer has also widened, resulting in smaller real-world CO_2 reductions than one would expect at first sight.

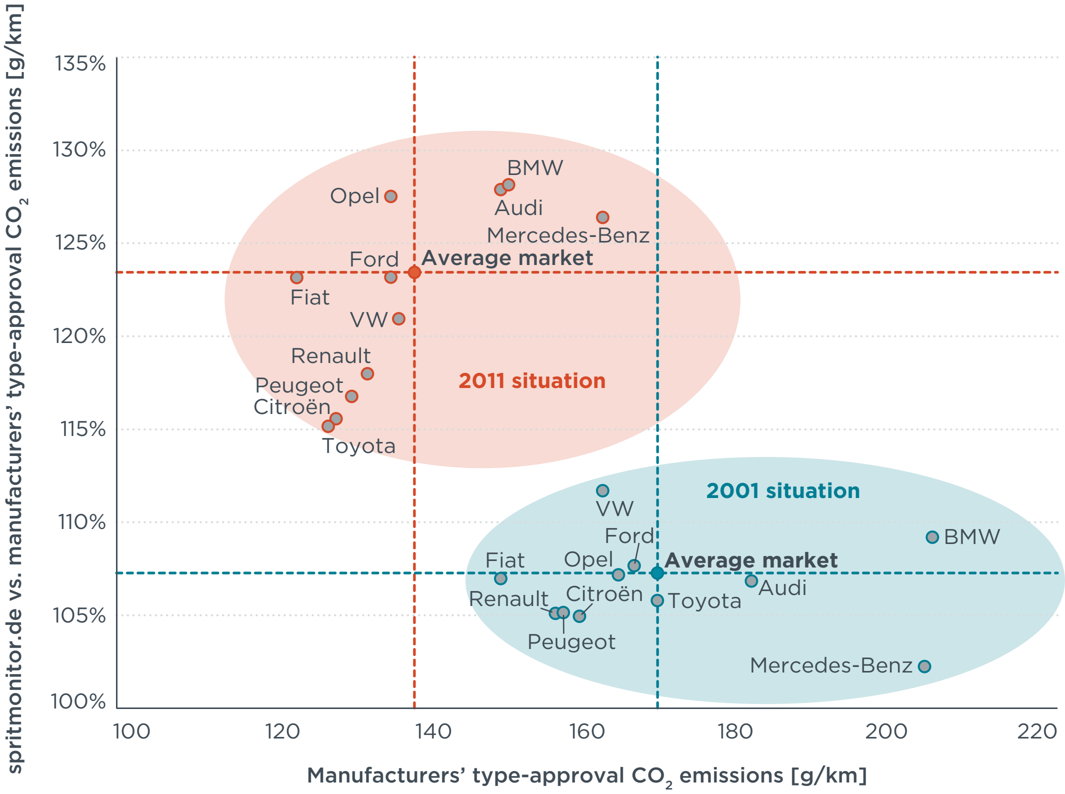


Figure 8. 2001 and 2011 CO_2 emission level and spritmonitor.de vs. type-approval discrepancy on average and for selected brands/manufacturers.

8 CO_2 data from Mock (2012c). Values may be different from those given in other reference materials for reasons provided in the source.

9 The official CO_2 emission value for 2011 was 136 g/km (EEA 2011). For reasons explained in Mock (2012c), the value used here differs slightly from this level.

Figure 9 illustrates the effect of these disparities on measurements of absolute CO_2 reductions achieved in Germany for new cars over the past ten years. According to type-approval data, the average CO_2 emission level decreased from 180 g/km in 2001 to 146 g/km in 2011, a 19 percent drop. According to spritmonitor.de data, though, the real-world emission level in 2001 was around 193 g/km (about 13 g/km higher than the type-approval level). Over the years, the gap widened to 34 g/km in 2011, which is equivalent to about 1.4 liters of fuel[10] per 100 km. According to the spritmonitor.de data, the real-world CO_2 emission reduction from 2001 to 2011 therefore was only about 7 percent instead of 19 percent. Also, the spritmonitor.de data register notable differences in deviations between manufacturers. While for some the gap amounted to only 22 g/km (*Min. manufacturer*), for others it was as high as 43 g/km (*Max. manufacturer*) in 2011. This represents almost a 0.9 liter/100 km difference in fuel consumption between manufacturers at the extremes.

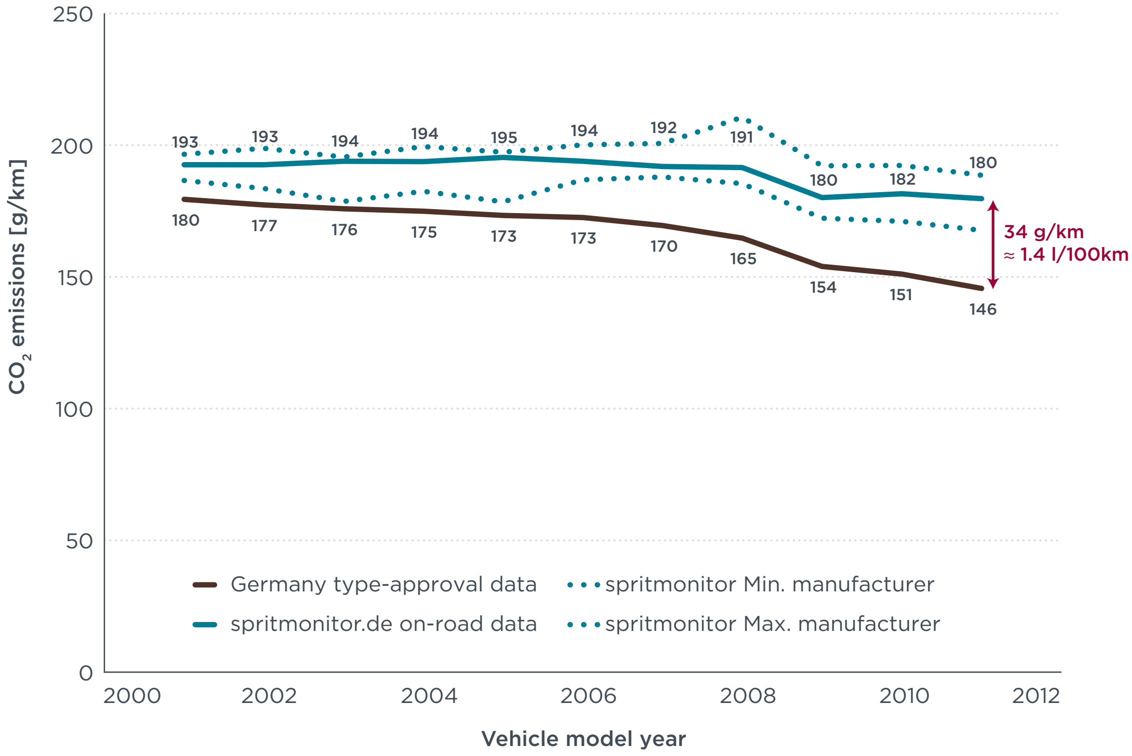


Figure 9. Average CO_2 emissions of new cars in Germany according to type-approval and spritmonitor.de data.

10 Conversion to fuel consumption assuming a market share of approximately half petrol and half diesel vehicles.

4.1.2 Travelcard (Netherlands)

Data type	**On-road**
Data availability	2004–11, approx. 15,000 entries per year
Data collection	Fuel consumption data, automatically recorded using a tank card when refueling at gas station
Fleet structure, driving behavior	Company cars, urban and extra-urban driving; fuel is usually paid for by the employer

DESCRIPTION

Travelcard[11] is a fuel card system introduced in the Netherlands that can be used at any gas station in the Netherlands and at more than 33,000 fuel stops across Europe. Travelcard is part of LeasePlan Corporation N.V. About 200,000 vehicles, out of the 8 million total in the Netherlands, regularly fill up with petrol or diesel using Travelcard. Typically, the fuel is paid for by the employer since many employees in the Netherlands have a company car as part of their job benefits.

For this study, detailed fuel consumption data for more than 260,000 Travelcard vehicles for the years 2004–11 were analyzed by TNO. In total, about 20 million individual filling events—after a thorough quality check—were used for the analysis. The following brand/manufacturer classification was applied: BMW (BMW), Daimler (Mercedes-Benz), Fiat (Alfa-Romeo, Fiat), Ford, General Motors (Opel), PSA (Peugeot, Citroën), Renault, Toyota, Volkswagen (Audi, Seat, Skoda, VW). Even though not separately analyzed, other brands (such as Mini, smart, Nissan, Lexus) are included in the calculations for overall average fleet values.

Among the distinct characteristics of the Travelcard dataset (see Figure 10), about 50 percent of the vehicles are powered by diesel fuel. This is about twice as much as for the Dutch vehicle fleet taken as whole. Given that—taking into account Dutch vehicle taxes and fuel prices, a diesel-operated vehicle is more economical above an annual mileage of about 20,000 km—diesel vehicles are very popular among business users. This is precisely the case for the Travelcard fleet, consisting mostly of company cars that have a higher annual mileage than average private vehicles. Automatic transmission is not common among Travelcard drivers; only about 8 percent of their vehicles make use of this technology, as opposed to about 18 percent on average in the Netherlands. Therefore, the amount of data on such vehicles is limited, and a separate analysis for automatic transmission vehicles was not carried out. At the manufacturers/brands level, BMW and Volkswagen are overrepresented in the Travelcard dataset compared with the Dutch fleet overall, while Daimler and Fiat are underrepresented. Small and mini models are also underrepresented in the Travelcard fleet. The average CO_2 emission value for model-year 2010 vehicles in the Travelcard dataset was 135 g/km, slightly lower than the average for new passenger cars in the Netherlands in that same year (137 g/km), despite the underrepresentation of small cars, owing to the larger share of diesel vehicles in the select group (Figure 11).

11 See http://www.travelcard.nl/en/homepage. The data used for this analysis were accessed in October/November 2012.

Figure 10. Characteristics of the Travelcard data analyzed in comparison with the Dutch new car market.

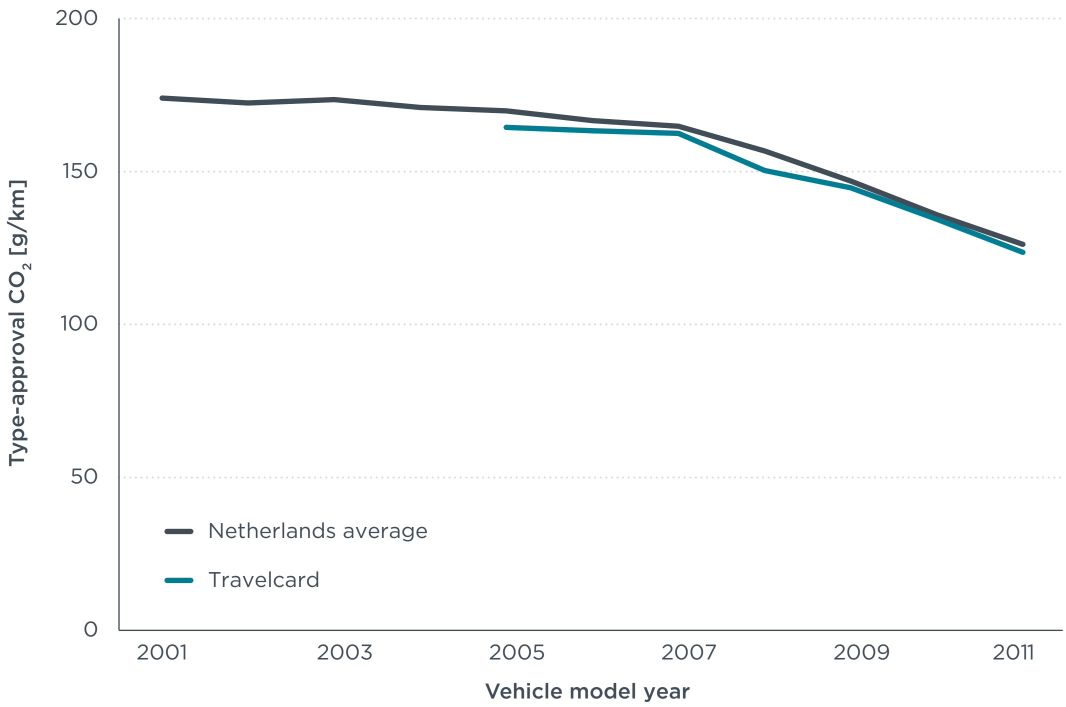


Figure 11. CO_2 type-approval data for Travelcard vehicle fleet and the Dutch new car market.

METHODOLOGY

The Travelcard data include manufacturers' type-approval fuel consumption figures for every vehicle[12] as well as the real-world fuel consumption rates determined by analyzing pairs of consecutive fueling events, with proper mileage data recorded on each filling occasion for each vehicle. Thus, the dataset can be analyzed without needing to reference other data sources. When aggregating individual vehicle data to fleet-wide averages, the Travelcard vehicle count was used to weight the results.

As with the spritmonitor.de data, fuel consumption reported by Travelcard is not based on laboratory measurements but reflects the in-use consumption experience of a large number of customers. The values are therefore considered a good representation of real-world CO_2 emission values but keeping in mind that the fleet is almost entirely made up of company cars.

Since fuel expenses are usually paid by the employer, Travelcard users are not likely to be much motivated by fuel conservation in their driving style. On the other hand, many motorways in the densely populated western part of the Netherlands have speed limits of 100 km/h and 80 km/h and tend to be relatively congested. These conditions have to be taken into account when comparing Travelcard to similar data from Germany (for example, spritmonitor.de), where much higher speeds are common on the Autobahn. Overall, the Travelcard drivers are a more homogeneous group than the spritmonitor.de users, with their company obligations largely responsible for the substantial mileage totals racked up.[13] Their fuel consumption may be pushed higher than average because their driving style is unconstrained by fuel saving concerns, but this is counterbalanced by the typical characteristics of their vehicle usage: longer trip distances and limited urban driving.

12 The type-approval data given was additionally validated by TNO using other sources.

13 Typically, during the first four years of the lifetime of a vehicle—while being used as a company car—about half of the total lifetime mileage of the vehicle is accrued.

RESULTS

As can be seen in Figure 12, the discrepancy between CO_2 emission values reported by Travelcard and manufacturers' type-approval values increased from 11 percent in 2004 to 28 percent in 2011. For the years prior to 2004, no data are available. As in the case of spritmonitor.de, the increase seems to have accelerated markedly since 2007, when the gap stood at 14 percent. The difference between petrol and diesel vehicles is more evident than is true for the spritmonitor.de data, again with a swifter increase for diesel vehicles during the past several years.

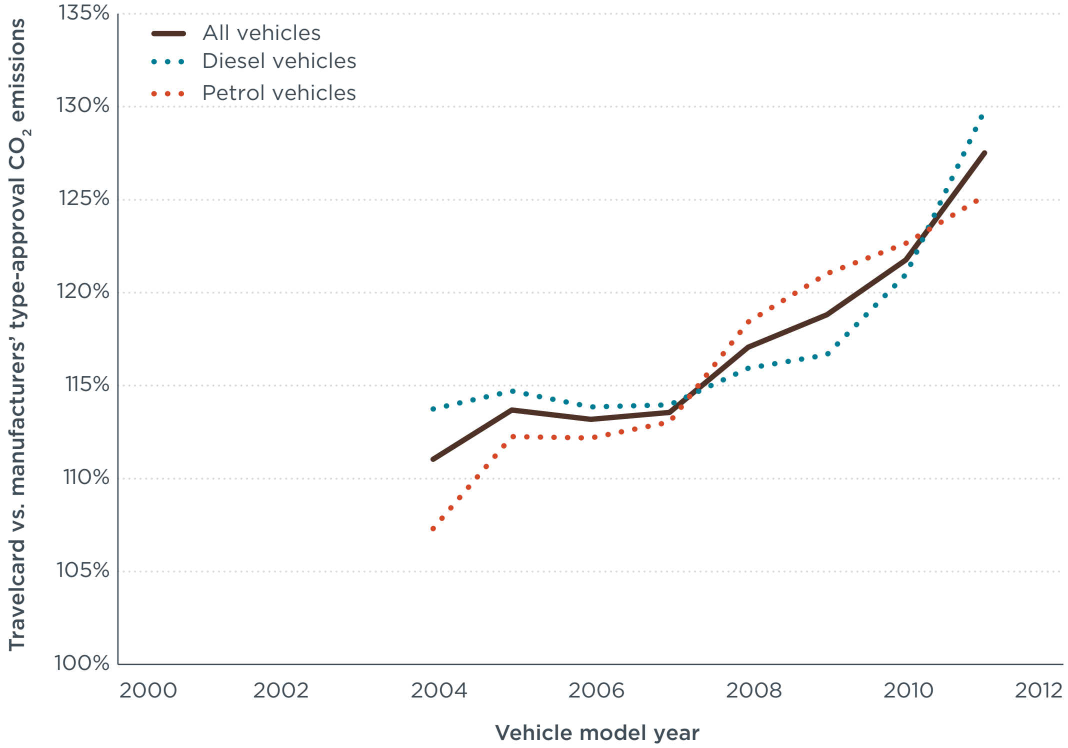


Figure 12. Divergence, Travelcard vs. manufacturers' type-approval CO_2 emissions on average, by fuel.

In analyzing the Travelcard data by vehicle segment (Figure 13), a larger discrepancy shows up for vehicles of the mini, small, and lower-medium-sized segments than for those of the medium and upper-medium-sized segments. Although the Travelcard dataset is biased toward larger cars, the number of smaller cars in the dataset is sufficient to generate significant results. What the figure does not depict is that the discrepancy is especially large for small diesel vehicles, more so than for petrol vehicles.

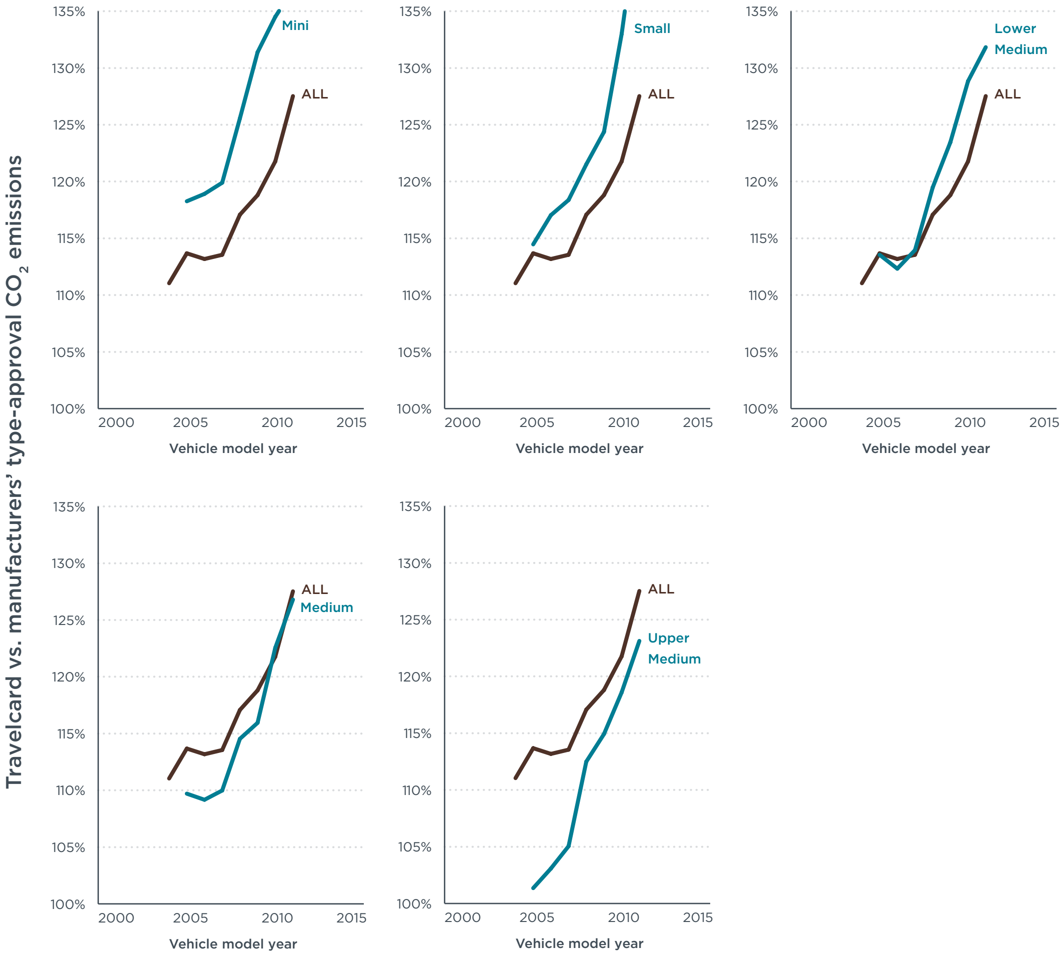


Figure 13. Divergence, Travelcard vs. manufacturers' type-approval CO_2 emissions by vehicle segment.

The analysis by vehicle segment is confirmed by means of classifying vehicles by 5 g/km CO_2 emission intervals (see Figure 14).[14] As shown by the linear regression lines in the figure, the discrepancy is largest for low-CO_2-emission vehicles, in which case the deviation is around or even exceeding 40 percent, with slightly higher values for diesel vehicles.[15] For high-CO_2-emission vehicles, the discrepancy is smaller, closer to 20 percent. Focusing on the absolute CO_2 emission levels instead of percentage differences, the observed differences would be more constant over the range of CO_2 emission intervals.

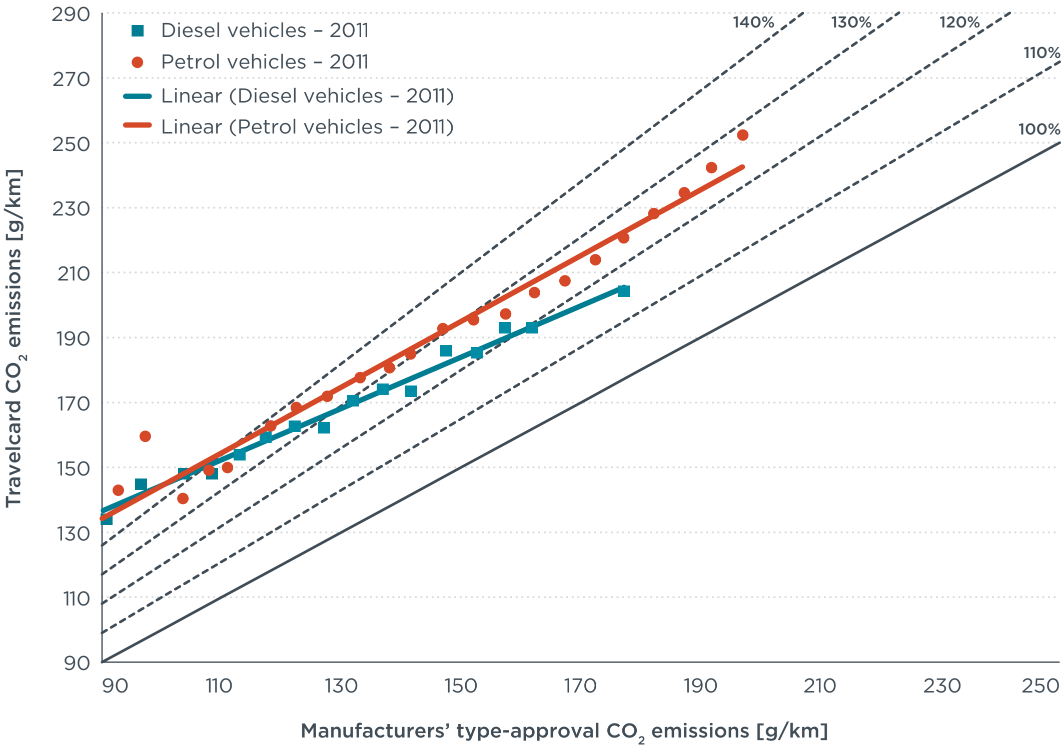


Figure 14. Correlation deviation, Travelcard vs. manufacturers' type-approval CO_2 emissions by CO_2 emission category.

