WHITE PAPER

SEPTEMBER 2017

ROAD TESTED: COMPARATIVE OVERVIEW OF REAL-WORLD VERSUS TYPE-APPROVAL NO_X AND CO_2 EMISSIONS FROM DIESEL CARS IN EUROPE

Chelsea Baldino, Uwe Tietge, Rachel Muncrief, Yoann Bernard, Peter Mock

icct
THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

ACKNOWLEDGMENTS

The authors thank the reviewers of this report for their guidance and constructive comments, with special thanks to John German, Jan Dornoff, and one anonymous reviewer.

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

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

Funding for this work was generously provided by the ClimateWorks Foundation and Stiftung Mercator.

EXECUTIVE SUMMARY

Following the discovery in 2015 of an illegal defeat device on 590,000 Volkswagen vehicles with diesel engines in the United States (U.S. Environmental Protection Agency, 2017), several independent European organizations and governments conducted emissions testing on Euro 5 and Euro 6 passenger cars. This paper combines the publicly available emissions data from these organizations and government bodies, as well as data that ICCT purchased from a commercial provider, to compare official laboratory-test and on-road nitrogen oxide (NO_x) emissions for 541 Euro 5 and Euro 6 diesel passenger cars, representing 145 of the most popular European models. Previous research found that there is a gap between type-approval and real-world carbon dioxide (CO_2) emissions that has grown from less than 10% in 2001 to 42% in 2015 (Tietge et al., 2016). We also include estimates of the real-world CO_2 gap from Spritmonitor.de in this analysis.

The various governments and organizations used a wide range of tests and procedures for the on-road or on-track components of their testing. All conducted real-world tests, with the majority utilizing a portable emissions measurement system (PEMS) for recording emissions. Two organizations or governments used smart emissions measurement systems (SEMS) equipment. Some of them followed the New European Driving Cycle (NEDC) speed profile on the road or track; some conducted testing following the real-driving emissions (RDE) testing procedure; and some followed other procedures. The RDE procedure is a new on-road emissions test that was recently introduced by the European Union (EU) as an amendment to the Euro 6 standard. RDE testing will come into force for new EU emissions type approvals beginning in September 2017.

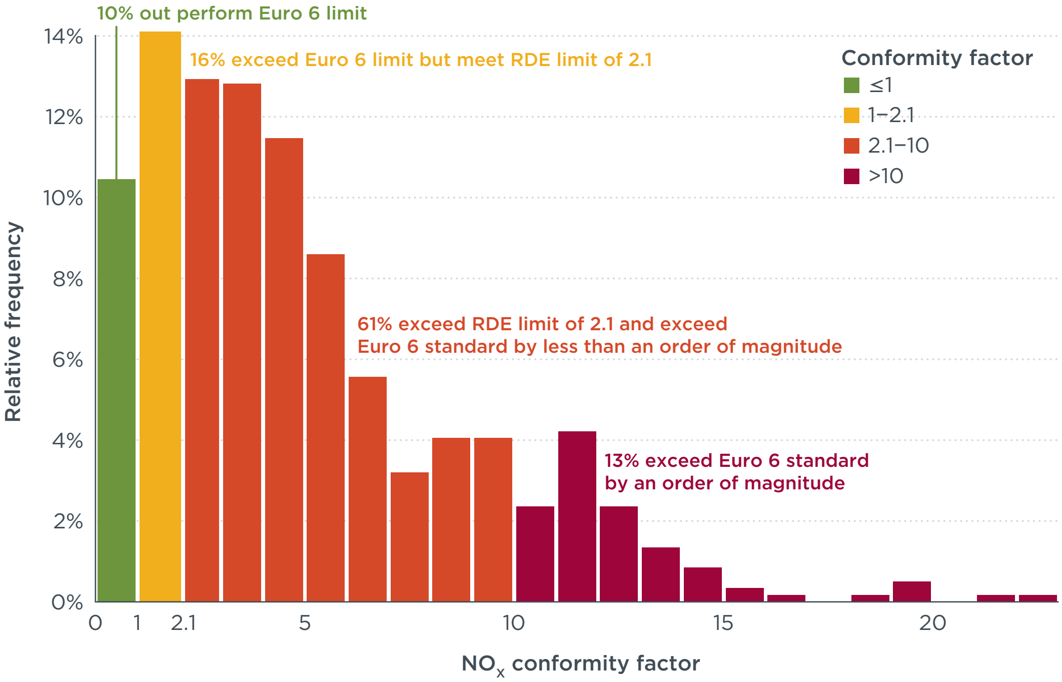

Figure ES-1: Euro 6 diesel passenger car histogram showing individual NO_x measurements.[1]