Like the spritmonitor.de data, the Travelcard results are detailed enough to permit a meaningful analysis of individual brands and manufacturers. Figure 15 summarizes the results. Only for Daimler are the data points too sparse to allow for any historical trend line. Because hybrid vehicles make up approximately 3 percent of vehicle sales in the Netherlands (compared to 0.7 percent on average in the EU) and around 25 percent of Toyota's vehicle sales in the country, the figures for Toyota were segmented to show nonhybrids only, in addition to Toyota overall.

14 For the Travelcard data, a conversion factor of 2.36 kg CO_2 per liter of petrol and 2.65 kg per liter of diesel fuel was used.

15 Note that the figure does not include any information on the number of vehicles for each data point. For example, the data point 95 g/km (type-approval) is based on approximately 1,600 vehicles for diesel and only about 100 vehicles for petrol. For a vehicle number weighted analysis, please see the previous figure, with data arranged by vehicle segments.

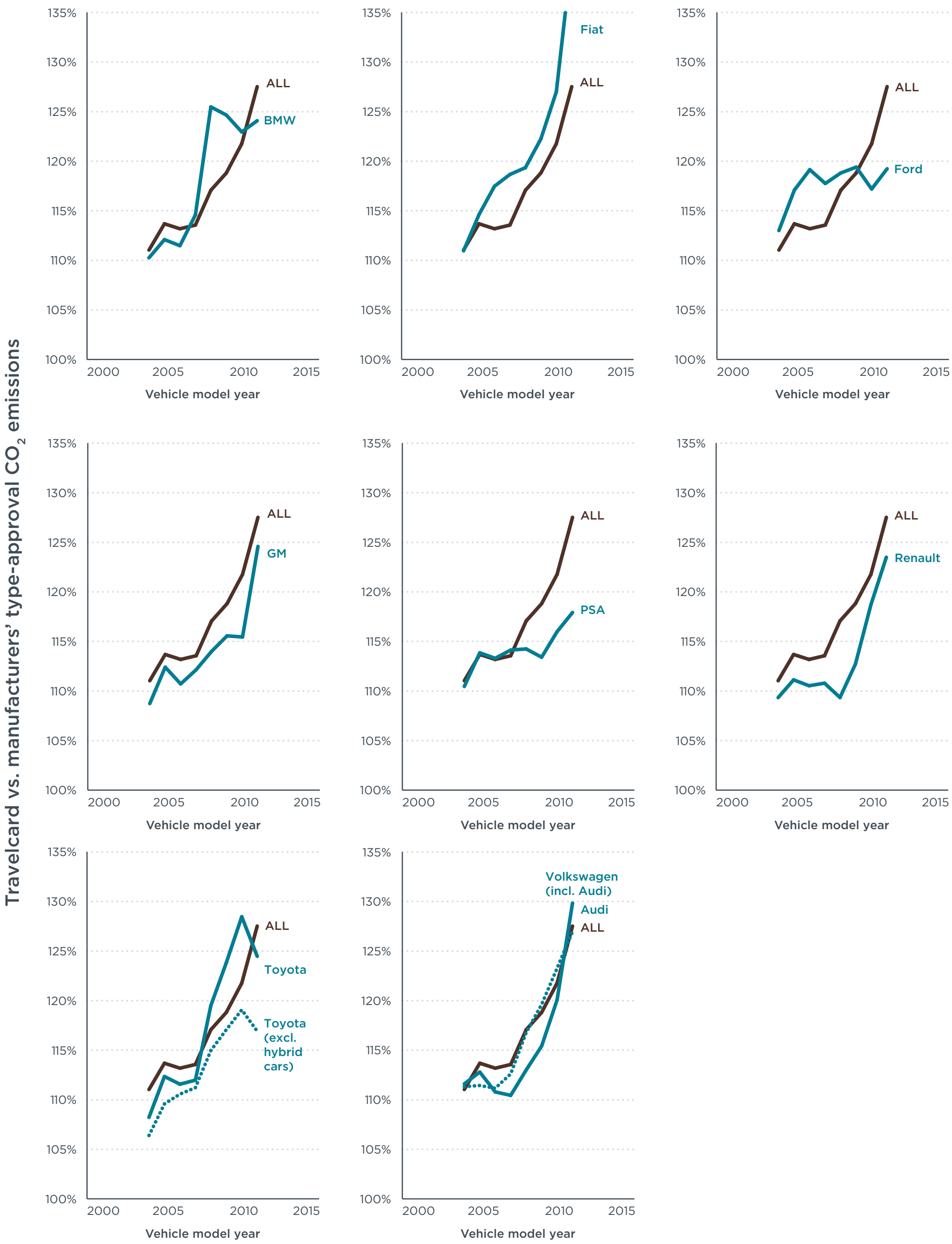


Figure 15. Divergence, Travelcard vs. manufacturers' type-approval CO_2 emissions by manufacturers/brands.[16]

16 There are insufficient data points to allow detailed analysis for Daimler. GM = General Motors (Opel), PSA (Peugeot-Citroën), Volkswagen (Audi, Seat, Skoda, VW)

Figure 16 illustrates the absolute CO_2 reductions for new cars in the Netherlands over the past few years. According to type-approval data, the average CO_2 emission level decreased from 171 g/km in 2004 to 126 g/km in 2011, a 26 percent reduction. However, according to Travelcard data, the real-world emission level in 2004 was around 190 g/km, about 11 percent higher than the certified figure. Over the years, the gap widened to 35 g/km in 2011, which is equivalent to about 1.4 liters of fuel per 100 km. Thus, according to the Travelcard data, the real-world CO_2 emission reduction over the seven-year period was only about 15 percent.

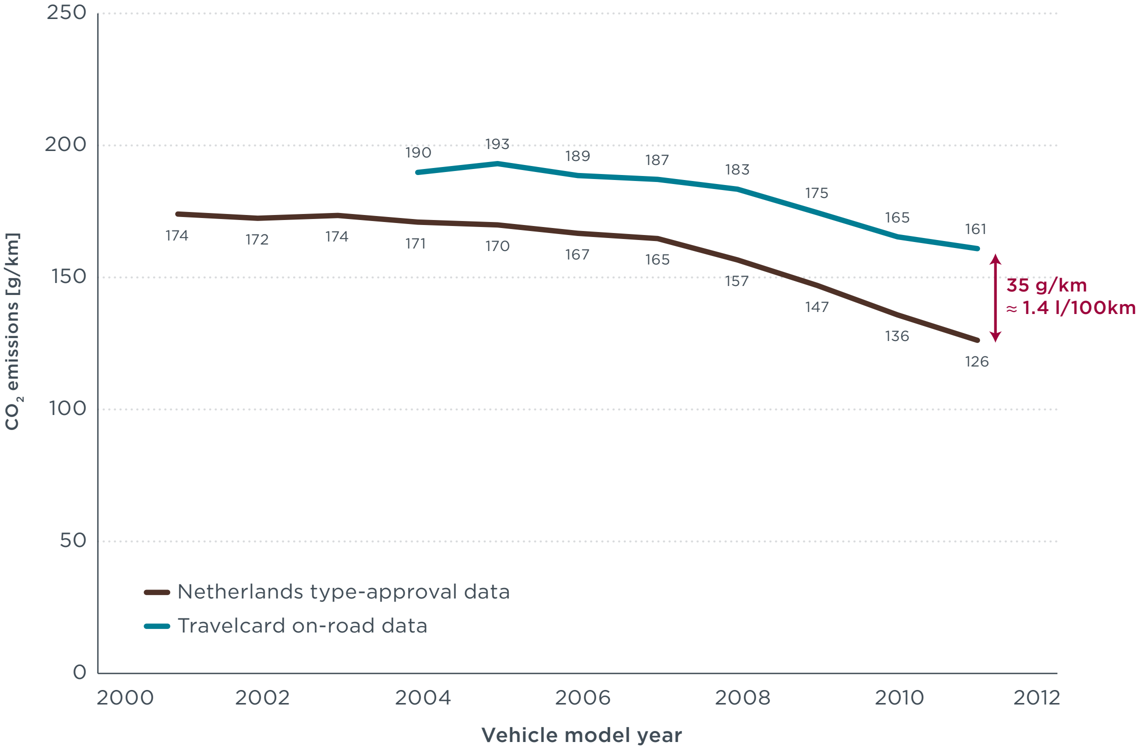


Figure 16. Average CO_2 emissions of new cars in the Netherlands according to type-approval and Travelcard data.

4.1.3 LeasePlan (Germany)

Data type	**On-road**
Data availability	2006–11, approx. 15,000 entries per year
Data collection	Fuel consumption data, automatically recorded using a tank card when refueling at gas station
Fleet structure, driving behavior	Company cars, mostly extra-urban and highway driving; fuel is usually paid for by the employer

DESCRIPTION

LeasePlan,[17] which offers Travelcard as one of its lines of business, is a global fleet and vehicle management company of Dutch origin. Established more than 45 years ago, LeasePlan has grown to become the world's leading fleet and vehicle leasing company, managing around 1.3 million vehicles of multiple brands and providing financing and operational fleet and vehicle management services in 30 countries. LeasePlan is located in the Netherlands and is 50 percent owned by the Volkswagen Group and 50 percent by Fleet Investments B.V.

For the analysis in this section, only passenger car data from LeasePlan Germany[18] were analyzed. LeasePlan Germany is a fully owned subsidiary of LeasePlan Corporation and oversees 80,000 vehicles. Its dataset is similar to the one compiled by Travelcard, only the geographic range is different (Germany versus the Netherlands). The following brand/manufacturer classification was used: BMW (BMW, Mini), Daimler (Mercedes-Benz, smart), Fiat (Alfa-Romeo, Chrysler, Fiat, Jeep), Ford, General Motors (Chevrolet, Opel), PSA (Peugeot, Citroën), Renault-Nissan (Dacia, Nissan, Renault), Toyota (Lexus, Toyota), Volkswagen (Audi, Porsche, Seat, Skoda, VW).

Only data for 2011 were available at a level of detail that allowed an analysis by segment or individual manufacturer. Data for 2006–10 were provided by LeasePlan only at an aggregate level. For the LeasePlan data, the model year of vehicles is not known, simply the fleet average in a given year. The LeasePlan data therefore represent a fleet-wide average rather than new vehicle data. According to LeasePlan, the average holding period for a lease is about three years, that is, there will be a time lag of about one to two years before the fuel consumption data provided for a certain year truly reflects the new vehicle average for that given year. Reductions in fuel consumption figures will therefore occur more slowly in the data than in real life.

The cars managed by LeasePlan are company cars and thus different in a number of respects from the type of cars typically found in the private car market. This becomes clear by comparing LeasePlan with the German new car market (see Figure 17). Almost all LeasePlan vehicles (94 percent) are diesel powered, whereas among the overall fleet only around 50 percent are. Information on transmission type is not available from the LeasePlan data for comparison. Looking at the market shares for segments, mini and small vehicles hardly show up at all in the LeasePlan statistics. The dataset mostly contains lower-medium-sized, medium and upper-medium-sized vehicle models, with the larger two of these size classifications strongly overrepresented compared to their share in the overall German market. In terms of individual companies, BMW, Ford, and Volkswagen vehicles tend to be more prevalent in the LeasePlan dataset than on the nation's highways, while Fiat, PSA, Renault-Nissan, and Toyota are less frequently found.

The average CO_2 (type-approval) emission value for 2011 in the LeasePlan dataset was 140 g/km, significantly lower than the average for new passenger cars in the Germany in that same year (146 g/km), especially when taking into account that the LeasePlan data

17 http://www.leaseplan.com
18 http://www.leaseplan.de

represent a fleet average and include as well 2009 and 2010 vehicles for 2011 (Figure 18). The reason is the much higher diesel vehicle share in the LeasePlan fleet, and the fact that CO_2 emission levels tend to be lower for diesel vehicles than for petrol vehicles.

Total number of vehicles with Leaseplan data evaluated: approx. 150,000

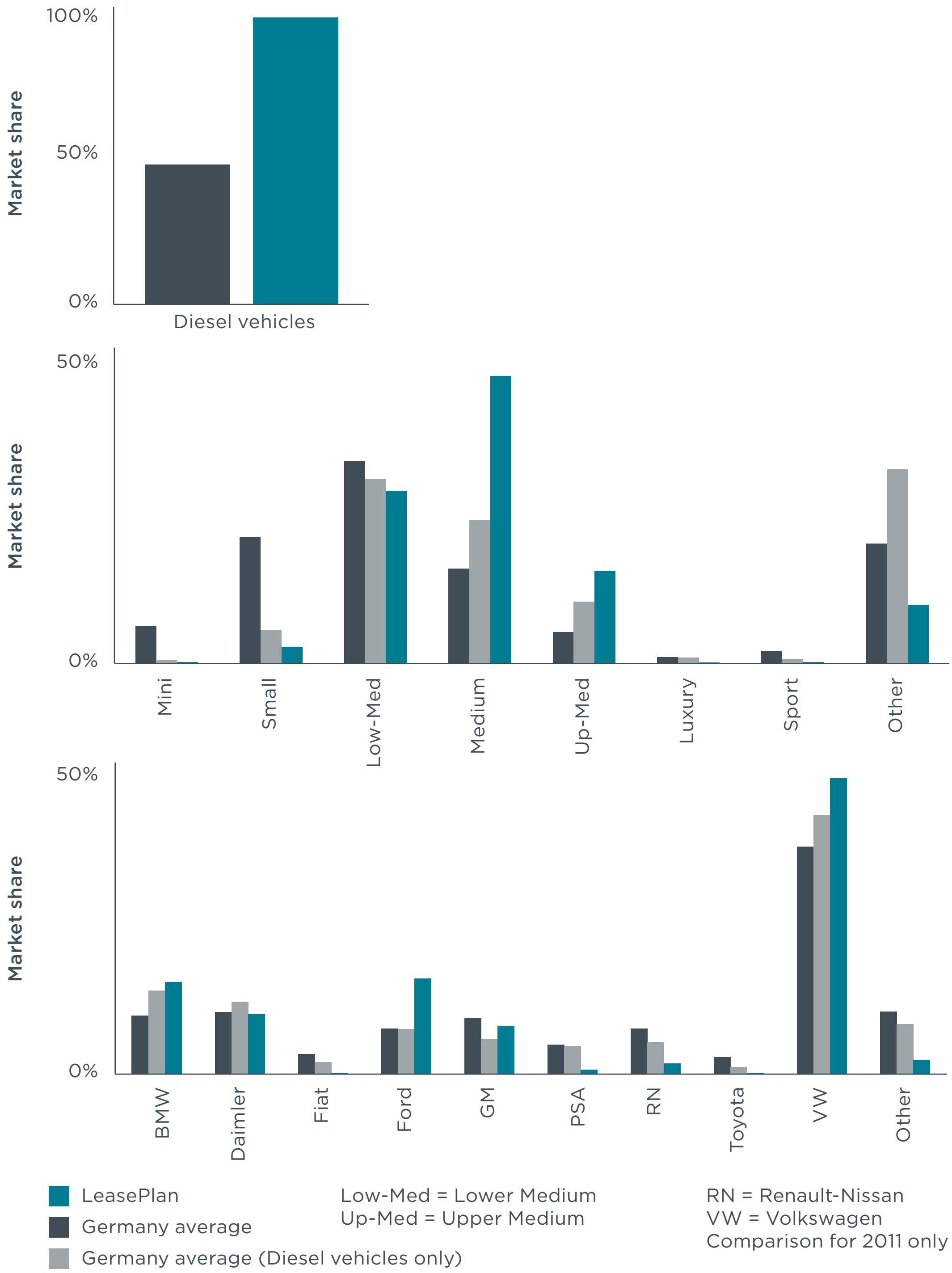


Figure 17. Characteristics of the LeasePlan data analyzed in comparison with the German new car market.

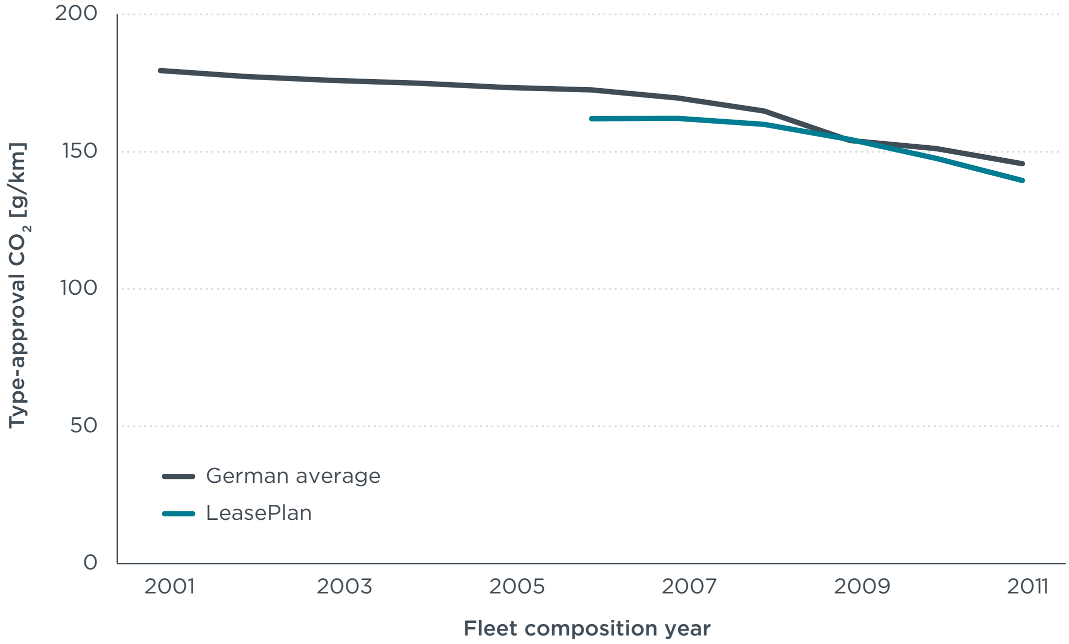


Figure 18. CO_2 type-approval data for LeasePlan vehicle fleet and the German new car market.

METHODOLOGY

The LeasePlan data include manufacturers' type-approval fuel consumption figures for each vehicle[19] as well as the real-world consumption measurements determined by summing up the fueling events for each vehicle. Therefore, the dataset can be analyzed without needing to consult other data sources. In aggregating the individual vehicle data to fleet-wide averages, the LeasePlan vehicle count was used to weight the results. In other words, the composite data do not reflect the distribution of the German market generally but instead the frequency with which a vehicle is included in the LeasePlan fleet.

Fuel consumption reported by LeasePlan, along the same lines as the spritmonitor.de or Travelcard data, does not depend on laboratory measurements but reflects the actual experience of a substantial customer base, so the values are a good representation of real-world CO_2 values. However, as with the Travelcard data, it needs to be taken into account that LeasePlan vehicles are company cars. LeasePlan drivers themselves generally do not have to pay for their fuel, which is covered by their employers. It is therefore to be expected that LeasePlan drivers have weaker incentives to drive in a fuel-efficient manner. At the same time, according to LeasePlan, many customers drive long distances on the Autobahn (for example, as sales representatives), often at speeds higher than 130 km/h, in which case CO_2 emissions increase drastically. Yet, as discussed for the spritmonitor.de and Travelcard data already, any bias in driving behavior is not expected to have significantly changed in recent years.

19 The aggregated data were provided directly by LeasePlan and could not be verified by ICCT.

RESULTS

LeasePlan data go back only as far as 2006. The degree of discrepancy starts at 21 percent in 2006 and increases to 33 percent in 2011, with a particular acceleration since 2008/2009 (see Figure 19). As discussed at the beginning of this section, only the fleet-wide average for a given year is reported—if focusing only on new vehicles, the increase in the discrepancy is thus projected to be even steeper than what the figure indicates.

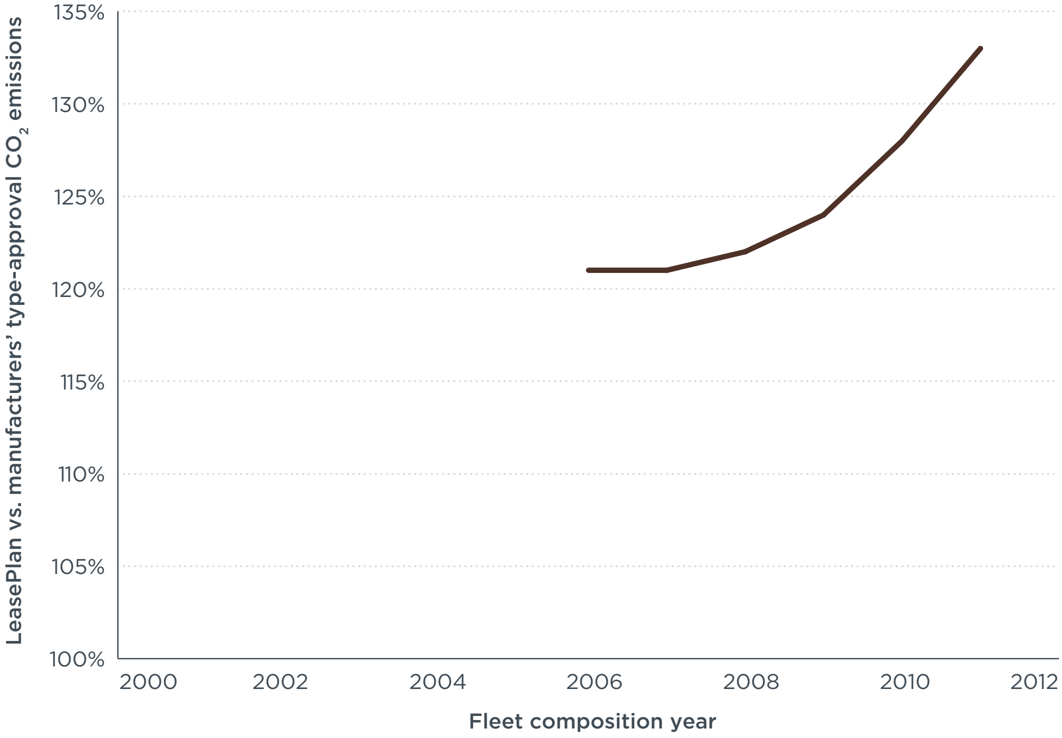


Figure 19. Divergence, LeasePlan vs. manufacturers' type-approval CO_2 emissions on average.

Differences between vehicle segments and manufacturers could only be analyzed for the year 2011, as for the years 2006–10 only aggregated data were provided by LeasePlan. So the results shown in Figure 20 to Figure 22 are only a snapshot in time. Moreover, because these are vehicle fleetwide data, the 2011 figures take in some vehicles that entered the market up to three years earlier.

Figure 20 shows the 2011 LeasePlan data by vehicle segment. While the discrepancy tends to be smaller for the mini and luxury/sport segments than for other vehicle segments, there is limited scope for data interpretation, given the low number of vehicles in the mini and small segments.

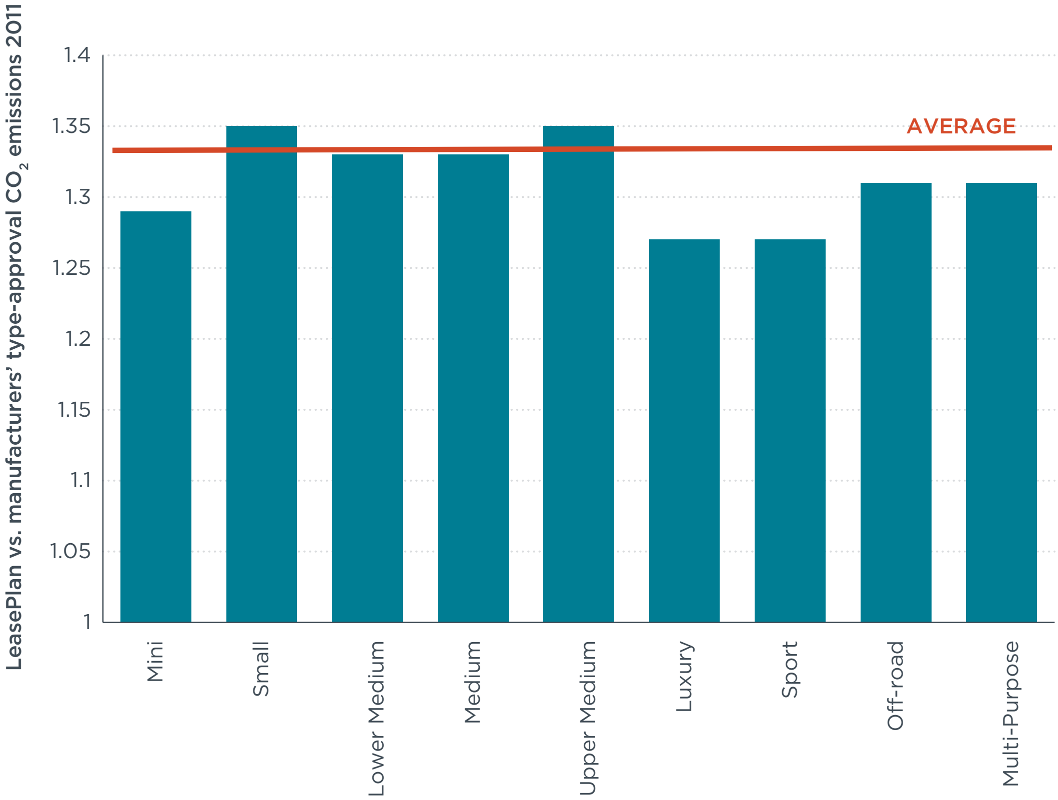


Figure 20. Divergence, LeasePlan vs. manufacturers' type-approval CO_2 emissions by segments for the year 2011.

Figure 21 provides a more detailed analysis by vehicle CO_2 emission 5 g/km intervals for the year 2011. According to the data, discrepancies are higher (closer to 140 percent) for low-CO_2-emitting cars than for high-CO_2-emitting cars (closer to 120 percent). However, given the scarcity of small and low-CO_2-emitting cars in the LeasePlan dataset, it is not possible to draw any solid conclusions regarding differences between vehicle segments when it comes to CO_2 emissions.

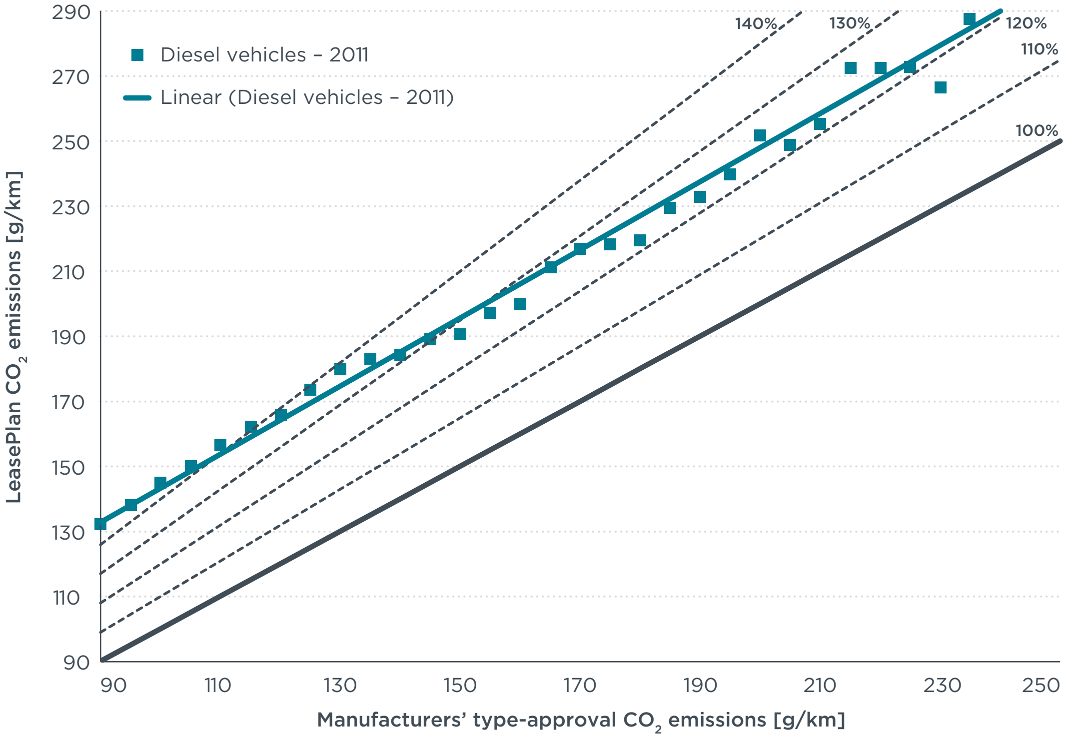


Figure 21. Correlation deviation, LeasePlan vs. manufacturers' type-approval CO_2 emissions by CO_2 emission category.

No major differences show up in the 2011 analysis by manufacturer, with all carmakers falling into a fairly narrow band, close to an average of 33 percent higher real-world CO_2 emissions than according to type-approval values. It may well be that for the years prior to 2011 differences would have been more pronounced and then converged, as was the case for the spritmonitor.de and Travelcard data.

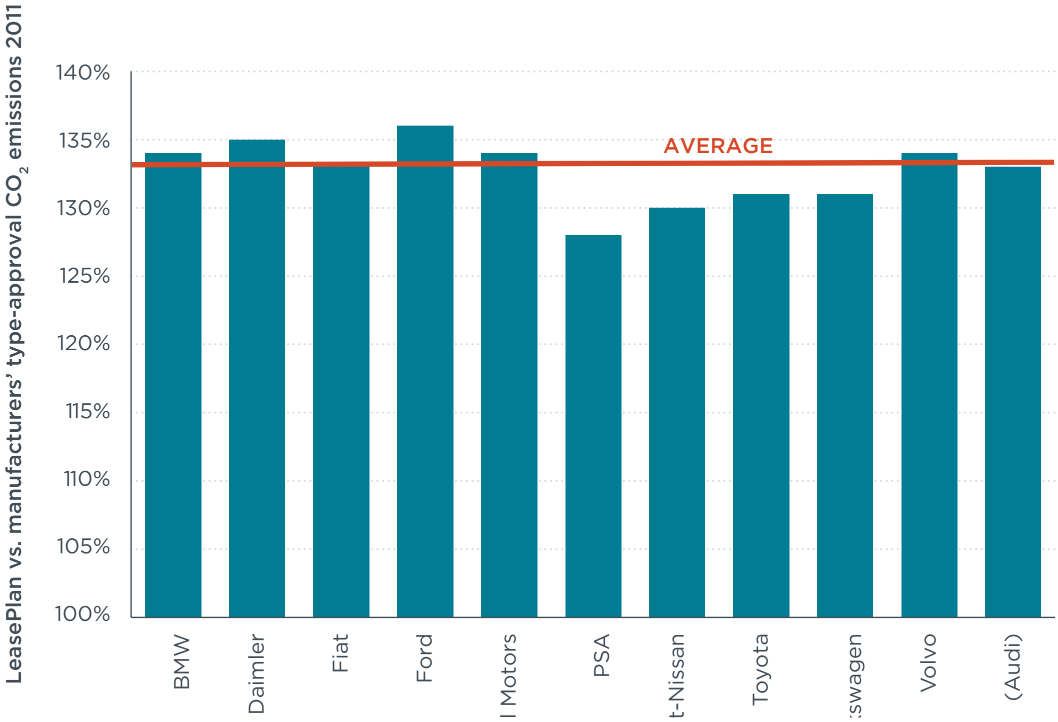


Figure 22. Divergence, LeasePlan vs. manufacturers' type-approval CO_2 emissions by brands/manufacturers[20] for the year 2011.

20 General Motors = Opel; Volkswagen includes Audi; PSA = Peugeot-Citroën

4.1.4 Honestjohn.co.uk (United Kingdom)

Data type	On-road
Data availability	2000–2011, approx. 3,000 entries per year
Data collection	Fuel consumption data, entered by vehicle drivers into publicly available online database
Fleet structure, driving behavior	Mostly private cars, urban and extra-urban driving, no details on driving style known

DESCRIPTION

Honestjohn.co.uk[21] is motoring website in the United Kingdom that allows anyone to submit real-world fuel-consumption data. Users can select a vehicle model and engine configuration and enter the fuel consumption figure that is based on their everyday driving experience. In contrast to spritmonitor.de, the honestjohn.co.uk fuel consumption data are entered directly by the user (in miles per gallon, MPG) and not calculated by the website itself based on the amount of fuel purchased and the odometer readings. The reported values are freely accessible, individually by vehicle model and engine configuration or aggregated by model or manufacturer. In total, approximately 37,000 user entries have been submitted so far, with 33,500 data entries being available for this analysis. Vehicle model-years 2000–2011 are included here, with all of these years having more than 600 data entries per year.

Comparing the honestjohn.co.uk dataset with the U.K. new car average for 2011 shows that there are more diesel vehicles in the honestjohn.co.uk data (58 percent vs. 51 percent) (Figure 23). The difference was even more pronounced for previous model years, with the honestjohn.co.uk fleet always having around 50–60 percent diesel vehicles, while the U.K. diesel market share steadily increased from 18 percent in 2001 to 51 percent in 2011. Information on the transmission type could not be analyzed in the context of this study. A differentiation by vehicle segments is possible and, for 2011, shows an overrepresentation of lower-medium-sized and upper-medium-sized vehicles in the honestjohn.co.uk dataset and an underrepresentation particularly of small vehicles. However, it has to be noted that there are fluctuations in the dataset when looking at the segment allocation for different model years, and the share of small vehicles is larger for most of the years before 2011.

Looking at the type-approval CO_2 emission levels of the honestjohn.co.uk dataset, it is obvious that the average of all honestjohn.co.uk vehicles registers a lower emission level than the U.K. new vehicle average (Figure 24)—128 g/km vs. 138 g/km in 2011.[22] To some extent this is caused by the above-average share of diesel vehicles in the honestjohn.co.uk dataset. However, the prevalence of diesel cannot fully explain the difference observed. Nevertheless, as the difference found is quite constant over time and as for the further analysis only relative differences between type-approval and real-world data are assessed, no further implications are expected.

21 See http://www.honestjohn.co.uk/realmpg/. The data used for this analysis were accessed in March 2013.

22 For the conversion from mpg to g/km (emissions) the following factors have been applied: 1 Imperial Gallon = 4.55 liters; 1 Mile = 1.61 km; 2.43 kg CO_2 per liter of petrol and 2.65 kg per liter of diesel fuel.

Total number of vehicles with honestjohn.co.uk data evaluated: 33,500

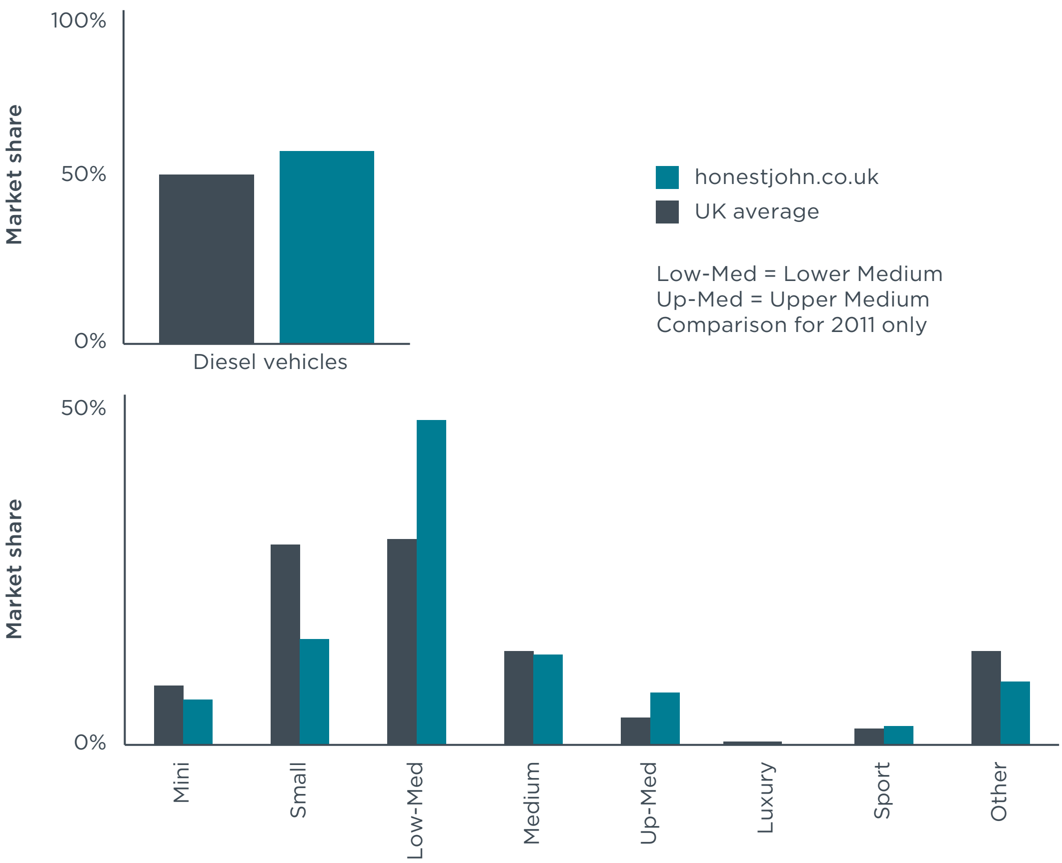


Figure 23. Characteristics of the honestjohn.co.uk data analyzed in comparison with the U.K. new car market.[23]

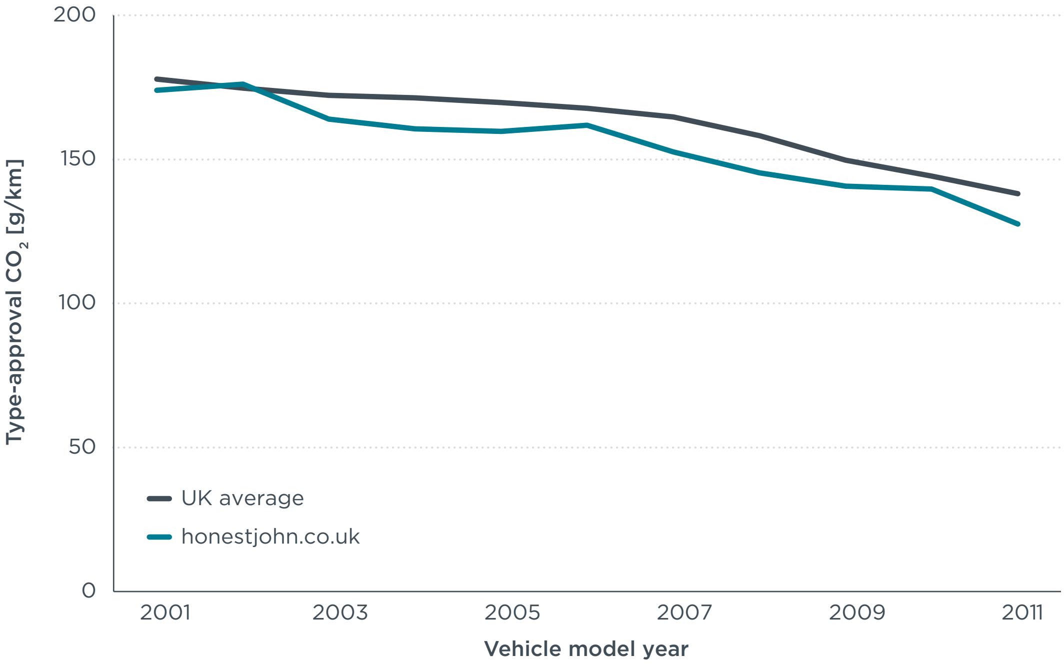


Figure 24. CO_2 type-approval data for honestjohn.co.uk vehicle fleet and U.K. new car market.

23 Market data taken from Mock (2012c).

METHODOLOGY

In contrast to spritmonitor.de, users of honestjohn.co.uk select their precise vehicle model and engine configuration from a list, and honestjohn.co.uk then matches the user's real-world data entry (after carrying out plausibility checks for the data entries) with the corresponding type-approval entry from a commercial database. Therefore, both real-world and type-approval data for all vehicles are directly provided by honestjohn.co.uk. The honestjohn.co.uk dataset for some vehicles includes a minimum/maximum range for the type-approval CO_2 emission level. In this case, the average level was used. The relative difference between real-world and type-approval data was calculated for each vehicle model and then aggregated using the honestjohn.co.uk user entry count.

As with the datasets previously examined, fuel consumption rates reported by honestjohn.co.uk are not based on laboratory measurements and are expected to reflect real-world driving of customers. Details on the driving style of users are not known. Nevertheless, any bias in the data reported to honestjohn.co.uk is expected to be largely consistent over time and should not affect the observed trends in the relationship between the real-world and the type-approval data.

RESULTS

The discrepancy between real-world and manufacturers' type-approval values according to honestjohn.co.uk increased from 3 percent in 2000 to 27 percent in 2011 (Figure 25). A significant difference in results between petrol and diesel vehicles cannot be determined based on the data.

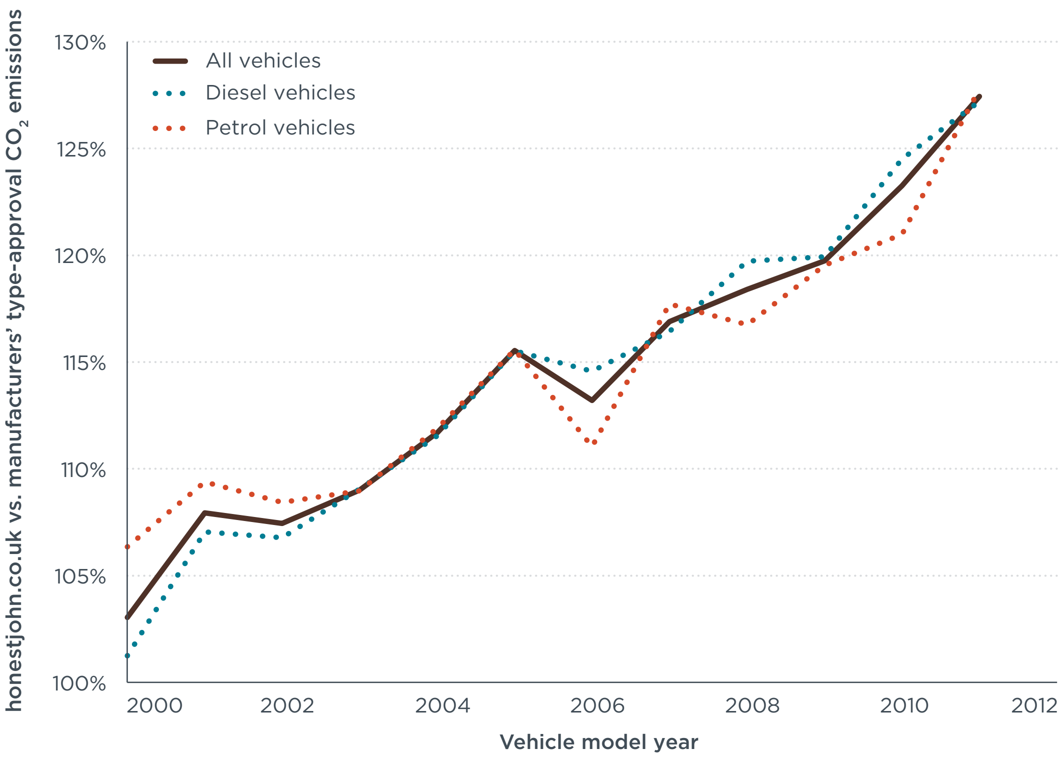


Figure 25. Divergence, honestjohn.co.uk vs. manufacturers' type-approval CO_2 emissions by fuel.

A more detailed analysis is possible only for some vehicle classes—for others, the number of data points per year is too low to allow for a meaningful trend analysis. As Figure 30 shows, no major differences can be observed for the small, lower-medium-sized, medium and upper-medium-sized categories. Overall, each vehicle class follows the general trend of displaying an increasing discrepancy over time.

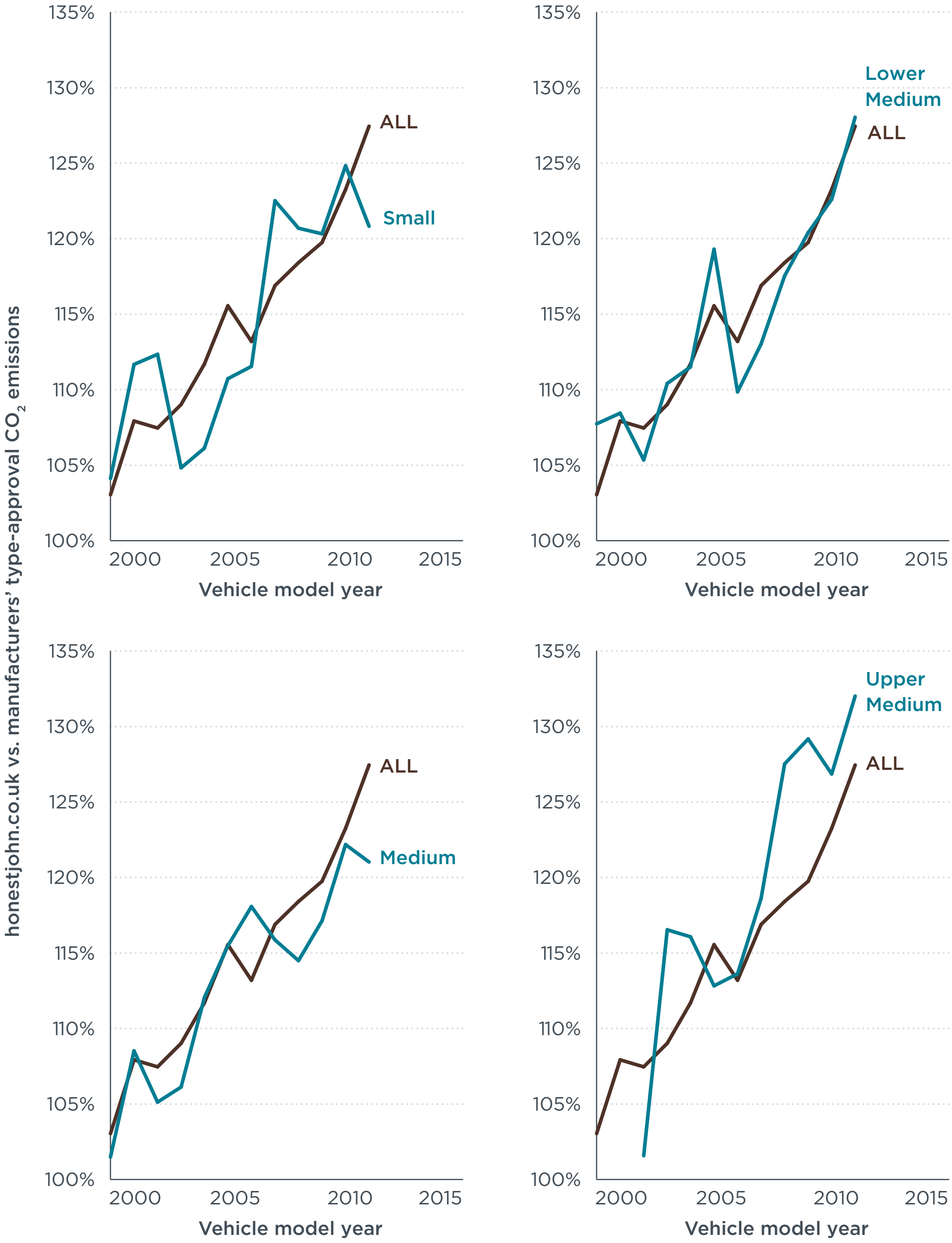


Figure 26. Divergence, honestjohn.co.uk vs. manufacturers' type-approval CO_2 emissions by vehicle segment.

An analysis of the honestjohn.co.uk data by manufacturer/brand does not provide any statistically meaningful results because of the relatively low number of data entries and is therefore not included in this report.

4.1.5 WhatCar? (United Kingdom)

Data type	On-Road
Data availability	2011–12, approx. 174 vehicle models tested
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

The UK magazine *WhatCar?* calls itself "Britain's biggest and best car buyer's guide,"[24] offering a section on its website ("True MPG") where readers can find out about the real-world fuel consumption of various vehicle models.[25] The underlying data source is a series of on-road vehicle tests using Portable Emission Measurement System (PEMS) equipment.[26] These tests are carried out by a company called Emissions Analytics[27] on behalf of the magazine.