---

[1] These measurements are organized into four conformity factor groups: less than 1 (= could meet the Euro 6 standard on the road), between 1 and 2.1 (= suggests compliance with the first phase of RDE), and above and below 10 (= order of magnitude higher than Euro 6 laboratory standards).

This paper reports NO_x emissions in terms of conformity factor (CF), or the ratio between the on-road NO_x emissions for a vehicle and the laboratory testing limit for NO_x emissions. For Euro 5 diesel vehicles, the limit is 180 mg/km; and for Euro 6, the limit is 80 mg/km. This paper finds that average on-road NO_x and CO_2 emissions from diesel passenger cars are much higher than laboratory emission standards and type-approval values. For Euro 5 diesel cars, these CFs ranged from just over 1, meaning that those cars almost met legal limits under real-world conditions, to 11, meaning that actual emissions were 11 times higher than the legal limit. The average CF for this category was 4.1. For Euro 6 cars, the CF range was slightly wider, from just under 1 to almost 12; the average CF for all tested Euro 6 diesel models was 4.5. Under both Euro 5 and Euro 6, Opel and Renault-Nissan cars, particularly the Opel Insignia and Nissan Qashqai, recorded some of the highest NO_x conformity factor readings, indicating the vehicles were the farthest out of compliance with standards. Figure ES-1 shows that 10% of the tested Euro 6 vehicles would probably meet the Euro 6 limits on the road. About a quarter had conformity factors that would probably meet the on-road emissions limit of the first regulatory step of the RDE standards, a NO_x conformity factor of 2.1.[2]