The vehicles are driven on a test route that encompasses urban and extra-urban roads with a hot engine and takes about 1.5 hours in total, including extended driving at 112 km/h on the motorway. The average speed during the test is approximately 60 km/h. According to Emissions Analytics, the test route is more aggressive than the NEDC as it has been matched to typical U.K. driving patterns. Vehicles are tested in the default state from the manufacturer. Therefore, any alternative driving settings available, such as "econ" modes, are not used. Air conditioning and other nonessential on-board systems are left switched off. The test drivers, says *WhatCar?*, move at "steady pace, avoiding heavy acceleration and braking whenever possible."[28] During the vehicle test, sensors measure various parameters, including vehicle speed, which allows subsequent adjustment of the CO_2 emissions measured in the test, depending on the volume of traffic and other conditions such as ambient temperature. This ensures that the final CO_2 emission figures are as consistent as possible when comparing the results from different test drives. The results are standardized to 20 degrees Celsius, one atmosphere of air pressure, and average humidity.

In total, 174 vehicle models have been tested by Emissions Analytics on behalf of *WhatCar?* in the time period September 2011 to December 2012, and the results were made available for this analysis. Fifty-seven percent of the vehicles tested are diesel, slightly more than the U.K. average in 2011 (51 percent) (see Figure 27). The distribution across vehicle segments is fairly representative but with fewer small vehicles and more upper-medium-sized and luxury-class vehicles being tested than would be characteristic for the U.K. market. BMW and Daimler cars are slightly overrepresented; Ford and GM cars are underrepresented. The type-approval CO_2 emission value calculated based on the *WhatCar?* data is 136 g/km. This is slightly lower than the U.K. new car average for 2011 (138 g/km). However, it should be noted that the *WhatCar?* dataset is a mix of 2011 and 2012 vehicles, which might explain the difference in CO_2 emission levels.

24 http://www.whatcar.com/truempg/how-we-did-it
25 http://www.whatcar.com/truempg/
26 In this case, SEMTECH-DS from Sensors Inc.
27 http://emissionsanalytics.com/
28 http://www.whatcar.com/truempg/how-we-did-it

Total number of vehicles with *WhatCar?* data evaluated: 174

Figure 27. Characteristics of the *WhatCar?* data analyzed in comparison with the U.K. new car market.

METHODOLOGY

The *WhatCar?* dataset includes type-approval as well as real-world test CO_2 emissions for every individual vehicle model variant tested. The dataset was linked to U.K. sales data for 2011 in order to allow the calculation of sales-weighted averages.

RESULTS

The discrepancy between type-approval and real-world CO_2 emissions based on the *WhatCar?* dataset is 25 percent. A historical analysis is not possible since only data for 2011–12 are available. Also, a more detailed analysis by vehicle segment or manufacturer has not been carried out, owing to the low total number of vehicles tested.

4.1.6 TCS (Switzerland)

Data type	On-Road and Laboratory
Data availability	1996–2012, approx. 20 vehicle models tested per year
Data collection	Laboratory testing + on-road driving for each vehicle, about 3,000 km
Fleet structure, driving behavior	Most popular vehicle models in Switzerland; professional drivers

DESCRIPTION

Touring Club Schweiz (TCS) is Switzerland's largest car club, with about 1.6 million members.[29] Since 1996 TCS has carried out vehicle tests to compare real-world fuel consumption with manufacturers' type-approval values. According to TCS, a key criterion for selecting test vehicle models is their popularity among Swiss car buyers. In total about 15–20 vehicles, provided directly by the manufacturers, are tested in each year. In the early years it was mostly petrol-powered cars, whereas in recent years approximately the same number of gas and diesel vehicles were tested.

TCS carries out two different tests: In an on-road test each vehicle is driven for about 3,000 km, and the real-world fuel consumption is recorded. According to TCS, these on-road tests are usually carried out by the same drivers, whose driving behavior has not changed over the years. The second test for each vehicle is on a chassis dynamometer in a laboratory. The laboratory test is intended to reflect closely the type-approval tests carried out by the manufacturers, making use of the NEDC and the procedures and settings used for type-approval testing.

METHODOLOGY

The dataset provided by TCS includes manufacturers' type-approval values as well as TCS on-road and laboratory test results for each vehicle tested. The percentage discrepancy was ascertained, and an average discrepancy level was calculated for each test year.

RESULTS

Figure 28 summarizes the aggregated results for the test years 1996 to 2012. The discrepancy (measured against manufacturers' results) found by TCS laboratory tests, using the same test cycle and procedure as used for type approval (including using road-load coefficients supplied by the manufacturers), usually is below 4 percent over the entire time period. It should be noted that the Swiss vehicle importers and TCS in 1997 agreed to a maximum allowed discrepancy between manufacturers' type-approval values and TCS *laboratory testing* of 0.6 liters/100km (Schwitzer and Löhrer 2008) (this equals approximately 8–10 percent). At the same time *on-road* discrepancy levels increased from close to zero in 1996 to 22 percent in 2012, with a particularly steep climb since 2008. Because of the low number of vehicles tested in each year, a separate analysis for petrol and diesel vehicles is not regarded as meaningful.

29 See http://www.tcs.ch

Figure 28. Divergence, TCS on-road and laboratory testing vs. manufacturers' type-approval CO_2 values.

4.2 LABORATORY TEST DATA (EUROPE)

In contrast to the datasets examined in Section 4.1, the data that follow are not derived from on-road vehicle tests but instead based on vehicle tests in a laboratory environment. This setting has the benefit that various sources of variability can be controlled, for example, ambient temperature, driving behavior, and air pressure, so that the test results are highly reproducible. The major downside is that a laboratory does not reflect real-world driving conditions. For example, uphill and downhill driving are generally not simulated in the laboratory, accelerations by ordinary drivers are often much sharper than those tested, and fuel efficiency in everyday driving is strongly affected by driving patterns, trip length, and ambient temperature.

4.2.1 ADAC EcoTest (Germany)

Data type	**Laboratory**
Data availability	2002–11, approx. 100 vehicles tested per year
Data collection	Laboratory testing, making use of the NEDC, with an extra high-speed part added, and air conditioning use[30]
Fleet structure, driving behavior	Selection of popular-selling vehicle models; no driving behavior influence in laboratory

DESCRIPTION

Allgemeiner Deutscher Automobil-Club (ADAC) is Europe's largest automobile club, with more than 17 million members. With its Landsberg technical center, ADAC has the facilities to perform vehicle tests similar to the ones that manufacturers carry out for the certification of a new vehicle. In 2002, ADAC started the EcoTest, a program

30 The ADAC EcoTest procedure was changed from 2012 onward; see the text that follows.

"designed to provide a fair, reliable and objective assessment of the environmental performance of cars. Aimed at informing consumers, it provides an incentive for manufacturers and gives credit to those who make eco-friendly cars." (ADAC 2009) The EcoTest is based on European vehicle emission and fuel consumption test procedures but extended by "procedures and parameters to cover a wide range of real-life driving scenarios in Europe." (ADAC 2009)

It should be noted that the ADAC EcoTest procedure was changed in March 2012 to include the new Worldwide Harmonized Light Vehicles Test Cycle (WLTC) and better to reflect up-to-date emissions legislation.[31] For the following analysis only test data up to 2011 was used, to be consistent with other data sources.[32]

The EcoTest consists of three separate tests:

» NEDC cold: duplicating the EU type-approval test (NEDC) but at a slightly lower test cell temperature (22°C) and using the actual weight of the tested vehicle instead of a typically lower NEDC test weight and discrete inertia classes;[33]
» NEDC hot: same as NEDC cold but starting with a warm engine and the air conditioning unit switched on (at a set point of 20°C);
» ADAC motorway: a dedicated cycle for driving on a motorway with speeds up to 130 km/h instead of 120 km/h for the NEDC.

Calculation of the overall EcoTest result is done by first averaging the results of the NEDC cold and NEDC hot tests. Then the result of the ADAC motorway cycle is added, weighting the NEDC average and ADAC motorway shares at 70 percent and 30 percent, respectively.

Testing at a slightly lower test cell temperature and using the actual weight of a vehicle instead of its inertia class is an improvement over the type-approval test procedures and will result in more realistic CO_2 emission values. Adding a motorway component to the NEDC and increasing the top speed for the driving cycle from 120 km/h to 130 km/h also sharpens the representativeness of the test.

However, 70 percent of the EcoTest is still based on the NEDC driving cycle, which in itself cannot be seen as representative of real-life driving behavior (see section 5.2.1). Thus, while the EcoTest was designed to deliver fuel efficiency values that are closer to what consumers will generally experience, in practice it can be expected to deliver results that fall somewhere between type-approval and real-world (such as spritmonitor.de) data.

An important shortcoming of the EcoTest methodology—as for most laboratory tests—is that it uses the same road-load characteristics (to take into account the rolling and air resistance of a vehicle) for the chassis dynamometer as applied by the manufacturer for the type-approval test procedure. There are indications that the current permitted flexibilities in the road-load determination procedure for certification may lead to road-load values that are too low, effectively leading to lower fuel consumption and CO_2 emissions results than are found in real-world driving (Zallinger and Hausberger 2009); Kadijk and Ligterink 2012).

31 See http://www.ecotest.eu/html/EcoTest_%20Protocol_120227_EN.pdf and http://www.zeit.de/auto/2012-03/ecotest-adac-umweltranking for details.

32 Future analysis is bound to include more recent ADAC EcoTest data. However, it is important to note that current vehicles are optimized for the NEDC. It is therefore likely that when testing those vehicles in the WLTC, CO_2 emissions will be higher than for the same vehicles when being optimized for WLTC/WLTP at a later point in time.

33 For historical reasons, the current test procedure makes use of a series of predefined inertia classes or "steps" instead of using the actual weight of a vehicle. This can create an incentive to push a vehicle into a lower inertia class for the testing but at the same time potentially results in less realistic emission test results. For details see http://www.theicct.org/blogs/inertia-classes-vehicle-emissions-tests-and-dead-hand-past.

From 2002 until 2011, ADAC tested 1,284 vehicles in the course of the EcoTest measurement program. A list of all vehicles, including the test results, is available online.[34] Of the 144 vehicles tested in 2011, 57 percent were diesel, more than for the German market overall in that year (47 percent) (see Figure 29). Medium and upper-medium-sized vehicle models are slightly overrepresented in the ADAC EcoTest dataset, at least for the year 2011. BMW, PSA, Renault-Nissan, and Toyota models appear with slightly greater frequency than they do on German roads, while Fiat, Ford, General Motors, and Volkswagen cars fall short of matching their actual market share.[35] ADAC EcoTest vehicles tested in 2011 include other brands as well, such as Hyundai, Honda, and Volvo, which explains why “other” shows up out of all proportion to its importance in the German market. Given the overrepresentation of larger vehicle models in the dataset, it is no surprise that the aggregated 2011 type-approval figure according to the ADAC EcoTest dataset is higher than the German average for that year (151 g/km versus 147 g/km).

34 http://www.adac.de/infotestrat/tests/eco-test

35 It needs to be taken into account that the ADAC EcoTest vehicle model tests are not sales weighted; that is, it is possible that a specific vehicle model is sold more often than others—yet every vehicle model counts the same for this analysis.

Figure 29. Characteristics of the ADAC EcoTest data analyzed in comparison with the German new car market.

METHODOLOGY

The ADAC EcoTest results incorporate the respective type-approval values for a vehicle, as reported by the manufacturer, for comparison. The percentage discrepancy was calculated, and an average discrepancy level was calculated for each test year.

RESULTS

Figure 30 summarizes the discrepancy between testing on a vehicle making use of the refined ADAC testing procedure and manufacturers' type-approval CO_2 emissions. It remains relatively stable at around 5–7 percent for the time period 2002–2007 but then increases steadily to about 11 percent for vehicle tests carried out in 2011. Overall, the extent of the discrepancy is smaller than for the on-road vehicle datasets. This is because the ADAC EcoTest covers only some aspects of real-world driving, and therefore its outcomes predictably are situated in between the NEDC test procedure and driving as experienced by consumers on the road. The ADAC EcoTest results may be further split up into subtests, helping to understand better the underlying reasons for the discrepancies found.[36]

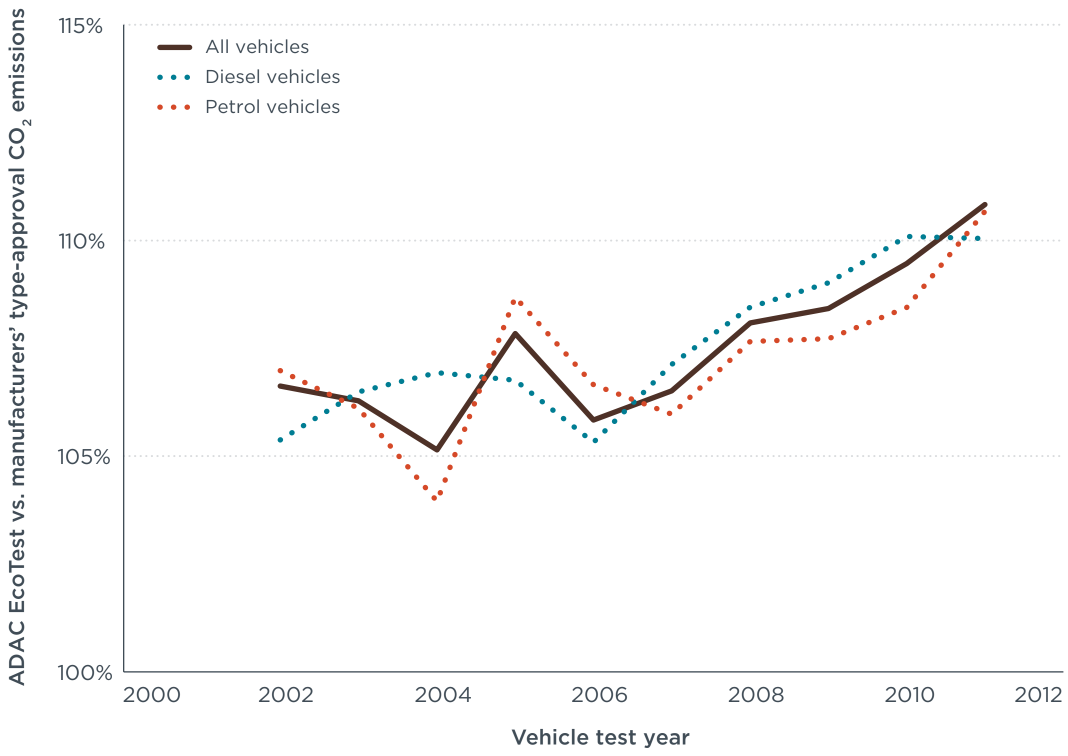


Figure 30. Divergence, ADAC EcoTest vs. manufacturers' type-approval CO_2 emissions by fuel.

A more detailed analysis of the ADAC EcoTest by vehicle segment or manufacturer is not statistically valid, given the comparatively low number of vehicles tested in a specific year.

36 For details, see the previous ICCT Working Paper (Mock et al. 2012).

4.2.2 QueChoisir (France)

Data type	Laboratory
Data availability	2011, 35 vehicle models tested
Data collection	Laboratory testing, making use of the NEDC, with an extra high-speed part added
Fleet structure, driving behavior	Selection of popular-selling vehicle models; no driving behavior influence in laboratory

QueChoisir,[37] or "What to Choose," a magazine published by the Federal Union of Consumers (Union Fédérale des Consommateurs) in France, in 2011 tested 35 vehicle models to determine their real-world fuel consumption (QueChoisir 2011). The tests were based on the NEDC test procedure, except that a segment was added to the test cycle in order to represent highway driving more accurately. The QueChoisir test drive includes speeds up to 130 km/h instead of the 120 km/h used in the NEDC. Other than that, no changes were made to the test procedure.

The test data on average resulted in CO_2 emissions 14.6 percent higher than the manufacturers' type-approval values. The lowest discrepancy was found for a Citroën C4 diesel vehicle (3.8 percent) and the highest for a Ford Focus flexifuel vehicle (47.1 percent). Most of the deviations were found to be between 8 and 20 percent.

The dataset is limited to just one year and—due to the low number of vehicles tested—was not analyzed in any further detail.

4.3 COMPARISON OF EUROPEAN DATA SOURCES

4.3.1 Average values over time

In comparing the various data sources analyzed for this report, one needs to differentiate between on-road and laboratory vehicle tests. While on-road vehicle CO_2 values capture all aspects of real-world driving, including uphill and downhill driving, traffic conditions, ambient temperatures, etc., laboratory tests leave out many. The resulting CO_2 emission levels obtained by laboratory tests therefore are less close to real-world driving than data obtained from on-road tests. On the other hand, a key advantage of laboratory tests is the repeatability of the tests and the results, whereas for on-road data meaningful trends over time can be derived only by aggregating a large number of data points.

Whether comparing results within one of these two main categories or between them, there are common trends over time, as can be seen in Figure 31 and Figure 32.

- Spritmonitor.de data for 2001 to 2011 suggest that real-world driving CO_2 emissions were about 7 percent higher than type-approval values in 2001 but swelled to 23 percent by 2011. The analysis for spritmonitor.de is based on about 5,000 vehicles per year.
- The Travelcard data closely match those of spritmonitor.de, with an increase from 11 percent in 2004 to 28 percent in 2011. The degree of discrepancy is slightly higher than for spritmonitor.de, especially in recent years. Travelcard data analyzed include approximately 15,000 vehicles per year, consisting mostly of company cars having a higher annual mileage than average cars for private use.
- The LeasePlan data for Germany are based on about the same number of vehicles as Travelcard and are also primarily company cars. While not directly comparable, in that it can only show the discrepancy for the current vehicle fleet in a given year, the LeasePlan data also mirror the increase seen in the Travelcard and spritmonitor.

37 http://www.quechoisir.org/

de data. The extent of the disparity increases from 21 percent in 2006 to 33 percent in 2011. Looking at the model year instead of fleet average vehicle age yields an even more pronounced gap.

- The honestjohn.co.uk data covers fewer vehicles (about 3,000 per year) but very closely follows the spritmonitor.de and Travelcard trend lines, with an increase in the discrepancy level from about 8 percent in 2001 to 27 percent in 2011.
- TCS data contain only about 20 tested vehicles per year but support the overall trend found, with an increase from a 7 percent discrepancy in 2001 to 18 percent in 2011.

While the trend is similar for all sources, there are differences in how wide the disparities are. These can be explained by variations in fleet composition and driving behavior.

- Spritmonitor.de users report fuel efficiency (by extension, CO_2 emission) data mostly for private cars, wherein the driver has to pay for fuel. The vehicles are driven on German roads, with some share of driving on the Autobahn, with speeds of 130 km/h and higher, a range that is not covered by the NEDC-based type-approval test. Furthermore, it is likely that spritmonitor.de users are generally more aware of their fuel efficiency, as they voluntarily report their driving data to the website.
- LeasePlan cars are company cars, for which the driver does not have to pay for fuel. The cars are—as with spritmonitor.de—driven mostly on German roads. However, according to LeasePlan, the share of Autobahn driving is especially high for LeasePlan vehicles.

Both these considerations make it likely that the discrepancy is higher for LeasePlan cars than for spritmonitor.de cars:

- CO_2 emission levels are in an optimum at speeds of approximately 60–80 km/h and increase rapidly toward lower and higher speeds. The NEDC extends only to a maximum speed of 120 km/h, thereby not taking into account higher speeds with drastically higher CO_2 emission levels, as observed for Autobahn driving.
- Drivers who have to pay for fuel themselves are more likely to drive in a way that minimizes fuel consumption and CO_2 emissions.

The Travelcard data rest in between those of LeasePlan and Spritmonitor.de. While the profile of drivers is similar to that of LeasePlan, driving speeds above 130 km/h are illegal in the Netherlands. Also, company cars in the Netherlands most likely tend to be driven more on urban roads than in Germany. This might explain why the CO_2 emissions of Travelcard cars are closer to the NEDC values and the degree of disparity is therefore lower than for LeasePlan drivers. In the United Kingdom, the speed limit on highways is set at 70 mph (112 km/h), suggesting that driving at high speeds is less common than in Germany. Yet, the level of discrepancy for honestjohn.co.uk data, for most years, is higher than that for the spritmonitor.de data. To understand in detail what circumstances led to this observation, a thorough analysis of driving behavior in both countries would be needed, which is outside the scope of this report.

For *WhatCar?* there is only one data point available, for 2011. The discrepancy stands at 25 percent, which is in between the spritmonitor.de and Travelcard/honestjohn.co.uk readings for the same year.

Potential underlying reasons for the growth in the disparity between type-approval and real-world results for fuel efficiency and emissions are discussed in detail in Chapter 5.

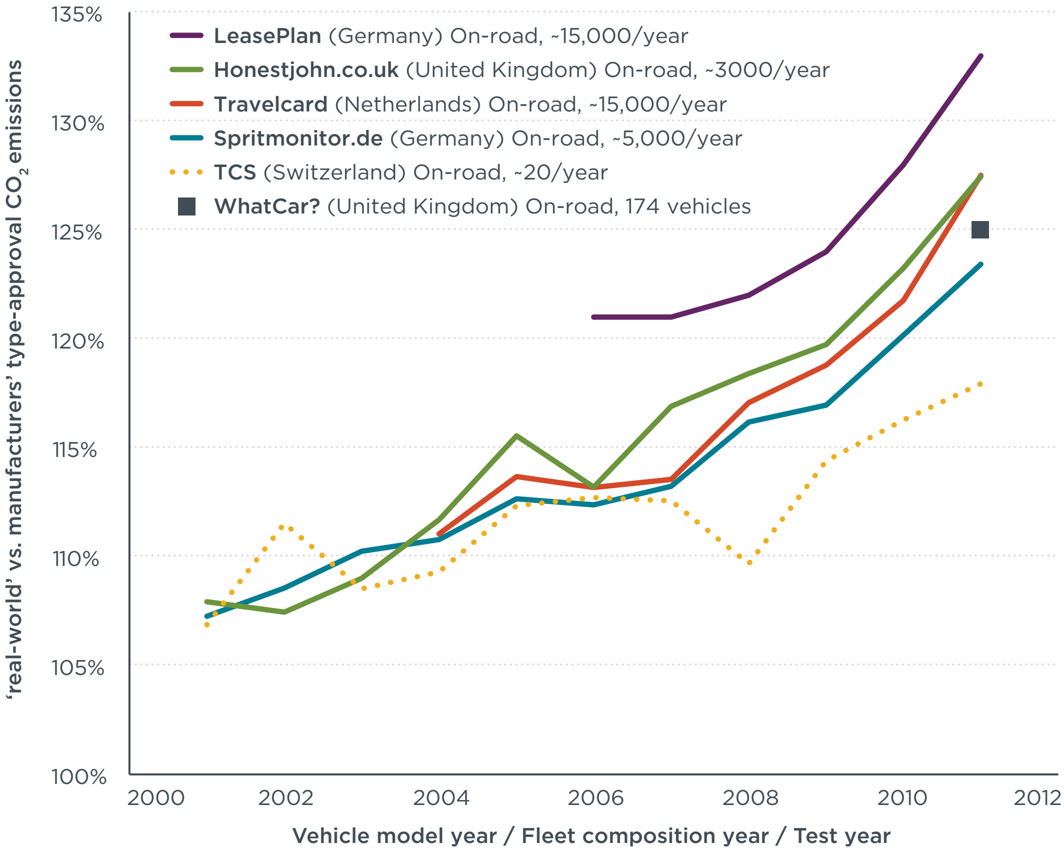


Figure 31. Divergence, real-world vs. manufacturers' type-approval CO_2 emissions for various on-road data sources.[38]

38 The TCS trend line is dotted to indicate that it is based on a much lower number of vehicles tested than for the other data sources.

The discrepancy displayed for various forms of laboratory data is—as expected—lower than that for on-road data (see Figure 32). ADAC EcoTest data, grounded in laboratory tests of about 100 vehicles per year, shows an increase from 7 percent of type-approval figures in 2002 to 11 percent in 2011. The EcoTest data are largely based on the NEDC, with a high-speed component of up to 130 km/h, the use of air conditioning, and some other elements added. In contrast, the TCS laboratory testing follows closely the type-approval procedure, without any highway driving or air conditioning use. As can be seen, this leads to a relatively small discrepancy level of about 3 percent for most years. *QueChoisir* tested 35 vehicles, also based on the NEDC, adding a high-speed segment of up to 130 km/h. The average disparity for this small dataset was 15 percent in 2011.

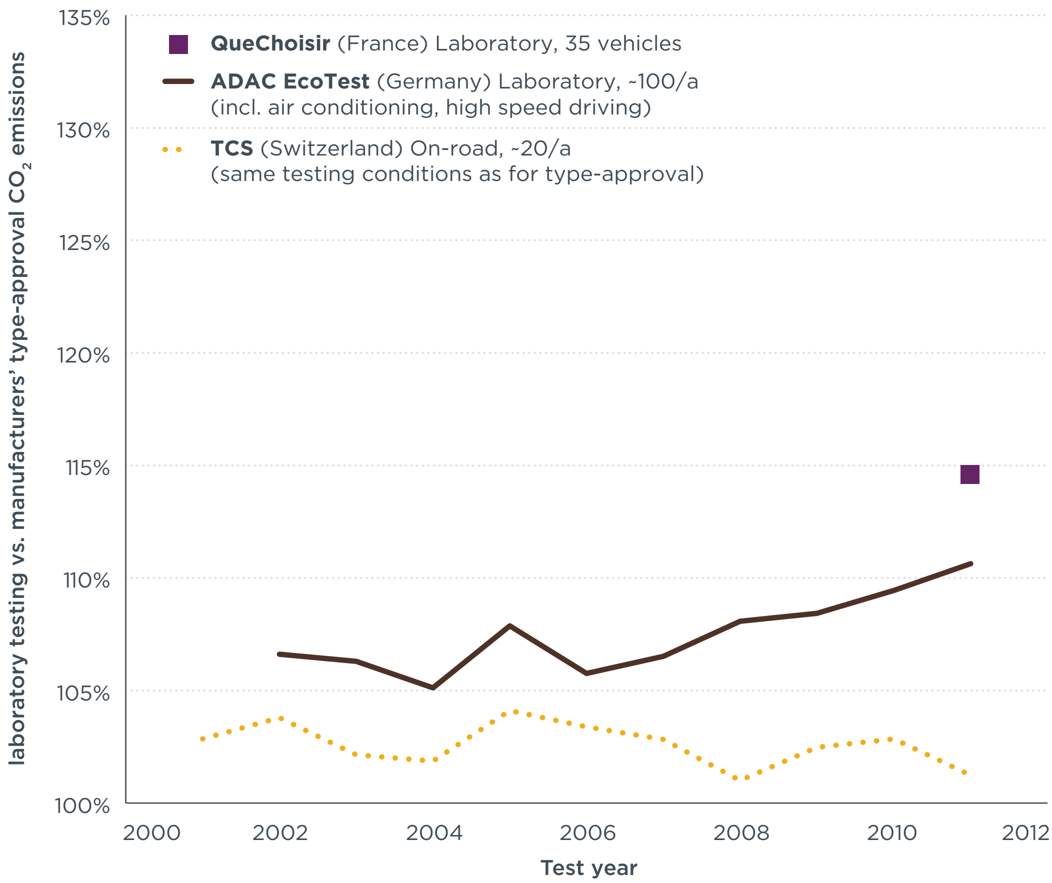


Figure 32. Divergence, real-world vs. manufacturers' type-approval CO_2 emissions for various laboratory data sources.

More important than the extent of the discrepancies, which is explicably different for each dataset, is the way in which they change over time. While data-gathering methodologies, driving behavior, vehicular fleet profiles, and so forth may differ for the various data sources, they are all fairly internally consistent. Hence, one would expect the discrepancy to remain approximately constant for each dataset. Instead, what the analysis repeatedly found in every case—except for the TCS laboratory values—is significant broadening of the real-world vs. type-approval disparity in subsequent years.

As Figure 33 shows, the average annual rate of increase in the level of discrepancy[39] is between 8 and 14 percent for the various data sources, looking at all the data available for each of the sources (time period 2001–11 or shorter, depending on data source). Focusing only on the time period 2008–11, the rates tend to be higher, between 12 and 19 percent, suggesting that the speed at which real-world and type-approval data diverge from each other has picked up since 2008.

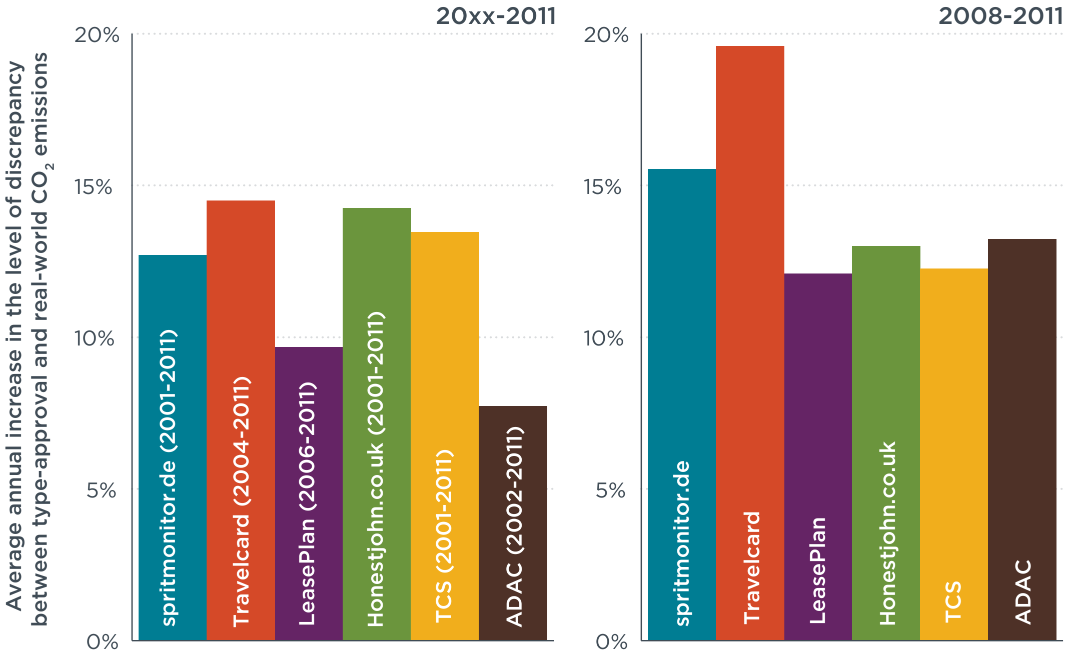


Figure 33. Annual average increase in the level of discrepancy between type-approval and real-world CO_2 emissions.

39 For example, an increase from a 10 percent discrepancy in year x to 11 percent in year x+1 is a 10 percent annual rate of increase

For Germany (the country with the most datasets available in the context of this analysis) Figure 34 shows the average level of CO_2 emissions for the vehicle fleets in each of the datasets examined, together with the degree of type-approval versus real-world discrepancy in CO_2 emissions. According to the CO_2 emission monitoring, emissions of new cars in Germany decreased from 180 g/km in 2001 to 146 g/km in 2011. This is based on type-approval data, hence there is no discrepancy. The level of CO_2 emissions from other sources is different owing to their differing fleet composition.[40] For example, the starting point for spritmonitor.de data, looking at the type-approval values given for the vehicles analyzed, was 175 g/km in 2001, and the endpoint in 2011 was 147 g/km. The disparity with real-world figures increased from 7 percent in 2001 to 23 percent in 2011.

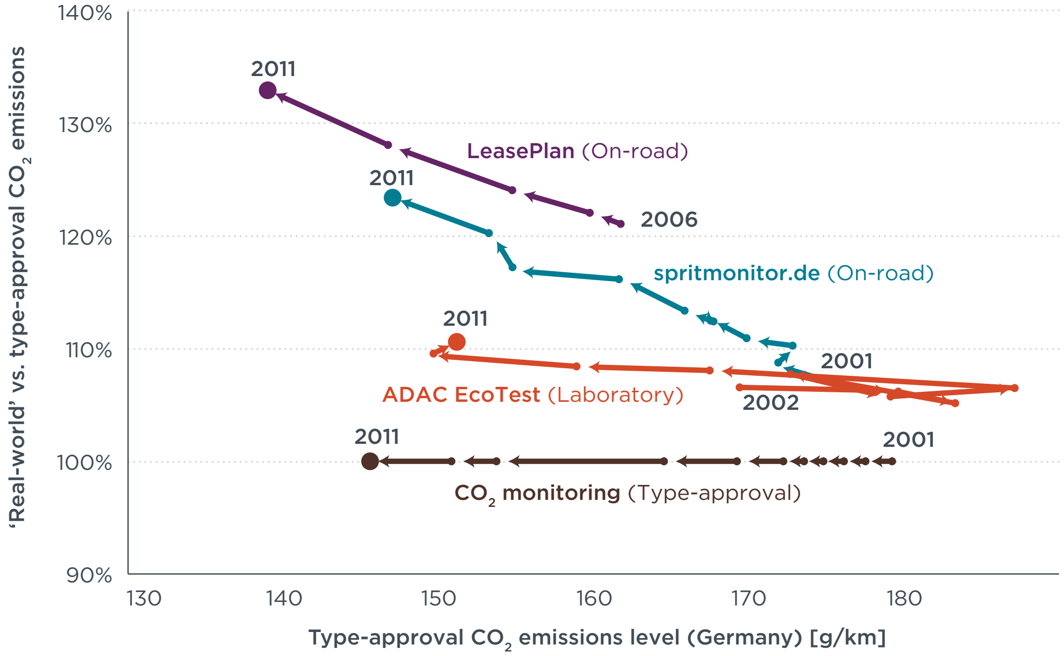


Figure 34. Absolute CO_2 emission level and discrepancy for various German datasets.

40 Note that the change in CO_2 over time is also related to shifts in the fleet composition.

Figure 35 depicts the two sources with the best data availability for Germany:

» Spritmonitor.de data as a proxy for new vehicles, both private and company cars, under real-world driving conditions,

» ADAC EcoTest data as a proxy for new vehicles under laboratory conditions that are somewhat more realistic than those for NEDC certification.

Between 2002 (the ADAC EcoTest data series begins only in 2002) and 2011, CO_2 emissions as measured in the NEDC dropped by 18 percent. As the figure demonstrates, spritmonitor.de data suggest that real-world CO_2 emissions fell by only 7 percent over the same time period. ADAC EcoTest data lie in between, showing an 11 percent decrease in emissions.

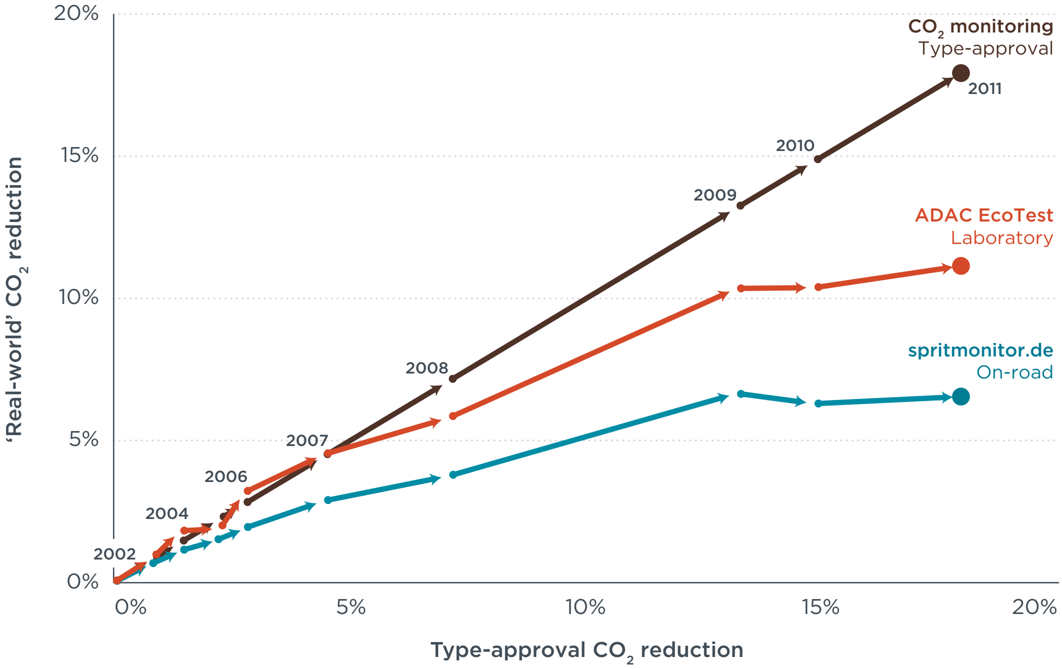


Figure 35. Germany: 2002–11 real-world CO_2 reduction vs. type-approval CO_2 reduction.

Assuming that the results from Germany can be extrapolated to the entire EU vehicle market, the real-world CO_2 emission level of new passenger cars in Europe would be higher than what is suggested by the type-approval values. Taking the EU CO_2 monitoring data—drawing on vehicle type approval—as basis and applying the respective discrepancy levels for each year derived from spritmonitor.de data results in a hypothetical real-world CO_2 trend line for the EU new car market. Emissions, by the reckoning of the spritmonitor.de data, would have decreased from about 182 g/km in 2001 to 167 g/km in 2011, instead of 170 g/km to 135 g/km as suggested by type-approval values (see Figure 36).

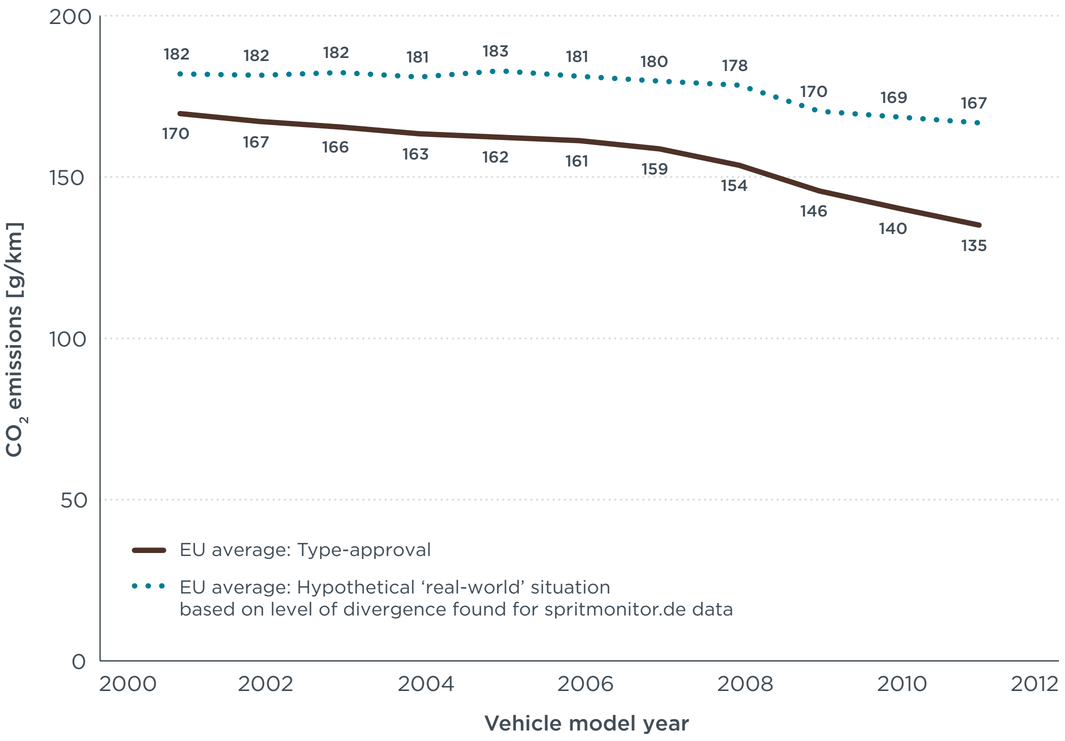


Figure 36. Applying spritmonitor.de and ADAC EcoTest findings to the EU average.

4.3.2 By vehicle segment

In the context of this report, spritmonitor.de, Travelcard, and in some cases honestjohn.co.uk data can be analyzed by vehicle segment over a period of time. Figure 37 summarizes the trends found in the datasets and compares them. While the widening of disparities between real-world and test-approval emissions is the same for all three datasets, there are some differences in their results when broken down by vehicle segments.

For the *mini segment*, only data from spritmonitor.de and Travelcard could be analyzed; for honestjohn.co.uk insufficient data points were available for a meaningful statistical analysis. The level of discrepancy was similar for both datasets in the years 2005 and 2006 but then increased drastically in the Netherlands, whereas in Germany it increased much more slowly. While the mini segment in the Travelcard data includes almost only petrol-fueled vehicles, the spritmonitor.de mini data were split up into petrol and diesel. However, even when comparing only spritmonitor.de data from petrol-powered cars with Travelcard data, the large difference in the degree of discrepancy between the two remains.

For the *small-vehicle segment*, a similar difference between Travelcard and spritmonitor.de data can be found. Yet, when focusing only on petrol vehicles in the Travelcard data, the difference is much smaller. It is mostly the small diesel vehicles that contribute to the pronounced growth in the level of discrepancy for the small-vehicle segment in the Netherlands. The honestjohn.co.uk data for the small-vehicle segment closely follow the trends observed in the spritmonitor.de dataset.

The large difference between the Travelcard data and other datasets for the mini- and small-vehicle category might be linked to the change in vehicle taxation that occurred in the Netherlands in 2008. Since that time the vehicle registration tax has been closely coupled with vehicle CO_2 emissions (about 100 euros or more per gCO_2/km) and can amount to several thousand euros (ACEA 2012). Exemptions are granted for vehicles with relatively low CO_2 emission levels. For company cars there is an additional tax in place that is also dependent on the level of CO_2 emissions. Vehicles with less than 110 g/km (petrol) or 95 g/km (diesel) emissions are currently subject to a lower tax rate. In the course of these changes in the taxation system, the share of new mini and small vehicles in the Netherlands new vehicle market significantly increased. The share of mini and small company vehicles likely increased over time as well. Analyzing this development and its potential impact on the level of discrepancy between real-world and type-approval values—potentially a strong incentive to demonstrate CO_2 emission values during type approval of vehicles that are below the taxation thresholds—is outside the scope of this study.

For the *lower-medium-sized and medium vehicle segments* the results from the spritmonitor.de, Travelcard, and honestjohn.co.uk datasets are very close to each other, as can be seen in Figure 37. For the upper-medium-sized vehicle segment the data suggest a lower level of discrepancy for the Travelcard dataset than for the others. However, the differences are not as pronounced as for the mini- and small-vehicle segments.

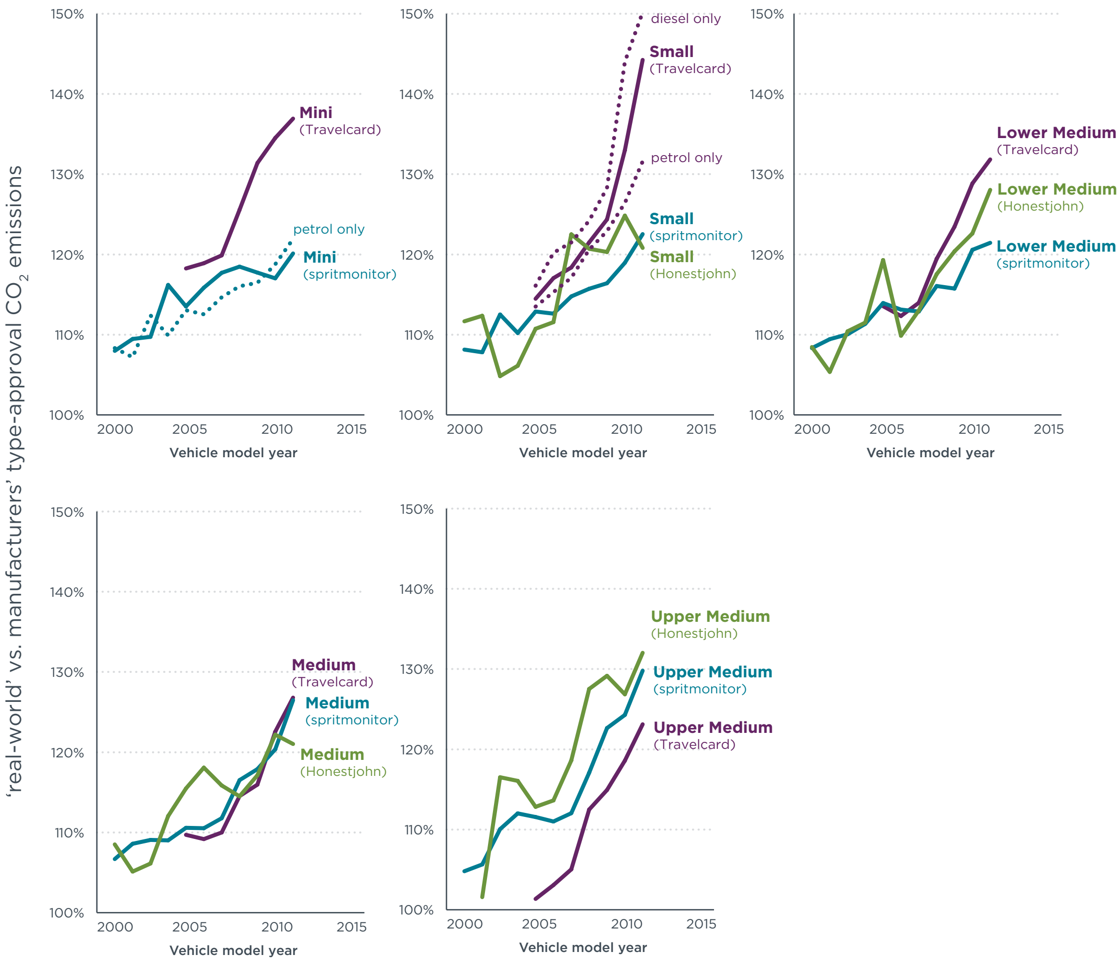


Figure 37. Comparison of spritmonitor.de, Travelcard, and honestjohn.co.uk by vehicle segment.

Figure 38 summarizes the trends found for spritmonitor.de, Travelcard, and LeasePlan when aggregating the data at 5 g/km CO_2 intervals. For spritmonitor.de a weak trend of higher discrepancies for low-CO_2 vehicles is observed. The level of discrepancy, both for petrol and diesel vehicles, is closer to 20 percent for vehicles with higher emissions and closer to 30 percent for vehicles with lower emissions. For Travelcard this trend is more evident, especially for diesel vehicles, with a discrepancy level of more than 40 percent for low-CO_2 vehicles. As in the discussion above making comparisons among vehicle segments, the underlying reason for this observation is the strong difference in discrepancies found for the mini- and small-vehicle segments for Travelcard versus spritmonitor.de. The LeasePlan data allow an assessment only for diesel vehicles and show a pronounced trend toward increasing discrepancy levels for low-CO_2 vehicles. However, it should be noted that the LeasePlan dataset includes only few vehicles with very low CO_2 emission levels, hence only a qualified interpretation of the LeasePlan findings is possible.

In summary, it must be said that a clear trend toward higher discrepancies for low-CO_2 emission vehicles cannot be found from the data analyzed. Such a tendency is evident for the Travelcard dataset but may be caused by country-specific framework conditions, and it cannot be directly confirmed by other sources, such as spritmonitor.de. Finally, it should be noted that, when focusing on the absolute discrepancy levels (in g/km CO_2 emissions) rather than the percentage levels, the differences between low- and high-CO_2 emission vehicles are smaller for all data sources.