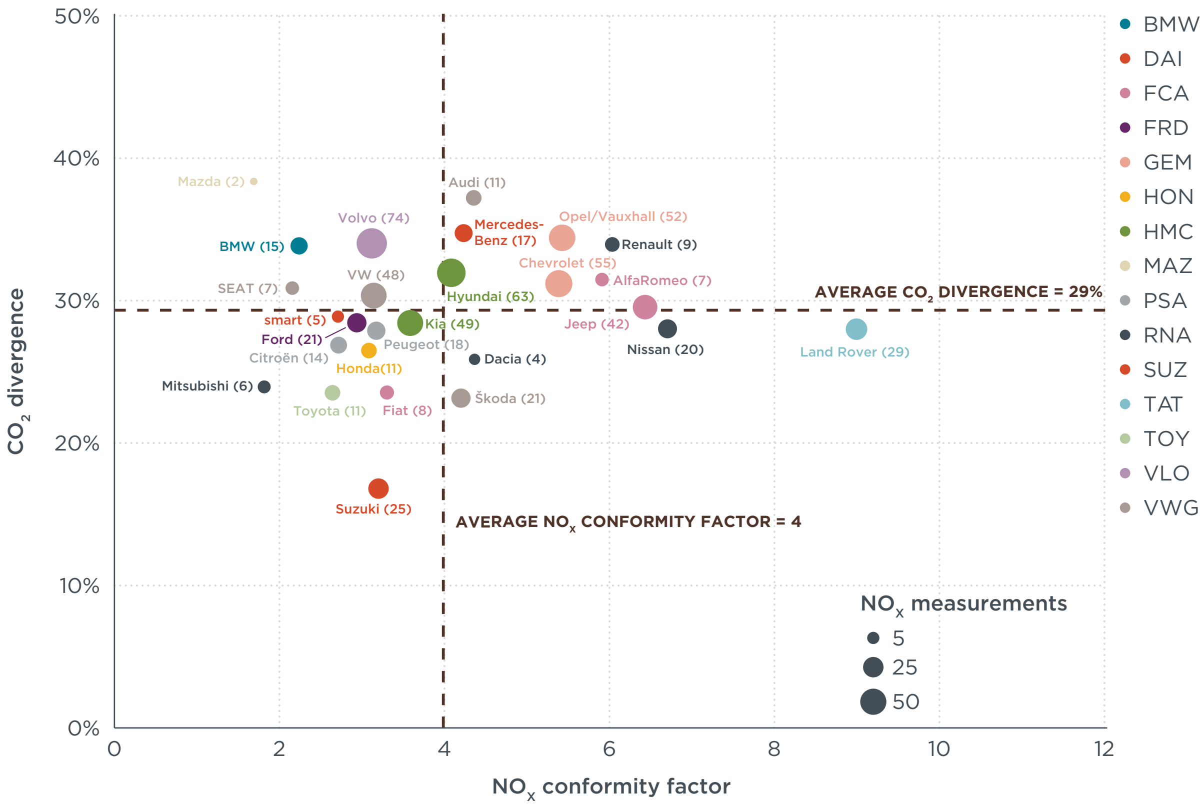

Figure ES-2: Euro 5 diesel passenger car gap between real-world and type-approval CO_2 emission values vs. on-road NO_x emissions conformity factors by manufacturer.[3]

---

[2] These results do not indicate compliance or lack of compliance with the NEDC and RDE tests because the testing methods varied for the different testing initiatives (e.g., test results that make up a car's conformity factor falling under 2.1 did not all follow the RDE protocol).

[3] Marker sizes are indicative of the number of measurements included in the NOX conformity factor calculation (i.e., the larger markers represent more measurements). Manufacturer group key: BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; GEM = General Motors; HON = Honda; HMC = Hyundai Motor Company; MAZ = Mazda; PSA = Groupe PSA; RNA = Renault-Nissan; SUZ = Suzuki; TAT = Tata (including Jaguar Land Rover); TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group. The average conformity factor indicated refers only to those vehicles for which sufficient entries were available to allow for an analysis at the manufacturer's level.

Fiat Chrysler Automobiles (Jeep), Tata Motors (Land Rover), General Motors (Opel/Vauxhall and Chevrolet), and Renault-Nissan (Dacia, Renault, and Nissan) cars recorded some of the highest CFs for Euro 5 (Figure ES-2). The Renault-Nissan and Fiat Chrysler groups were also on the high end of NO_x conformity factors under Euro 6 (Figure ES-3). Under both Euro 5 and Euro 6, the BMW group, which includes Mini, had some of the best CF readings for NO_x (Figure ES-2). Under Euro 6, several brands belonging to the Volkswagen group had average CFs lower than 2 (Figure ES-3).

Figure ES-3: Euro 6 diesel passenger car gap between real-world and type-approval CO_2 emission values vs. on-road NO_x emissions conformity factors by manufacturer.[4]

With respect to CO_2 emission values, this analysis shows that a divergence between type-approval and real-world CO_2 emissions exists for every manufacturer and car model. The average CO_2 divergence for Euro 5 and Euro 6 was approximately 30%.[5] The manufacturers with the highest divergences were Mazda, Audi, Mini, BMW, Volvo, Opel/Vauxhall, Chevrolet, Renault, and Mercedes-Benz (Figures ES-2 and ES-3). The lowest divergences belonged to Škoda, Toyota, Fiat, Suzuki, and Mitsubishi (Figures ES-2 and ES-3).

---

[4] Marker sizes are indicative of the number of measurements included in the NO_x conformity factor calculation (i.e., the larger markers represent more measurements). BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; GEM = General Motors; HON = Honda; HMC = Hyundai Motor Company; MAZ = Mazda; PSA = Groupe PSA; RNA = Renault-Nissan; SUZ = Suzuki; TAT = Tata (including Jaguar Land Rover); TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group. The average conformity factor indicated refers only to those vehicles for which sufficient entries were available to allow for an analysis at the manufacturer's level.

[5] The 30% value refers to the average CO_2 gap for Euro 5 and Euro 6 vehicles built between 2011 and 2015. This average is lower than most recent estimates–40% for vehicles built in 2015 because the gap has been growing over time (see Tietge et al., 2016).

This paper concludes by outlining steps that can be taken to reduce on-road NO_x and CO_2 emissions from passenger diesel cars, namely:

1. PROVIDING TRANSPARENT, ACCESSIBLE DATA:

The on-road emission tests inspired by the Volkswagen defeat device should be the beginning of a long-term monitoring program. It is important to ensure that all data collected during future testing campaigns, not only for NO_x but also for CO_2 and other emissions, are made publicly available within a reasonable timeframe. Disclosing the data allows independent third parties to confirm the findings and helps rebuild consumer and public trust. The emissions testing should be continued on a regular basis, carried out by government agencies, independent technical services, or both. Vehicles for testing should be independently sourced and financed, rather than being provided by manufacturers. The testing should not be funded by manufacturers to ensure full objectivity of the monitoring programs.

2. IMPROVING TEST PROCEDURES:

The introduction of RDE testing in Europe is a first step toward improving vehicle testing standards. But absent high ambitions, it will fall short of completely addressing high NO_x emissions on the road (Miller & Franco, 2016). As part of a further development of the RDE test procedure, legislation needs to ensure that on-road testing applies not only to prototype vehicles, as is the case today, but also to production vehicles randomly selected for in-service conformity testing. A broad market surveillance program for on-road emission levels of new vehicles should include third parties, in addition to type-approval authorities, to ensure independent findings. Finally, CO_2 emissions are still not covered in the RDE testing procedure and are measured only under laboratory conditions, not on the road. But, as we have pointed out in earlier studies, including CO_2 in future on-road testing regulations is imperative for ensuring that production vehicles meet declared values (Tietge et al., 2016).

3. PROPERLY ENFORCING CURRENT AND FUTURE EMISSION STANDARDS:

Even the most advanced testing procedures are effective only if properly enforced. The emission test results collected by government agencies during recent months provide a wealth of information, and in many cases strong indications of illegal defeat devices. It is the responsibility of type-approval authorities to ensure that vehicles comply with standards and, when necessary, order recalls that would remove identified defeat devices and ensure a significant reduction in vehicle emissions. In addition, particularly where a retroactive fix is not possible, it is the responsibility of type-approval authorities to issue fines as a warning that defeat devices and exceeding emission standards will not be tolerated. The European Commission should take a stronger role in coordinating vehicle emissions testing and enforcement, as suggested in the currently debated overhaul of the EU type-approval framework directive (European Commission, 2016b).

These steps could greatly reduce on-road CO_2 and NO_x emissions from diesel passenger vehicles and help rebuild consumer trust in declared emission values. This issue is crucial to the goal of clean transportation, as NO_x is a major component of smog and CO_2 is a principal greenhouse gas contributing to climate change.

TABLE OF CONTENTS

ABBREVIATIONS

ACEA	European Automobile Manufacturers' Association
CF	Conformity factor
CO_2	Carbon dioxide
DCCCRF	French Competition, Consumer Affairs and Prevention of Fraud department
DUH	Deutsche Umwelthilfe (a German environmental NGO)
EA	Emissions Analytics
EGR	Exhaust gas recirculation
EU	European Union
EUDC	Extra urban driving cycle (of the New European Driving Cycle laboratory test)
KBA	Kraftfahrt-Bundesamt (Germany's Federal Motor Transport Authority)
LNT	Lean NO_x trap
NEDC	New European Driving Cycle
NO_x	Nitrogen oxides
PEMS	Portable emissions measurement system
RDE	Real-driving emissions
RDW	Dutch vehicle authority
SCR	Selective catalytic reduction
SEMS	Smart emissions measurement system
TNO	The Netherlands Organisation for Applied Scientific Research
UDC	Urban driving cycle (of the New European Driving Cycle laboratory test)
UK	United Kingdom
ZDF	Zweites Deutsches Fernsehen(a German television network)