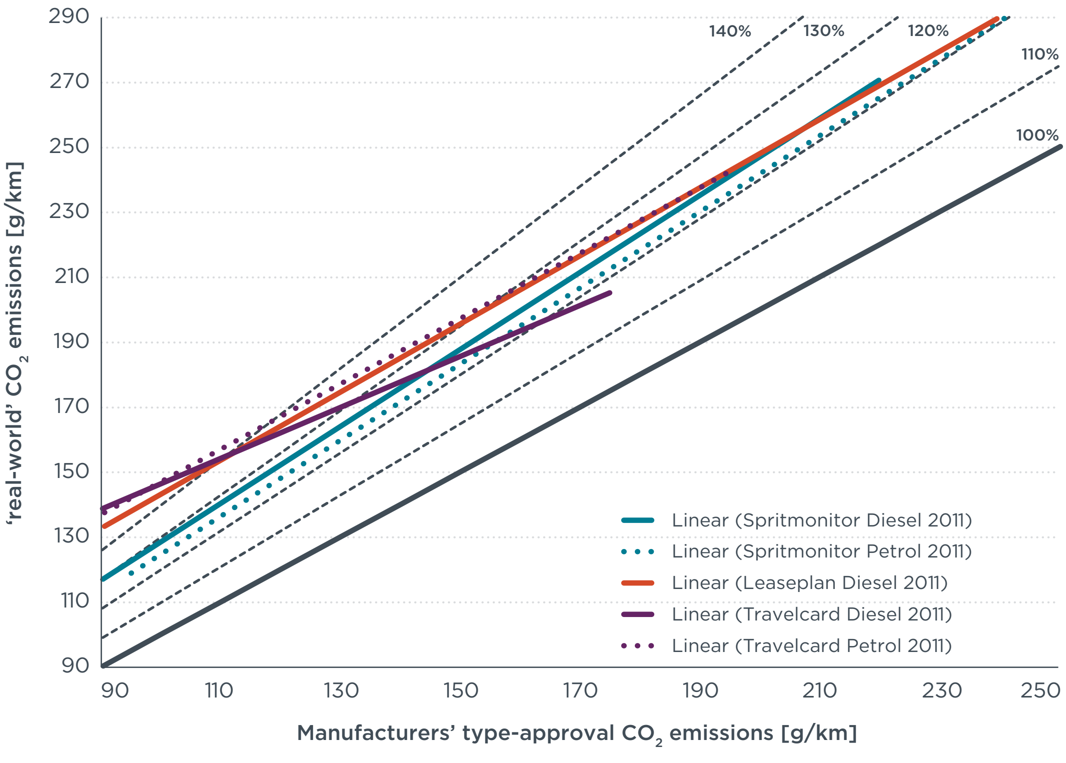


Figure 38. Real-world vs. type-approval CO_2 emissions by CO_2 emission category.

4.3.3 By manufacturer / brand

Analyzing the spritmonitor.de and Travelcard data by vehicle manufacturer and brand in most cases results in similar trends over time (see Figure 39). Notable differences can be found only for Fiat and Toyota.

In the case of Toyota, by splitting the Travelcard statistics into hybrid and nonhybrid classes, one finds that the nonhybrid results are comparable to those from spritmonitor.de. Hybrid vehicles make up approximately 25 percent of vehicle sales of Toyota in the Netherlands but only about 7 percent in Germany.[41] At the same time, the difference between NEDC type-approval and real-world CO_2 emission levels of hybrid vehicles observed in the Travelcard data tends to be especially large. One possible explanation might be that, because Travelcard vehicles are mostly company cars, the hybrid vehicles are to a significant extent driven on highways, while they can demonstrate their full CO_2 reduction potential only in urban traffic conditions.

For Fiat, the vehicles in the Travelcard data are generally compact cars. The average type-approval value is below 120 g/km, yielding a large relative discrepancy between type-approval and real-world CO_2 emissions. In terms of the absolute difference the values are more similar to other brands.

As mentioned earlier (see section 4.1.1), various manufacturers' data often cannot be directly compared: differences in driving style and vehicle use need to be taken into account, and ideally manufacturers with a similar customer base should be compared with each other. Another concern is the use of technologies that potentially show a greater benefit during type approval than during typical on-road driving. This matter will be discussed further in Chapter 5.1.2 but is highly relevant, for example, when comparing the BMW trend line with those of other manufacturers. The market share of new BMW vehicles equipped with start-stop technology increased quickly from 2007 to 2010 and was around 30 percent in 2010, while the new vehicle market average in the same year was still below 10 percent.[42] The NEDC consists of about 25 percent idling time, an instance where start-stop technology can demonstrate significant CO_2 savings. In real-world driving, the frequency of idling is lower for most customers, especially if driving mostly on extra-urban roads and highways. By its early introduction of the start-stop technology, BMW therefore most likely increased the discrepancy between type-approval and real-world CO_2 emissions, while other manufacturers are still catching up with this development and may well reach similar levels with increasing adoption of start-stop in their own vehicle fleets.

Data from honestjohn.co.uk is not differentiated by manufacturer/brand because of the smaller number of data entries, which does not allow for a meaningful statistical analysis. Similarly, for Daimler, insufficient vehicle numbers are included in the Travelcard dataset to allow for the construction of any meaningful trend lines over time.

41 Based on internal ICCT data estimates.
42 Based on internal ICCT data estimates.

Figure 39. Comparison of spritmonitor.de and Travelcard by brand/manufacturer.[43]

43 GM = General Motors (Opel); PSA (Peugeot, Citroën).

4.4 ON-ROAD DRIVING DATA (UNITED STATES)

Data for the United States are analyzed separately here from the EU data. The reason is that both the test cycle and test procedure to determine vehicle CO_2 emissions data are different from the way type-approval data are collected in the EU. Furthermore, the United States has an in-use compliance program to ensure that prototype/early-production vehicles chosen for type approval are representative of the mass-production vehicles that are delivered to customers later on (Maxwell and He 2012). Finally, driving behavior of customers in the United States is likely to be substantially different from that in the EU.

4.4.1 DOE/EPA "My MPG" (United States)

DESCRIPTION

In the United States, the website fueleconomy.gov,[44] run by the U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA), provides fuel consumption data as well as emissions data for new and used cars. The website also offers a section called "My MPG," where users can register and input real-world fuel consumption data for their own vehicles. Depending on personal preference, users can opt to make these data available to others or keep it private.

When registering, as a first step, users have to select their vehicle from a list of all available models. They must choose the vehicle model year, the make, the model name, and engine and transmission options.

For entering consumption data, "My MPG" offers three different options:

1. Users can enter the fuel consumption rate (in miles per gallon) directly ("MPG I have calculated") as well as an estimate of the time range for which the figure was computed, the underlying driving conditions, and the number of fill-ups on which the calculation is based.
2. Users can choose to use a virtual diary, whereby one can keep track of fuel purchases by typing in the fill-up date, the miles traveled between fueling events, the gallons purchased, and some additional information on driving conditions.
3. Users can simply record the odometer reading, date, and the gallons of fuel purchased, in which case, a virtual diary is again displayed.

A sample of the "My MPG" database, including the aggregated fuel consumption data,[45] was provided to the ICCT by Oak Ridge National Laboratory.

METHODOLOGY

Before analyzing the "My MPG" data, a number of steps were necessary to filter and compile the information. Only data from registered users who had agreed to share with others was selected. Where only odometer readings were provided, the resulting fuel consumption in MPG was calculated, making sure that only plausible odometer readings were chosen.

44 http://www.fueleconomy.gov/
45 From January 2013.

The final dataset contained

1. MPG values calculated by the users themselves for 22,750 vehicles
2. MPG values computed from trip mileage provided by the users for 8,350 vehicles
3. MPG values derived from odometer readings supplied by users for 7,897 vehicles

The real-world MPG figures were converted into CO_2 emission equivalents and juxtaposed with the official CO_2 data for each vehicle model as found in the DOE/EPA "Find a Car" table.[46] Linking the two datasets was possible since a common identifier was readily available in both tables. Finally, the data were aggregated according to model year by averaging the differences between real-world and official CO_2 emission values based on the number of vehicle entries in the "My MPG" dataset.

RESULTS

Figure 40 summarizes the trends indicated by the data. In the United States, a distinction is made between the MPG provided by the manufacturer based on vehicle certification tests and the "adjusted MPG", a value that is based on the unadjusted MPG but combined with a specific multiplier to provide more accurate fuel consumption information.

Looking at the unadjusted values, according to the data, up until about 2003 the discrepancy between real-world and type-approval CO_2 values was consistently around 20 percent. From 2004 onward it steadily increased to about 35 percent in 2012. Petrol-powered vehicles make up the majority of passenger cars in the United States, although from 2000 forward limited data for diesel and hybrid vehicles are available as well. According to these figures, the discrepancy for hybrid vehicles typically is greater than that for petrol-only vehicles, with a similar upward-sloping trend line. For diesel vehicles the discrepancy is smaller and seems to have remained steadier over recent years. However, because conventional gas-powered vehicles predominate, neither diesels nor hybrids have any significant influence on the overall degree of discrepancy.

The EPA applies a correction factor to adjust the MPG ratings determined by vehicle tests and make them closer to what consumers experience in real-world driving. This correction factor was updated in 2008.[47] However, all values in this analysis make use of the post–2008 correction factor to provide a consistent data series. As seen in the figure, the trend line that is based on adjusted MPG mirrors the contours of the unadjusted MPG values. Only the absolute level of discrepancy is different, with the adjusted values being close to 90–100 percent of the type-approval values, while the disparity for the unadjusted figures is substantially greater. For hybrid vehicles, the discrepancy level found is closer to the fleet-wide average when using the adjusted MPG numbers. This indicates that the updated correction factor, which now is nonlinear and adjusts higher MPG numbers (as typically found for hybrid vehicles) more than lower MPG numbers,[48] results in more realistic adjusted MPG values for hybrid vehicles.

46 http://www.fueleconomy.gov/feg/ws/
47 See http://www.fueleconomy.gov/feg/ratings2008.shtml.
48 See http://www.epa.gov/carlabel/basicinformation.htm.

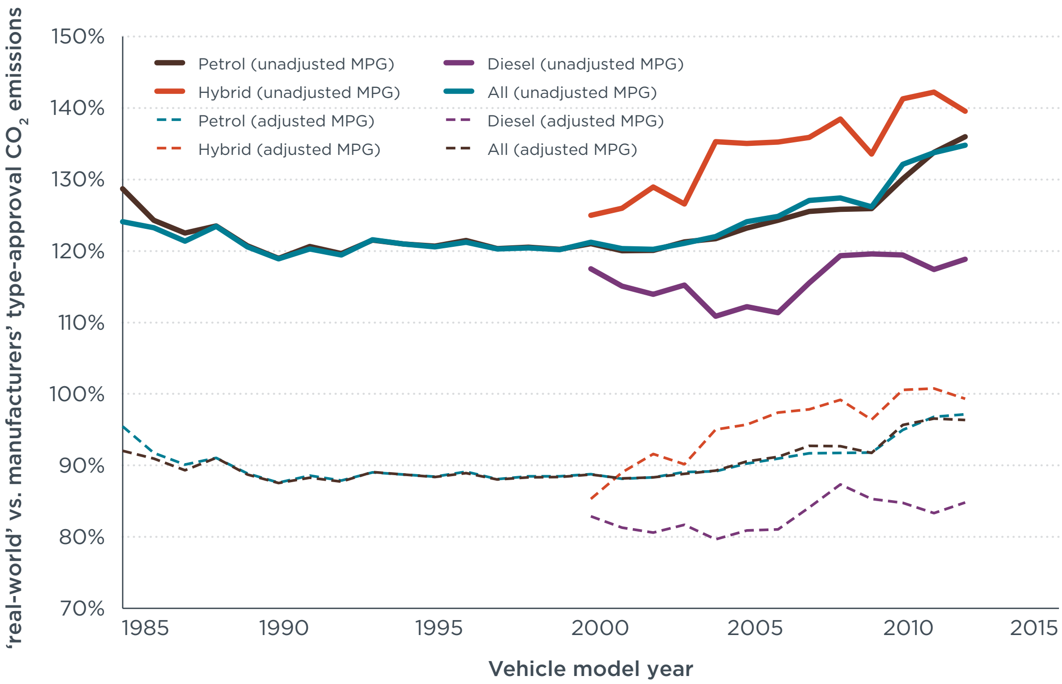


Figure 40. "My MPG" real-world vs. official CO_2 emissions by vehicle model year.

In total, about 38,000 vehicle data entries were analyzed. However, as Figure 41 shows, the availability of data varies widely for different vehicle model years, with the bulk coming from the model-years 2005–2008.

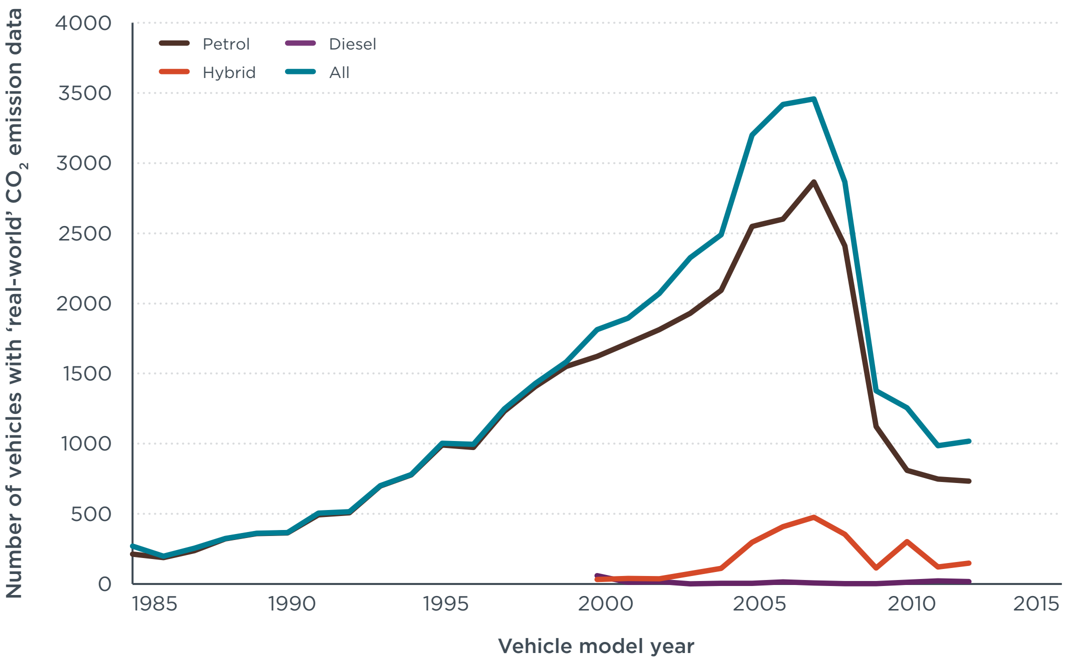


Figure 41. Number of vehicles with real-world fuel consumption data in the "My MPG" dataset by vehicle model year.

The "My MPG" website was launched around 2004, so data entries began only at that point. Since the dataset includes model years prior to 2004, the vehicles in some cases were 15 or more years old at the outset. To make sure that the aggregate age profile did not affect the results, it was necessary to examine whether any correlation between model year and vehicle age in terms of their effect on the level of discrepancy could be found.

As Figure 42 demonstrates, the level of discrepancy rises with later model years. However, within a model year, no effect of vehicle age was found. In other words, vehicles of the same model year tend to show approximately the same degree of discrepancy, no matter how old the vehicles were at the point when the data were entered into the "My MPG" database.

	MODEL YEAR																												
VEHICLE AGE	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0-1																				123%	124%	127%	126%	127%	127%	125%	132%	134%	135%
2																				123%	123%	125%	122%	125%	127%	129%	132%		
3																		114%	121%	119%	122%	120%	123%	128%	128%	129%			
4																		120%	120%	122%	119%	119%	124%	127%	128%				
5																	122%	123%	119%	120%	120%	127%	125%	126%					
6																122%	121%	121%	120%	121%	125%	126%	123%						
7															121%	120%	121%	117%	122%	121%	122%	123%							
8														120%	119%	120%	120%	124%	121%	122%	126%								
9													120%	120%	120%	119%	124%	123%	120%	122%									
10												118%	125%	118%	117%	124%	121%	122%	120%										
11											118%	122%	122%	119%	126%	117%	120%	120%											
12										122%	117%	120%	116%	126%	124%	119%	121%												
13									116%	122%	120%	118%	128%	120%	123%	121%													
14								121%	118%	119%	118%	129%	124%	117%	124%														
15-...	124%	124%	123%	121%	123%	121%	119%	120%	121%	122%	127%	119%	118%	121%															

Figure 42. Discrepancy between real-world and type-approval CO_2 emission values for vehicles in the "My MPG" dataset, differentiated by model year and vehicle age.

For the United States, the data examined in the context of this paper are seen only as a starting point for future analysis. For some preliminary conclusions based on the available U.S. data, see Chapter 6.

5 POLICY CONTEXT

The data gathered in Chapter 4 indicate that a gap exists between manufacturers' type-approval (officially certified) values for fuel consumption (which serves as a proxy for CO_2 emissions) and the fuel consumption rates reported by customers. Moreover, this gap has increased over recent years. This chapter will investigate the reasons for this persistent disparity as well as its tendency to grow over time and what the implications are for different stakeholders such as consumers, the automotive industry, and officials in charge of tax policy and environmental legislation and regulation. It also outlines the development of a new test procedure that will address some of the current NEDC test procedure's shortcomings. Finally, it will offer recommendations on supplementary solutions, beyond revamping the standard laboratory tests, to further narrow the gap. The focus of the discussion will be on the EU regulation, with some remarks about and links to the situation in the United States.

5.1 CURRENT TYPE-APPROVAL TESTING

When analyzing the underlying reasons for the observed discrepancy between type-approval and real-world CO_2 emissions, one has to differentiate between two different elements:

» Aspects that are constant over time and are responsible for an inherent gap between type-approval and real-world values.

» Aspects that change over time and potentially explain the increase of the gap over time.

Section 5.1.1 will focus on those aspects that are constant over time and related to the concept of type-approval testing itself, while section 5.1.2 will summarize the elements that changed in recent years. In section 5.1.3 the impacts of both aspects from the perspective of various stakeholders will be discussed in more detail.

5.1.1 Purpose and concept of type-approval testing

When the first test procedure and the New European Driving Cycle (NEDC) were introduced back in 1970, the purpose was mainly to reduce pollutant emissions. The driving cycle was not necessarily developed as being representative of real-life driving; it was merely an abstract representation of some everyday driving conditions. For pollutant emissions the objective was to reduce emission levels drastically (for example nitrogen oxide diesel emission standards were tightened by 60 percent from Euro 3, introduced in 2000, to Euro 5, introduced in 2009), and the precision needed was (and still is) lower than what is needed for CO_2 emissions. Fuel consumption was also measured, to be used as customer information, but there were no regulatory consequences attached to it. So the type-approval test was never intended to serve as a means to derive a representative CO_2 value. It was designed primarily as a reproducible test method to verify if pollutant emissions complied with the limits and to a lesser extent to provide a basic figure for fuel consumption. This is very different from what policymakers require today.

Even if the objective is to come up with a representative drive cycle and test procedure, it is still difficult to define what 'representative' means for a type-approval test. Though most people think they have a general understanding of what is meant by "representative driving conditions," in practice, these are not so easy to define, considering that there are

» differences in vehicles and vehicle performance,

» distinctions among car owners and their driving style, and

» variations in vehicle use and circumstances (trip length, ambient temperature, infrastructure quality, traffic conditions, etc.).

Figure 43 shows as an example the range of reported fuel consumption from the Travelcard data for one particular vehicle type, which is tied only to differences in vehicle use and ownership.

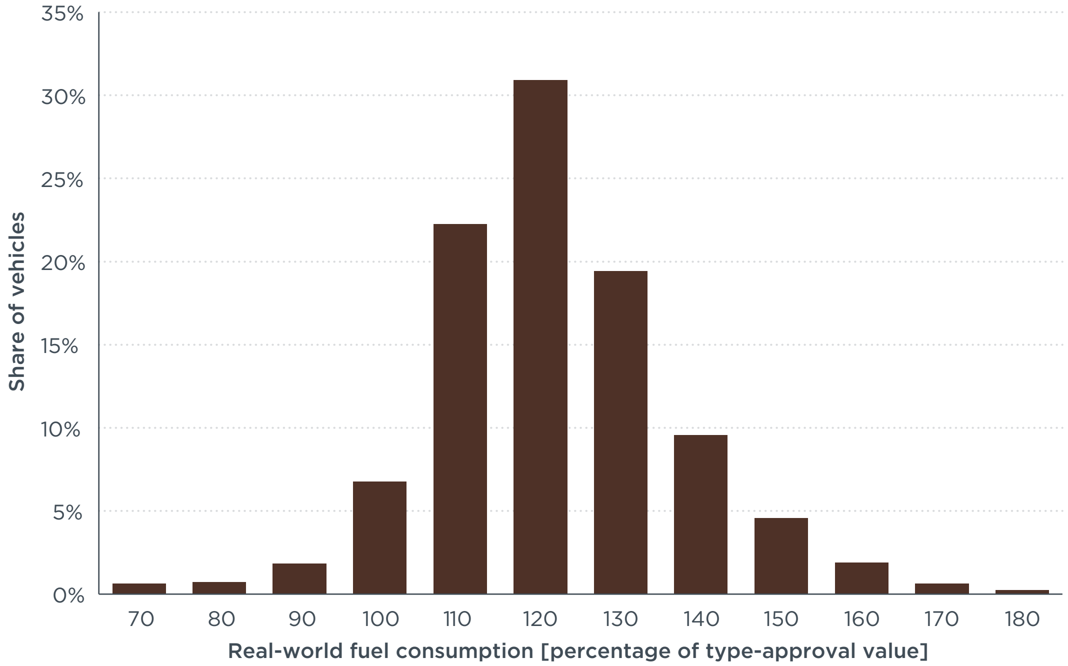


Figure 43. Range of reported fuel consumption from Travelcard data for a common vehicle type.

This figure shows that fuel consumption rates for the same kind of vehicle can vary widely, depending on how it is used. In this example, they range from 70 to 180 percent of the type-approval number. The representative fuel efficiency for this vehicle could be defined as the average of all data entries, weighted according to the individual driving distances. To determine this particular fuel efficiency from one test would require a driving cycle that comprises all of the fuel-consumption-relevant characteristics, including ambient temperature. This shows that it is not easy to develop a driving cycle that is truly representative. It would require a lot of real-life driving data as well as decisions on how to weight these.

A further consequence—specifically for a type-approval test cycle—is that it needs to be appropriate for every vehicle. This means, for example, that even underpowered vehicles have to be able to perform the accelerations of the driving cycle. For a high-powered sports car such modest pickup will be far from real-life driving behavior.

Besides representativeness, another principal consideration—is reproducibility. Finding a satisfactory compromise between representativeness and reproducibility in some cases is a serious challenge, as illustrated by the example of state of charge (SoC) for the starter battery (see Figure 44. Relationship between the best case, worst case, real-life operation range, and representative value for a vehicle parameter.).

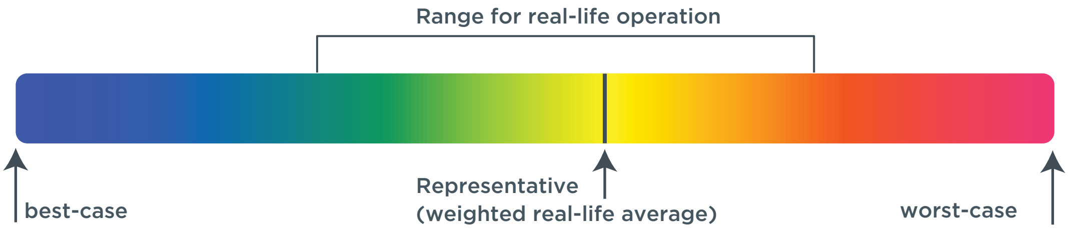


Figure 44. Relationship between the best case, worst case, real-life operation range, and representative value for a vehicle parameter.