1. INTRODUCTION

In 2014, researchers at West Virginia University commissioned by the ICCT conducted on-road emissions testing on three diesel passenger cars in California. This led to the discovery of an illegal defeat device on 590,000 Volkswagen vehicles with diesel engines in the United States (U.S. Environmental Protection Agency, 2017). Shortly following this discovery, Volkswagen acknowledged that more than 8 million passenger cars in Europe were fitted with the same defeat device and that a worldwide total of 11 million Volkswagen vehicles were affected (Muncrief, German, & Schultz, 2016). European legislation prohibits the use of instruments that reduce the effectiveness of emission controls. However, of 28 type-approval authorities in the European Union (EU), only Germany's Federal Motor Transport Authority, the Kraftfahrt-Bundesamt (KBA), has made an official finding that Volkswagen used an unauthorized shutdown device to manipulate the emission values of diesel cars during testing (Untersuchungsausschuss, Deutscher Bundestag, 2016). Other investigations by regulators and courts, including those of manufacturers other than Volkswagen, are ongoing. Manufacturers are pointing to alleged grey areas in the regulations that allow the use of defeat devices for protecting the engine and emissions-control system against damage (United Kingdom Parliament, 2016).

Manufacturers manipulating emissions controls in passenger cars is a significant problem because the transport sector is one of the largest contributors of NO_X in the EU; a recent study estimated that excess diesel vehicle NO_X emissions in 2015 were linked to ~38,000 premature deaths worldwide, with the EU having a high number of deaths compared to other regions. In fact, if diesel vehicle NO_X emissions were within EU certification limits, the mortality burden in Europe would drop by 10% each year (Anenberg et al., 2017).

In reaction to the discovery of the Volkswagen defeat device, several European national agencies and governments conducted their own emissions testing on Euro 5 and Euro 6 diesel passenger cars, focusing on real-world nitrogen oxide (NO_X) emissions, but also covering carbon dioxide (CO_2) emissions. Gasoline passenger cars were not included because previous research found that typically these cars comply with NO_X emissions standards in the real world (although a CO_2 gap does exist; Miller & Franco, 2016). In this paper, we combine the publicly available data that these agencies and government bodies collected to compare official and on-road[6] NO_X emissions levels for 541 Euro 5 and Euro 6 diesel passenger cars, representing 145 of the most popular models. We added real-world CO_2 emission values from Spritmonitor.de, a free web service allowing roughly 400,000 users to track their on-road fuel consumption. We included CO_2 data in this paper because previous research documented a divergence, or "gap," between CO_2 type-approval values and real-world CO_2 emissions for passenger cars in Europe that has grown from less than 10% in 2001 to 42% in 2015 (Tietge et al., 2016). This gap is important because passenger cars represent 12% of total EU CO_2 emissions. We analyze this NO_X and CO_2 data by model and manufacturer, and we also assess how individual NO_X measurements compare with laboratory standards and manufacturer averages. We discuss observed differences in performance between passenger cars and in manufacturers' responses.

---

[6] In this paper, we define "on-road" NO_X emissions to mean those emissions that were measured on the track or road, with the exception of the NO_X data collected by the Walloon Ministry of the Environment in Belgium, where cars were tested not on the road but on a four-wheel chassis dynamometer using PEMS. These Walloon test results are included in this assessment because the driving profile was based on a "real-world" speed trace and road grade, which was recorded during an on-road drive. Please see the Methodology section of this paper for a more detailed description of the Walloon government's methods.

2. METHODOLOGY

This paper assesses publicly available, on-road NO_x emissions data from diesel passenger cars as of October 2016, collected from British, Dutch, French, and German government reports.[7] We also include data from the Walloon Ministry of the Environment (in Belgium), where cars were tested under "real-world" conditions on a four-wheel chassis dynamometer using a portable emissions measurement system (PEMS). In addition to government reports, a number of independent organizations conducted emissions tests in the aftermath of "Dieselgate." Because the purpose and scope of these tests were similar to the government investigations, those results are also included in this analysis. The independent organizations were the Netherlands Organisation for Applied Scientific Research (TNO); Deutsche Umwelthilfe (DUH), a German environmental NGO; and the German TV network Zweites Deutsches Fernsehen (ZDF).[8] We also include purchased data from a commercial provider, Emissions Analytics, an independent testing business, which uses PEMS to measure real-world fuel economy and on-road emissions. A list of the cars included in this analysis, as well as the associated data sources, are provided in Table A1 in the appendix.