There is no way to measure accurately the actual SoC of a starter battery. The only values that can be practically determined are 0 percent (empty battery) and 100 percent (fully charged). Still, it is a relevant parameter since the CO_2 emissions will be higher if the SoC increases over the course of the test cycle and vice versa. For normal operation of a vehicle, the SoC can vary within a range, as indicated in Figure 44. Relationship between the best case, worst case, real-life operation range, and representative value for a vehicle parameter.. Ideally, the SoC at the start of the test would be set to the representative value, being the weighted average of this range.[49] But in the absence of a way to determine the SoC or a method to align it with the representative value, it is impossible to obtain repeatable results from the test. Since reproducibility is generally more important for a type-approval test than representativeness, the only solution is to use a starting point that can be well defined. For the NEDC test procedure, the selected state is a fully charged battery (best case). As a result, CO_2 emissions will be lower than in real-life conditions since the best case is outside the normal operating range, and this will distort the fuel consumption figure as well.

For other parameters, it is considered impractical to reproduce representative conditions during the NEDC test procedure. A good example is the temperature in the test cell and the area where vehicles are kept prior to the laboratory tests (soak area). To represent real-life conditions, these should be kept at average European outdoor temperatures (about 10°C). Yet, for practical reasons, it was decided for the current NEDC regulation to specify a temperature between 20°C and 30°C, which is much higher than the European mean. Conversely, it is also considered impractical to simulate high ambient temperature conditions and air conditioning use.

5.1.2 Potential reasons for an increasing gap

As was discussed in section 5.1.1 there are reasons why real-world CO_2 emissions will always deviate from type-approval values to some extent. What is found by the analysis in chapter 4 – and what is concerning for a number of reasons explained in section 5.1.3 – is the fact that this level of discrepancy has been increasing significantly in recent years.

Even if the driving cycle and test procedure are not fully representative and do not reflect typical vehicles, vehicle use, and driving style, there is no reason to expect that these characteristics would have changed drastically over time. Figure 45 illustrates this, using spritmonitor.de data for the years 2001 and 2011. As mentioned before, CO_2 emission values will vary for different vehicles and drivers. This can be seen in the 'spread' of values: in the case of the 2001 data it ranges from about 85 to 135 percent of the type-approval value. Nevertheless, when aggregating a large quantity of vehicles and driver information (in this case about 5,000 entries), a normal distribution (Gauss function) is the result. For 2001 it is evident that most drivers experience about 5–10 percent higher CO_2 emissions than according to type-approval values, with a decreasing likelihood toward either side of this narrow band. Looking at the 2011 values, the 'spread' of results has changed somewhat, but still a normal distribution of the observations is found. However, the average has now clearly shifted, with most drivers experiencing about 20 percent higher CO_2 emissions than according to type approval. Hence, while vehicle use and driving style supposedly have remained relatively constant, there must have been other determinants that caused a drastic shift in the average discrepancy level observed.

49 Note that the weighted average is not necessarily in the middle of the range.

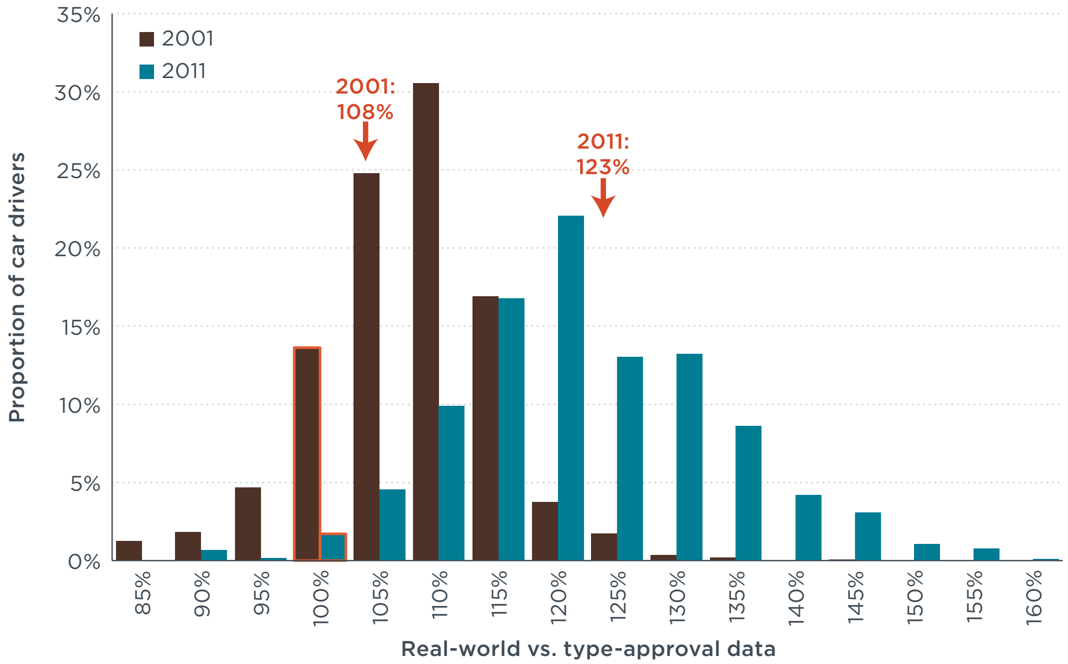


Figure 45. Range of reported real-world versus type-approval figures in spritmonitor.de, comparison for the years 2001 and 2011.

In terms of causes that may have contributed to this increased gap between real-world and type-approval values, there are three main categories that need to be distinguished:

1. **Increasing application of specific technologies that show a higher benefit in the type-approval test procedure than under real-world driving conditions.** One example of this is the use of the start-stop technology that turns off the engine when stopped at a traffic light or in similar driving situations. The share of European new vehicles equipped with start-stop technology increased from zero percent in 2001 to around 10 percent in 2010 and is still rising.[50] Under the NEDC—which consists of about 25 percent idling—start-stop technology promises significant CO_2 reduction, while for an average driver the frequency of idling generally is less[51] and therefore the impact of start-stop technology is lower than estimated for the NEDC. This is particularly true for drivers who predominantly travel on extra-urban roads and highways. An increasing deployment of start-stop technology therefore provides some explanation for the observed increase discrepancy between type-approval and real-world CO_2 emissions, although, thanks to the still relatively low market share, a limited one. Other examples of technologies that offer a substantially greater CO_2 reduction potential under the NEDC than under real-world driving conditions include hybrid technology, advanced automatic transmissions, and downsized turbocharged engines (see Kasab, Shepard, and Casadei 2013; Smokers et al. 2012).

2. **Increasing use of 'flexibilities' in the type-approval test procedure.** As discussed previously, reproducibility is a key criterion when developing a vehicle test procedure. Keeping in mind that today's test procedure was not originally designed for the determination of CO_2 emissions, the need for reproducibility helps explain why the test procedure has a number of flexibilities, for example, when tolerances are allowed during testing or when procedural steps are not always defined in every single detail and allow for some freedom of interpretation. One instance is the determination of road-load coefficients during the type-approval test. These coefficients are needed

50 Based on ICCT internal data estimates.
51 As shown by EU real-world driving data collected within the scope of the WLTP development.

to simulate the load of a vehicle when being tested on a chassis dynamometer in the laboratory, where the vehicle is held static and usually only the tires of the drive axle are in motion. For determination of the road-load coefficients, 'coast-down' tests are generally carried out by the manufacturer, whereby a vehicle is accelerated on a long, flat straightaway and then the time that the vehicle needs to decelerate to a specified target speed is measured. In the context of these coast-down tests some flexibilities are permitted, as discussed in detail in a recent TNO report (Kadijk, G., and Ligterink, N., 2012). For example, the tire specifications used could be different from the tires typically sold, and the tire pressure applied during the test could be higher than typically observed for vehicles at the point of sale. TNO quantifies the potential impact on CO_2 emissions attributable to wheel and tire specifications as 2 percent and an additional 2.8 percent due to rolling resistance flexibilities. In another study, TNO tested eight vehicles and found that in total the road-load levels measured under "realistic conditions, representative of in-use vehicles driven in realistic conditions are found to be substantially higher than those of the Type Approval road loads"—up to 30 percent higher at high speeds and up to 70 percent at low speeds (Kadijk and Ligterink 2012). The study, based on the eight vehicles tested, also found differences between older (Euro 4) and more recent (Euro 5/6) vehicles, with the more recent vehicles having approximately 11 percent lower CO_2 emissions because of the higher road-load coefficients than those of older vehicles. Other potential flexibilities in the type-approval procedure are discussed in detail in the previously mentioned TNO report (Smokers, Kadijk, and Dekker 2012).

3. **External factors changing over time.** Other contributors to an increasing gap between type-approval and real-world CO_2 emissions could include the increasing use of air conditioning systems. The average annual extra CO_2 emissions of a passenger car linked to the use of the air conditioning unit is estimated to be about 5 percent (Weilenmann, Alvarez, and Keller 2010). The number of vehicles equipped with air conditioning systems has increased significantly over time, in Germany from about 25 percent of all new passenger cars in 1995 to about 96 percent in 2008 (Hoffmann and Plehn 2010). Similarly, more and more vehicles make use of energy-intensive entertainment and comfort systems (such as seat heating) that are linked to higher CO_2 emissions in real-world driving. Other examples may include the increasing use of winter tires in some EU countries and the increasing share of biofuel for combustion. It should also be noted that the fleetwide trend toward lower CO_2 emissions and fuel consumption will also increase the type-approval/real-world gap in percentage terms. This is because some of the loads on the vehicle are relatively fixed, regardless of efficiency, such as the loads imposed by air conditioning and lights. The actual impact of these loads is relatively constant in terms of grams of CO_2 per kilometer, so as the measured gCO_2/km through the NEDC goes down, the percentage impact of the in-use loads goes up. In fact, the U.S. Environmental Protection Agency (EPA) specifically accounted for this when it revised its fuel economy labeling in 2008, applying a larger percentage adjustment to vehicles with lower fuel consumption.

A systematic quantification of potential external influences is outside the scope of this study. For more details on specific aspects, see, for example, Smokers, Kadijk, and Dekker (2012).

5.1.3 Consequences of an increasing gap

Having analyzed the discrepancy between type-approval and real-world CO_2 emissions and its increasing trend in more detail, the consequences of the recent developments are discussed from the angle of different stakeholders.

FOR CUSTOMERS

Given the extreme discrepancies between type-approval and real-world values, car owners generally evince little confidence in the manufacturers' declared fuel consumption. As a result, there is a danger that customers become frustrated by misleading information, decide that fuel economy considerations might be meaningless, and, thus, do not invest in new fuel-saving technologies. Though the relevant aspect for customers is clearly fuel consumption, it is directly linked to CO_2. Assuming a discrepancy level of 34 g/km, as was determined based on spritmonitor.de data for 2011 (see section 4.1.1), the financial impact—in terms of additional fuel costs—is on the order of 300 euros per year.[52] This means that an average customer would end up spending about 300 euros more per year on fuel than was to be expected based on the manufacturers' declared type-approval fuel consumption. Given the increasing discrepancy between type-approval and real-world values, it is therefore no surprise that consumer associations are interested in the issue and are asking for a quick resolution (Mock 2012b).

A more realistic fuel consumption figure could help to restore consumer confidence, so that customers attach more value to fuel economy as a selling point. Yet, at the same time, it needs to be emphasized publicly that individual driving behavior and how a car is routinely used have a big influence on fuel consumption, no matter how 'representative' the declared fuel consumption rate may be.

FOR REGULATORS (CO_2 REDUCTION ASPECT)

CO_2 emission targets on any scale from regional to global are receiving more attention from authorities, and CO_2 emissions from cars are no exception since the transport sector is one of the main greenhouse gas contributors. Because there is no other objective parameter available to determine vehicle CO_2 emissions, the declared value at type approval forms the basis of any automotive CO_2 legislation, such as the target fleet average of 95 g/km that manufacturers have to meet in 2020 in the EU. As long as the gap between real-life and type-approval values remained more or less constant, every CO_2 reduction achieved on paper would also be accomplished in fact. However, if the gap increases over time, real-world emission reductions will be lower than expected and emission targets will not be met (see section 4.3.1).

From the viewpoint of legislators and regulators, it is therefore critical that the type-approval CO_2 emission figure be a suitable indicator. The more representative the test procedure in terms of real-life conditions and the better the enforcement provisions, the higher the chance that improvements over the test cycle will also translate into lower CO_2 exhaust on the road.

FOR REGULATORS (TAXATION ASPECT)

Many EU member states by now have redesigned their vehicle taxation schemes so that they are based, at least to some extent, on CO_2 emissions.[53] Any variable taxation scheme needs a reliable parameter on which to base the taxes; in the case of a CO_2-based system, the type-approval CO_2 value is used. With an increasing discrepancy between type-approval and real-world emissions there is a risk of unintended consequences, creating a run on vehicles billed as low-CO_2 emitters that perform well based on type-approval values but disappoint under real-world conditions. This would not only create frustration among customers but at the same time would result in lower tax revenues.

For a country with a vehicle tax system strongly based on CO_2, the consequences can be dramatic. For example, in the Netherlands every gCO_2/km above a threshold of 95 g/km

52 Assuming a fuel price of 1.5 euros per liter and an average annual driving range of 15,000 km.

53 In 2006, nine EU member states based passenger taxes partially or totally on a vehicle's CO_2 emissions; in 2009, this was the case for sixteen member states.

(for diesel cars) or 110 g/km (for petrol-powered cars) is taxed by at least 94 euros at the time of vehicle registration. A gap of 35 g/km, as was found based on the Travelcard data for the Netherlands (see section 4.1.2), would therefore result in a registration tax that is more than 3,000 euros lower than if based on real-world CO_2 emissions. With about half a million new vehicles per year, the resulting effect on Dutch tax revenues would be on the order of 1.5 billion euros per year.

In Germany, vehicle ownership tax is partly based on CO_2, with a rate of 2 euros per g/km of CO_2 above a threshold of 110 g/km (ACEA 2012). Assuming a discrepancy level of 34 g/km, as found based on the spritmonitor.de data, and about 3 million new registrations, the effect on tax revenues would be around 200 million euros per year. Taking into account not only the new vehicle registrations in a single year but the effects on vehicle stock, that is, all vehicles in use, would result in a significantly higher estimate.

An improved test procedure with a more representative driving cycle would therefore help to improve the suitability of CO_2 emissions as a tax parameter. As the benchmark for CO_2 emissions changes, this should be reflected in the CO_2-based tax regime as well.

FOR VEHICLE MANUFACTURERS

Given consumer skepticism from when it comes to fuel consumption values and regulators' mistrust when it comes to CO_2 emission values, the car industry suffers from a lack of credibility. However, carmakers are faced with a dilemma. If they were to take a more straightforward approach to the type-approval CO_2 emission readings, they would engender tax penalties and their competitive position would suffer—in particular if only some manufacturers were to move in this direction and others did not.

From this perspective, official measures to establish a more realistic test cycle and procedure would help to create a more level playing field between the car manufacturers. Though it seems counterintuitive, tightening the tolerances and eliminating unnecessary flexibilities in the test procedure could redound to the benefit of the industry as a whole.

5.2 DEVELOPMENT OF A NEW TEST PROTOCOL

In November 2007, the United Nations Economic Commission for Europe (UNECE) decided to develop a new testing regime to secure more accurate CO_2 emissions readings and fuel economy rates. This end result of this process is referred to as the Worldwide Harmonized Light Vehicles Test Procedure, or WLTP for short. The intention is first of all to reach a harmonized approach to testing CO_2 and pollutants from passenger cars for all world regions. The other important purpose is to resolve, as much as is possible, the known shortcomings in current emission testing procedures (Regulation ECE-R83 for Europe with the NEDC test cycle).

There are two main areas in which refinement of the testing procedure is being pursued:

- » Developing a test cycle that is more representative for average driving conditions, which means that it is built up from actual driving data. As a result, the cycle will include more realistic accelerations and more dynamic speed variations. Since WLTP aims at world harmonization, the new test cycle should be representative for average driving behavior worldwide.
- » Developing an improved test procedure. Existing test procedures are being thoroughly reviewed, and proposals for improvements are in discussion. These improvements are to be achieved in different ways: by modifying the test procedure according to the state-of-the-art measurement technology, tightening allowed tolerances where possible, disincentivizing the resort to expediencies (e.g., by introducing correction methods), addressing relevant test issues that were

previously overlooked or vehicle technologies that have yet to be covered, etc. Special attention is being given to devising a sound procedure for a more accurate determination of the road load, which is an important input for the emission test.

The work on WLTP is ongoing: according to the road map, the new test procedure should be finalized by mid-2014. In a next step, incorporation of the WLTP into EU legislation will then follow.

5.2.1 Issues addressed by WLTP

Concerning the discrepancies between type-approval and real-life fuel consumption, WLTP will improve the representativeness of the test in three main areas: driving cycle, road-load determination, and test procedure.

DRIVING CYCLE

As mentioned in an earlier report (Mock et al. 2012), the current test cycle is not representative of real-life driving conditions but is rather a stylized driving pattern with low accelerations, constant cruising speed, and many idling events.

One of the goals for WLTP is to develop a test cycle that is representative for average worldwide driving behavior. This task was accomplished by collecting large amounts of driving data from all over the world, weighting these data according to the respective total distances traveled, storing these in a database, and designing a driving cycle for which relevant characteristics correspond to the averages found in the database. The result is a more realistic driving cycle (called WLTC), with higher accelerations and maximum speeds as compared with the NEDC (see Figure 46).

Surprisingly, the initial results show that both cycles, old and new, yield similar fuel consumption values (see, for example, Kasab, Shepard, and Casadei 2013). Though the WLTP cycle is more demanding, the engine is working in more fuel-efficient operating conditions. Further, the length of the WLTP cycle is 1,800 seconds, while the NEDC is only 1,180 seconds long (Figure 46). Therefore, the relatively high fuel consumption during the cold-start phase of the cycle has a lower effect on overall fuel consumption.

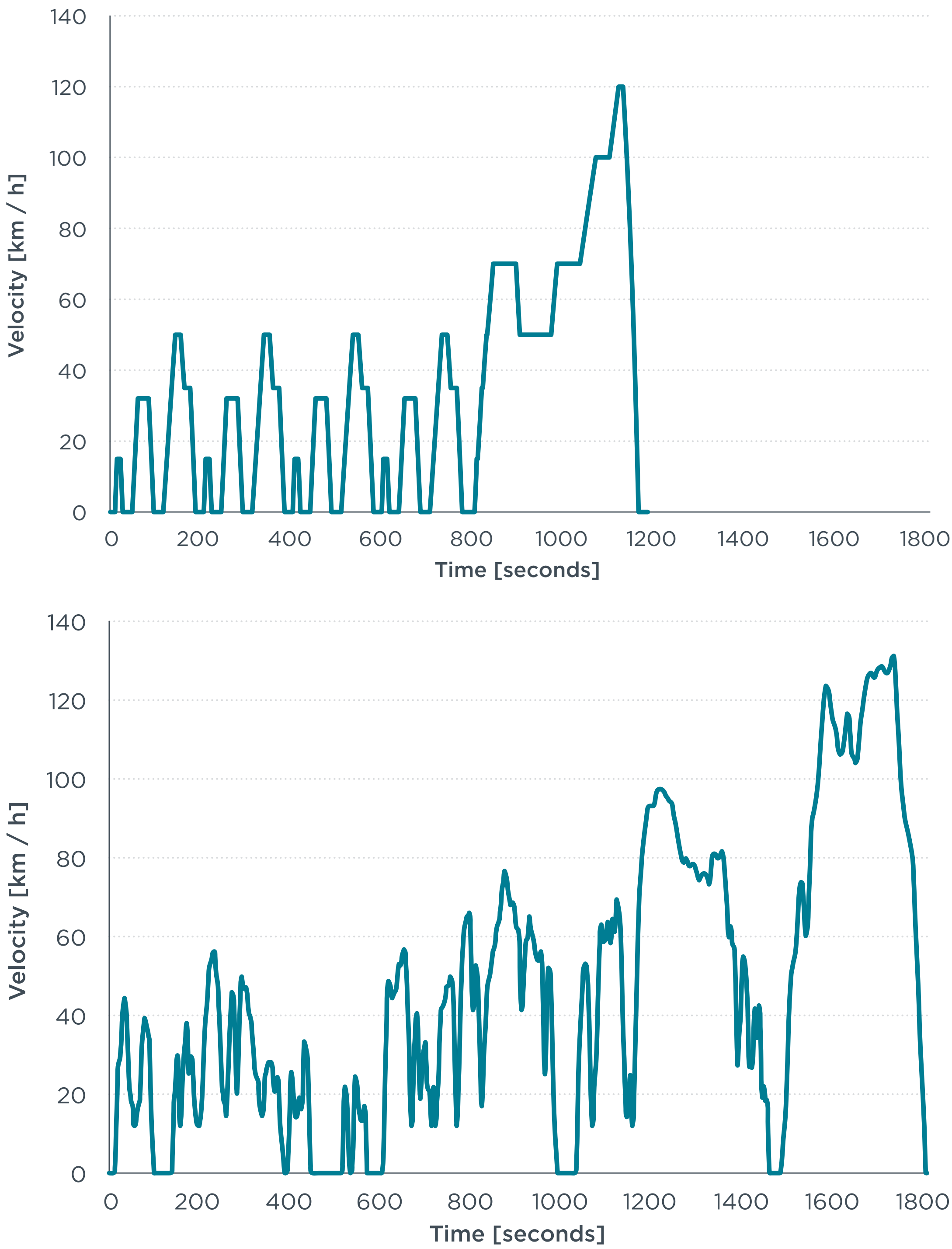


Figure 46. NEDC in comparison to WLTC drive cycle (WLTC).[54]

Even though the representativeness of the test cycle has improved considerably, there are still departures from reality. Since every vehicle still needs to be able to drive the cycle, accelerations are relatively, for some uncharacteristically, low. Other real-life features such as road inclination and curves are not simulated in the laboratory.

54 WLTC version 5 (status January 2013).

ROAD LOAD

Vehicles are tested on a chassis dynamometer since it is not possible today to measure CO_2 emissions accurately with sufficient repeatability on a moving vehicle. Because the vehicle is standing still in the laboratory, there is no opposing aerodynamic drag force, and the rolling resistance on a steel roller is different from normal tire/road contact.

These differences can be compensated for by the chassis dynamometer control system but require as an input the actual resistance forces of a vehicle moving on the road. This "road-load determination" process is part of the type-approval test procedure and is most commonly done by coasting a vehicle from high to almost zero speed on a straight and flat test track with a disengaged clutch. The resistance force at any speed is calculated by considering the deceleration and mass of the vehicle.

The main road-load issues recognized under the test procedure in Regulation ECE-R83 that will be addressed by WLTP are the following:

- *Slope of the test track:* For the road-load determination it is important to have a level test track so as not to bias the results in any respect. Though there are limits on the maximum allowed slope of the track, there still is some potential to influence the road-load determination even if the tests are required to be performed in opposite directions. Furthermore, the calculation method used in the NEDC to average results in both directions contained a simple error that reduced the resulting road load. In WLTP the error will be corrected and further restrictions added to the longitudinal slope of the opposite straights of an oval test track.
- *Vehicle selection:* The road-load determination procedure is normally performed at a time when the vehicle being type-approved is still a prototype. Currently, there is no adequate mechanism in place to verify whether this prototype vehicle is the same as the eventual production vehicle. Hence, some vehicle body options might not be installed for the prototype, or tires with low rolling resistance might be applied, etc. On production models a variety of wheels and tires will be installed, which set a range for the test vehicle. Generally, the manufacturer will test only the vehicle version with the lowest weight and the fewest options. In WLTP the influence of aerodynamic options on road load will be calculated or measured and corrected accordingly. The mass of the road-load test vehicle will be made more realistic by adding weight that represents carrying extra passengers and luggage/payload. Since WLTP is only a test procedure and not a certification scheme, it is not possible to include verification of the similarity between test and production vehicle. Still, this matching up is explicitly requested in the procedure, so this could be used as a placeholder for the certification process at the regional level. Also, discussions are starting now to see if road-load verification can be included in the obligatory requirements for in-service conformity checks, together with the evaluation of in-service CO_2 emissions, similar to what is already being done in the United States. Such an approach would reduce the discrepancy between type-approval and real-life road-load values (Riemersma 2012).
- *Vehicle preparation:* The current test procedure offers some flexibility and tolerances for the treatment of the test vehicle, such as preparing the brakes (pushing back the brake pads to avoid parasitic drag), realigning the wheels, improving aerodynamic performance, reducing friction of wheels and transmission, increasing tire pressure to lessen rolling resistance, etc. Where possible, these issues are dealt with by WLTP. One example is the requirement to demonstrate braking of the vehicle before the coast-down to keep the brakes from being specially prepared.

A full overview of road-load issues is presented in Smeds and Riemersma (2011). While a lot of the known issues are largely resolved and tolerances tightened by WLTP, it is still unavoidable that some room for adjustments needs to be offered. Without any allowed flexibility, the test track, test vehicle, or test itself would all too often be rejected.

TEST PROCEDURE

Apart from the test cycle, the test procedure is equally important for the emissions measured during the test. It lays down the requirements for setting the chassis dynamometer, specifications of test equipment and the calibration procedures, preparation of the vehicle, etc.

The first improvement achieved by WLTP was to update the procedure to incorporate state-of-the-art measurement techniques since some of the prior specifications refer to outdated equipment. An example is the inertia setting of the vehicle. In earlier days, chassis dynamometers were not yet electronically controlled. Inertia simulation was done by physically attaching flywheels to the rollers. So that the test laboratory did not need to buy and store a large set of different flywheels it was decided to use a limited number of inertia classes. As data analysis shows, this led to a situation in which manufacturers would tend to develop their vehicles so that they would just manage to reach a lower inertia class and thereby be awarded some CO_2 benefit that would not necessarily be experienced by customers (Mock 2011). Nowadays, almost all chassis dynamometers are able to simulate electronically the exact test mass of the vehicle. Therefore WLTP will adopt a step-less (continuous) inertia simulation principle.

The difficulty of delimiting a representative start condition for the starter battery has already been outlined in section 5.1.1. The current test procedure therefore allows the battery to be fully charged for the test. This will decrease the CO_2 measured over the cycle since the energy absorbed by the generator is lower compared to a cycle when the battery starts on an 'average' SoC value. According to Schmidt and Johansen (2010), this effect may lead in an extreme case to an almost 30 percent reduction in CO_2 emissions. Normally, the effect will be much smaller, but this example shows the significant influence of the starter battery condition. In WLTP this is pragmatically solved by requiring a preconditioning cycle to be driven after the battery is fully charged. The required 30 minutes of driving in the WLTP test cycle is considered sufficient to bring the battery into a representative yet reproducible condition.

Currently, the EU test procedure uses, as a reference mass for the vehicle family, the lowest mass for the vehicle in running order, with an added weight of 100 kg for driver and luggage. Any additional mass from installed options is not included. This is considered an underestimate of the average real-life mass of the vehicles. By contrast, in the United States the highest-selling vehicle configuration needs to be tested within each base level (Fung and He 2010). Two major changes will be implemented by WLTP (Mock, Riemersma, and Rijnders 2012). First, the reference mass will be increased by a variable mass to represent the carrying of passengers, luggage, or payload. This added mass will be a fixed percentage of the net carrying capacity of the vehicle. Second, the CO_2 emissions will be measured for the lightest and heaviest vehicle of the family for which type approval is sought. By interpolation from these results, the CO_2 emission for each vehicle in the family can be determined, based on the actual mass of the vehicle and its installed options. These improvements will not only reduce the gap between real-life and type-approval fuel consumption, but the interpolation scheme will help to match the values better to individual vehicle performance.

ELECTRIFIED VEHICLES

A subgroup of experts in WLTP is dealing with issues relating to electrified vehicles. On a general level, the technical terms and definitions used in different regions (Europe, Japan, and the United States) are harmonized and supplemented with terminology regarding battery and vehicle parameters, such as electric ranges under different driving conditions.

With respect to the current UNECE Regulations 83 and 101, WLTP will bring improvements on a number of issues:[55]

» Definition of the cold-start test with respect to the electrified components of hybrid electric vehicles (HEVs).

» A method to correct the CO_2 emission figure as a function of the change in the charge condition of the battery in HEVs during the test, particularly those that need no external charging.

» For plug-in HEVs (with external charging), different testing methods have been developed to establish the range of the vehicle in charge-depleting (CD) and charge-sustaining (CS) modes of driving, with relevant break-off criteria to determine when the test is finished. By weighting the results of the tests in CD and CS mode according to their respective ranges, an overall fuel and electric energy consumption value is obtained. In calculating the weighting factors, the type of hybrid technology used is also taken into consideration.

» The determination of electric range (with relevant break-off criteria) and the corresponding electric energy consumption for battery electric vehicles (BEVs).

In a later phase of WLTP, some other issues will be explored, such as temperature dependency and durability of the main battery.

5.2.2 Issues not addressed by WLTP

Though significant improvements are achieved in WLTP, there are also issues that for practical reasons are not dealt with. A good example is the ambient temperature during vehicle testing. This is still under discussion but likely to be harmonized at a set point of 23°C. This is much higher than the representative European average temperature. Since beyond the EU, for example, in countries like India, average temperatures are higher, and since it is easier and more cost-effective to heat a laboratory than to cool it, the temperature for the world-harmonized test procedure is purposely kept at this high level. Within the EU, a discussion is ongoing as to whether it is possible to correct the fuel consumption rate to a more representative temperature, for example, by using the results of the -7°C temperature test. However, such a correction would be outside the scope of WLTP and would be part of regional certification requirements.

There are also issues that cannot be completely solved. The test procedure has to allow certain tolerances, otherwise, it would be impossible to comply with the procedure's prescriptions. For test laboratories that have equipment capable of meeting tolerances more tightly than required, this may offer the manufacturer a possibility to exploit this to its own benefit. For instance, the test procedure is offering a tolerance on tracing the speed profile set by the test cycle, as it is impossible to follow the respective target speeds precisely during the test. The current proposed tolerance window is +/-2 km/h and +/-1 second. For an experienced lab driver or a robot it is possible to use some of this tolerance window to reduce the workload of the vehicle, thereby lowering its fuel consumption. Because the WLTP test cycle is much more dynamic than the current NEDC, it will be more challenging to stay within this tolerance, so room for optimizing is expected to be less. On the other hand, some of the more dynamic peaks in the cycle may be 'flattened' to reduce fuel consumption.

Some other examples of issues that are not or are only partially addressed by WLTP are listed below:

» *Cycle characteristics*
As previously indicated, a type-approval test cycle needs to be appropriate for every

55 Most of the earlier issues mentioned for conventional internal combustion engine vehicles may also apply to electrified vehicles.

vehicle. This means that, for example, even underpowered vehicles have to be able to perform the accelerations of the driving cycle. Even though a classification scheme is introduced in WLTP with dedicated test cycles for low-powered vehicles or those with low maximum speed, the accelerations will still have to be suitable for vehicles at the lower end of the power-to-mass ratio range. For cars with relatively high power-to-mass ratios, such gentle accelerations will be far from real-life driving behavior.

» *Correction formulas*
The road-load determination is determined on a test track, so the ambient conditions such as air temperature, pressure, and humidity may vary from day to day. In effect, the measured road load will be affected. This has been resolved already in current legislation by adjusting the measurements to standard conditions. There are, however, indications that high temperatures still alter the road-load determination, which means that the correction formulas are not fully adequate. Within WLTP there are no resources to check and improve upon these corrections.

» *Smooth test track*
It is acknowledged that the smoothness of the test track will influence the rolling resistance of a vehicle for which the road load is determined. So far it has proved difficult to find a suitable indicator for the roughness of actual road surfaces. Even if such an indicator were found, it would be a difficult political decision to require a less smooth surface if this would render some of the test tracks inadequate.

» *On-board energy consumption*
An increasing number of on-board systems are using energy from the engine, such as the air conditioner, lights, electric window heating, seat heaters, etc. These will negatively impact the fuel consumption rate when switched on. However, not every vehicle has the same kind of options installed, and to what extent they are used will depend on the circumstances and customer habits. For some of these amenities (e.g., the air conditioner) the amount of energy used is linked to the external conditions such as outside temperature and solar radiation. In order to keep the type-approval process manageable, on-board energy consumption has not been incorporated in the test procedure. For air conditioners in passenger cars, the European Commission is currently working on a separate test procedure, the Mobile Air-Conditioning Test Procedure (MACTP).

» *User-selectable devices*
Manufacturers are increasingly offering options that change how the engine and transmission operate. This is especially a problem for automatic transmissions, where users can often select “economy” or “sport” modes. Procedures are needed to ensure that manufacturers do not test their vehicles in economy mode only, at least without demonstrating that such modes will be routinely used in practice. This issue is being discussed in the context of WLTP and is likely to be dealt with at least to some extent. Possible solutions considered for WLTP include a) defining a default/predominant mode that will determine in which mode the vehicle should be tested or b) averaging best- and worst-case modes, in case no agreement on a robust definition of a default/predominant mode can be found.

Currently, discussions are taking place in WLTP to correct systematic deviations from the target value in what is called a ‘normalization’ procedure. This could be done by post-processing of the test results toward normal conditions. It has not yet been decided if this approach will be applied and, if so, if it would be added to the WLTP test procedure itself or implemented at the regional level. For a more detailed discussion on options for reducing test cycle flexibilities, see Smokers, Kadijk, and Dekker (2012).

5.2.3 Outlook

There is no doubt that the new WLTP will offer considerable improvement in terms of reducing the gap between real-life and type-approval CO_2 values. As indicated in the previous section, the main differences with the NEDC test procedure lie in the tightening of tolerances to reflect current, state-of-the-art measurement technology, increasing the accuracy of the CO_2 emission value for individual vehicle models, and more precise specifications to cut down on flexibilities. At the same time, as noted, it is recognized that not all contributors to the disparity can be fixed to the last detail. At the EU level, three supplementary solutions are being considered to close the gap further (Smokers, Kadijk, and Dekker 2012):

» *Correction methods*
For most test parameters, normally a target value is specified, together with an allowed tolerance. The tolerance will ordinarily be wider than what the system controlling the parameter is capable of, thus offering carmakers the possibility of deviating systematically from the set point. For example, a slightly elevated soak or test temperature may lower the measured CO_2 emission value. If the measurement result is adjusted by an appropriate correction method, though, such variances are eliminated. This correction is also referred to as 'normalization.' The EU Commission is currently investigating which parameters should be normalized and by what correction method. The normalization procedure is performed as a postprocessing of the measurement data and can therefore be organized at the regional level, for example, to reflect local conditions. However, some of the correction methods may also be included in WLTP.

» *In-service conformity*
According to current EU legislation, manufacturers have to demonstrate pollutant emission conformity for in-use vehicles. If the requirement for in-service conformity also included CO_2 emissions, this would help to discourage the exploitation of testing flexibilities. Such a requirement could state that the CO_2 generated by an in-use vehicle may not exceed the type-approval value by more than a given percentage. The efficiency of this tool would be further increased by random checks on the road load of production vehicles, carried out by an independent body. The reason is that the prototype vehicle that is submitted for type approval will not always be identical to the final production vehicle. This may be contributing to the discrepancy between real-world and type-approval figures. Adding in-service conformity requirements for the road load and CO_2 emissions would prevent such inconsistencies from occurring (Riemersma 2012). To keep the permissible variance in CO_2 emission values within a narrow band, it will still be necessary to tighten the requirements and tolerances in the test procedure and preferably to perform a normalization procedure as well.

» *Mobile air conditioning systems*
Nearly all new vehicles in the EU today are equipped with air conditioning systems. The average annual extra CO_2 emissions of a car caused by the use of the air conditioning unit is estimated to be about 5 percent (Weilenmann, Alvarez, and Keller 2010). Yet, air conditioning is not considered in the NEDC test procedure and will not be part of the WLTP either. Instead, the European Commission is developing a separate test procedure for mobile air conditioning systems (MACTP).[56] While the work on the test procedure itself is being completed, laboratory testing to confirm the reproducibility of the test results is under way.

Parallel to the development of WLTP, the European Commission will investigate if and how these supplementary solutions can be implemented in the EU legislative framework.

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56 See https://www2.unece.org/wiki/display/trans/MACTP+5th+session for details.

6 CONCLUSIONS AND RECOMMENDATIONS

The rate of reduction in CO_2 emissions from new cars in the European Union increased significantly with the adoption of a mandatory regulation in 2008–2009, from below 2 percent to 4 percent per year. But that regulation applies only to type-approval CO_2 emission values, as measured by the NEDC procedure. To make that progress real, reductions in the level of CO_2 emissions recorded in the laboratory during type-approval testing must match, at least approximately, "real-world" driving conditions.

A technically precise definition of real-world driving conditions is elusive, thanks to variations in vehicle design and in the ways that drivers drive. But by aggregating large sets of on-road driving data, clear trends can be observed. This analysis makes use of several such datasets, for both private and company cars, from various EU member states and Switzerland. It reveals an overarching trend: while the average discrepancy between type-approval and on-road CO_2 emissions was below 10 percent in 2001, by 2011 it had increased to around 25 percent.

Methods of collecting on-road CO_2 emissions differ from source to source, as do fleet characteristics and driving styles, and therefore the absolute discrepancies found vary from one data source to another as well. But more important than absolute discrepancy is the increase over time, and the annual rate of increase is similar for all sources examined.

It is reasonable to assume that driving behavior has not changed appreciably over the past ten years. Instead, the observed increase in the type-approval/real-world gap most likely results from a combination of the following developments:

» Increasing application of technologies that show a higher benefit in type-approval tests than under real-world driving conditions (for example, start-stop technology)

» Increasing use of flexibilities in the type-approval procedure (for example, during coast-down testing)

» External factors changing over time (for example, increased use of air conditioning)

It should also be noted that some of the influences (specific technologies, flexibilities in the test procedure, and external features) may have an absolute impact in terms of grams of CO_2 per kilometer and are not dependent on the overall CO_2 emission level of a vehicle. As CO_2 emission levels decrease over time, the relative importance (in percentage) of these considerations increases, and that could—to a limited extent—explain the increasing gap observed between laboratory and on-road results. It was not the objective of this study to quantify each of the potential influences, however. Other studies have already looked at this question, and more detailed research is needed for a better understanding of the interaction of those developments with the trend described in this analysis.

The underlying data show that the increase in the gap was especially strong after 2007–2008, when a number of EU member states switched to a CO_2-based vehicle taxation system and the mandatory EU CO_2 regulation for new cars was introduced. The coincidence of those two events with that sudden intensification of the trend toward an increasing disparity between type-approval and real-world values is at a minimum suggestive. Certainly, the changes to vehicle taxes and the CO_2 regulation increased the pressure on vehicle manufacturers to demonstrate lower CO_2 emission values in the NEDC test procedure.

It is important to clarify that nothing in this analysis suggests that manufacturers have done anything illegal. However, the NEDC was not originally designed to measure fuel consumption or CO_2 emissions, and some features of the test procedure can be exploited to influence test results for those values. Manufacturers appear to be taking advantage of permitted flexibilities in the NEDC, resulting in unrealistically low CO_2 emission levels. Results from tests that closely resemble type-approval testing, such as the TCS *laboratory* test, appear to confirm this. In such tests, run using vehicles provided directly by manufacturers and laboratory settings that are in line with those customary for type approval, the discrepancies between laboratory and real-world results fall below 5 percent and do not show any sign of a marked increase over time. However, a number of flexibilities (such as for coast-down testing or vehicle weight definition), as well as other aspects (such as high-speed driving and the use of air conditioning systems) are not reflected in these type-approval-like tests.

Vehicle manufacturers are only one stakeholder group that is negatively affected by the shortcomings of the current EU test procedure. Consumers are frustrated by unrealistic fuel consumption figures for their vehicles, and if frustration becomes distrust that could inhibit investments in new fuel-saving technologies. In countries with CO_2-based vehicle taxes, the effect of unrealistically low type-approval CO_2 emission values on tax revenues can be drastic. And regulators must be concerned if CO_2 emission targets are not being met in reality.

The new Worldwide Harmonized Light Vehicles Test Procedure (WLTP), with its more realistic test cycle and tightened test procedure, is expected to result in more realistic CO_2 emission values and therefore a narrower gap between type-approval and real-world values. However, the WLTP will not resolve all known issues with the current procedure, and it may itself have vulnerabilities that are not yet recognized. For example, it remains to be seen how plug-in hybrid electric vehicles and other electrified vehicles will perform in the WLTP as compared to on-road driving.

It is too much to hope, then, that following the introduction of the WLTP, type-approval CO_2 emissions will fully reflect real-world driving. Nevertheless, the objective should be to bring both values into greater agreement, reversing the recent widening of the gap between them. That will spur development of technologies that reduce CO_2 emissions under real-world conditions, thus avoiding misdirected investments. The WLTP should therefore be adopted in the EU as soon as is feasible after it is finalized (expected in 2013/2014), taking into account necessary lead time for industry. Moreover, its adoption ought to be accompanied by additional correction methods, which are currently being investigated by the European Commission.

The UNECE, which is leading the process of developing the WLTP, is also developing a separate test procedure for vehicle air conditioning systems, the Mobile Air-Conditioning Test Procedure (MACTP). The recommendations offered here pertaining to the WLTP apply equally to the MACTP: this test procedure must be as realistic as possible and should be introduced into EU legislation as soon as possible.

Finally, in-service conformity checks for CO_2 similar to those that already exist for air pollutants emissions should be introduced into EU legislation, to ensure compliance of the on-road vehicle fleet as well as individual test vehicles. This legislation should also mandate publication of road-load coefficients measured by vehicle manufacturers and used during the type-approval procedure. These are currently not offered in the EU (in contrast to the United States, where this information is publicly available), but they are critical for verification of road-load results by independent bodies.

In the long run, the EU should answer the question of whether there are better ways to determine CO_2 emission levels of vehicles than making use of a fixed driving cycle and test procedure. For air pollutants, the European Commission is currently assessing the use of portable emissions measurement systems to determine emission levels during actual driving. Technically, it would be possible to use the same type of system to measure CO_2, but a number of open issues would have to be resolved before such an option could be considered in practical terms.

As this analysis has shown, the level of discrepancy observed in some cases differs between vehicle segments or vehicle manufacturers/brands. Generally, the size of the discrepancy does not appear related to whether the vehicles are low- or high-CO_2 emitters. The lone exception is a significantly higher gap found in the Dutch data for the mini- and small-vehicle segments, which is most likely attributable to unique aspects of the vehicle taxation system in the Netherlands. Similarly, while the data suggest that the gap differs among individual manufacturers and brands, differences in typical customer profiles, technologies applied or chosen, and other framework conditions may all influence that outcome. The data do not support any type of manufacturer ranking; rather, the analysis by manufacturer/brand demonstrates that the observed increase in the gap is universal, a systematic problem for the entire industry. Nevertheless, differences identified by the analysis should be studied in greater detail and, if warranted, should be taken into consideration when switching from the current NEDC procedure to the new WLTP to account for any differences in the level of vehicle technology deployment or other framework conditions.

As next steps on the research side, the collaborators in this project plan to continue collecting real-world CO_2 emission data for new vehicles from various data sources across Europe, to support an even more detailed analysis of historical trends and underlying causes. A desirable complement would be the systematic collection of real-world data, making use of data loggers that can be installed on vehicles to record on-road CO_2 emissions. The ICCT has commissioned a feasibility study of such a data collection program in the EU, which will be published by mid-2013.

For the United States, the data examined in the context of this paper are seen as merely a starting point for future analysis. One conclusion to be drawn from the analysis of U.S. practices is that the “adjusted MPG” values provided as consumer information closely match what drivers actually experience on the road. A similar system could be introduced in the EU, in which NEDC—or later WLTP—test values were adjusted, to better reflect on-road CO_2 emission values, and the adjusted values used as the basis for consumer information, in particular, on the car’s CO_2 label. Also, in the United States as in the EU, supplementing publicly available on-road CO_2 emission data with information systematically collected by a large-scale data logger project is an important step toward better understanding of individual technologies’ real-world performance and their potential for reducing emission levels in the future.

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8 ANNEX

Number of data entries underlying the statistical analyses.

SPRITMONITOR.DE

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
All vehicles	4528	4647	4913	5283	6115	7394	7866	7545	7749	6476	6489
Diesel	1765	2075	2432	3065	3417	4251	4726	3959	3121	3494	3668
Petrol	2763	2572	2481	2218	2698	3143	3140	3586	4628	2982	2821
Automatic transmission	659	682	796	808	756	922	1013	1023	1219	1160	1321
Manual transmission	3869	3965	4117	4475	5359	6472	6853	6522	6530	5316	5168
Mini	341	293	290	240	263	425	406	488	763	468	399
Small	832	940	962	1024	1188	1464	1609	1453	1707	1423	1473
Lower medium	1474	1480	1657	1877	2649	3015	3216	3196	3123	2695	2455
Medium	1235	1322	1312	1454	1333	1532	1551	1457	1217	1013	1065
Upper medium	351	343	348	317	324	378	412	289	168	170	220
Sport	156	128	165	152	161	223	223	214	267	146	135
Audi	304	361	375	486	485	600	681	611	568	447	464
BMW	497	540	576	620	710	852	1173	1050	743	507	702
Daimler	419	367	406	523	482	514	396	422	470	466	454
Fiat	167	149	141	128	91	204	235	306	297	161	220
Ford	516	612	639	611	851	812	923	870	823	533	619
General Motors	602	558	598	702	889	994	952	799	633	487	627
PSA	344	368	352	372	552	635	629	560	497	408	404
Renault-Nissan	269	309	311	286	297	283	281	311	448	482	489
Toyota	144	178	156	277	353	522	481	377	488	230	183
Volkswagen	1464	1443	1616	1637	1806	2410	2609	2687	3230	3099	2608

TRAVELCARD

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
All vehicles				123748	30777	27734	19969	21642	16237	16520	5165
Diesel				72858	18068	16547	11329	11637	8143	7708	2738
Petrol				50890	12709	11187	8640	10005	8094	8812	2427
Mini					362	611	640	1029	851	1081	226
Small					3333	4208	3116	3728	2344	1637	1006
Lower medium					12946	12467	8211	10827	8426	7204	2178
Medium					8070	7235	4699	5976	5053	3566	1142
Upper medium					1440	1209	994	1040	1001	726	258
Sport					112	103	92	59	86	81	
Audi				4696	1726	1271	893	1336	1278	1422	362
BMW				3865	1312	1277	1161	1450	941	967	288
Daimler				1583	348	258	240	309	216	224	
Fiat				4722	968	1059	1042	931	398	490	210
Ford				14233	2960	3220	1462	2305	1856	1126	306
General Motors				13923	2257	2641	1891	1472	1222	1040	388
PSA				19897	4786	3435	3511	3253	1757	1736	497
Renault-Nissan				15191	3806	2439	1213	1380	1025	1439	334
Toyota				6045	1844	1742	1350	1842	1443	1665	317
Volkswagen				30364	8649	8490	5273	5582	4860	5433	2191
				6866	2217	1545	1490	1058	1030	1041	355

LEASEPLAN

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
All vehicles											50983
Diesel											49164
Petrol											1819
Mini											123
Small											1358
Lower medium											13927
Medium											23211
Upper medium											7461
Sport											70
Audi											9587
BMW											7534
Daimler											4881
Fiat											113
Ford											7831
General Motors											3951
PSA											374
Renault-Nissan											850
Toyota											89
Volkswagen											24203

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	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
All vehicles	619	1440	2233	3527	3374	3354	4054	5322	3623	2780	1429
Diesel	386	849	1257	2138	1973	2054	2588	2956	1938	1790	825
Petrol	233	591	976	1389	1401	1300	1466	2366	1685	990	604
Mini		3	311	48	276	44	267	421	72	29	92
Small	83	340	151	84	308	862	792	1443	624	742	216
Lower medium	114	223	728	2389	865	557	1047	1193	1587	738	663
Medium	284	310	454	544	1242	372	1036	1281	354	136	184
Upper medium		98	284	131	179	111	159	215	175	392	107
Sport		50	101	151	187	231	48	120	48		38

ADAC ECOTEST

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
All vehicles	619	18	86	160	103	62	193	193	178	147	144

TCS

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
All vehicles	15	21	20	18	19	18	19	18	20	19	18	19	18	21	18	17	17
Diesel	1			1	2	3	2	1	1	4	7	7	4	9	5	10	7
Petrol	14	21	20	17	17	15	17	17	19	15	11	12	14	12	13	7	10

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