On-road testing is carried out on a car while driving in normal traffic conditions. Table 1 provides an overview of the testing protocols from the reports included in this paper. The most commonly used technique for recording emissions is PEMS, in which a main PEMS unit is temporarily attached to the back of the vehicle to collect and analyze exhaust emissions and record data as the vehicle is driven. The Dutch government and TNO, which collaborated to produce their protocols, used a version of PEMS called smart emissions measurement systems (SEMS). SEMS is a NO_x emission screening tool that contains a data logger; a NO_x and oxygen sensor, which measures volume concentrations; and a thermocouple, a type of temperature sensor. The NO_x sensor and the thermocouple are installed in the tailpipe of the vehicle (Kadjik, Ligterink, van Mensch, & Smokers, 2016). During cross-validation experiments, SEMS NO_x values fell to within 10% of the emissions values collected from cars tested in the laboratory.

Some of the governments and organizations followed the New European Driving Cycle (NEDC) test on a track or road, either with a hot or cold engine start, and in some cases without preconditioning. The British, Dutch, and German governments also performed variations of the NEDC test, for example by increasing the prescribed velocities by 10%. These variations were meant to detect large changes in emissions in response to small deviations from the cycle, which would potentially signal the use of a defeat device.

Additionally, some governments and independent organizations conducted testing following the real-driving emissions (RDE) protocol, a new on-road emissions test that was recently introduced by the EU as an amendment to the Euro 6 standard and will come into force beginning in September 2017 (Mock, 2017). The RDE protocol mandates road testing using PEMS in addition to laboratory trials. Although the RDE directive is more realistic than laboratory tests, it underestimates real-world conditions because the protocol incorporates many boundary conditions for inclusion or exclusion of raw measurement data; the excluded raw values are likely to be higher than those that are included. For example, at engine loads that are currently outside the operating conditions covered by the RDE test, NO_x emissions grow exponentially (Miller & Franco, 2016). Additionally, the raw measurement data is normalized to account for variation across trips.

---

[7] Please see the appendix for a list of the government reports included in this assessment.

[8] The organizations and governments also tested cars on the chassis dynamometer, but with the exception of the Walloon chassis dynamometer testing, which utilized a "real-world" speed trace and road grade, these results (primarily from NEDC testing) were not included in this assessment.

The Walloon Ministry of the Environment in Belgium tested cars on a four-wheel chassis dynamometer using PEMS. These data are included because these tests did not follow a standard driving cycle. Instead, researchers created their own driving profile based on a "real-world" speed trace and road grade recorded from an on-road drive. The investigators also did not do any vehicle pre-conditioning, a common procedure for standard chassis-dynamometer testing.

After collecting on-road NO_X values from the reports, we calculated the average of all the NO_X measurements available for each passenger car model for Euro 5 and Euro 6. We also calculated average NO_X values by car manufacturer. All NO_X measurements for a single manufacturer or model were directly averaged together so that no measurements carried more weight in the average than others. Although we did not assess or address differences in findings between individual sources, we did assess whether there was a difference between average on-road NEDC and RDE findings, based on all available on-road NEDC and RDE findings.

To match CO_2 data with the NO_X values for these cars, we used Spritmonitor.de, a web service that allows users to track their fuel consumption for no charge.[9] Users select a vehicle model and configuration, then enter data on fuel consumption and distance traveled. Reported fuel consumption values are publicly accessible, with roughly 400,000 users registered on Spritmonitor.de. We chose to use the Spritmonitor.de gap estimates instead of the CO_2 measurements from the governments' and organizations' reports because not all governments and organizations provided CO_2 values, and the Spritmonitor.de database is a more comprehensive source. A discussion of the validity of Spritmonitor.de data can be found in a number of studies (see Mock, German, Bandivadekar, & Riemersma, 2012; Tietge et al., 2016). Only diesel vehicles from Spritmonitor.de were included in this analysis.

Not all of the passenger cars for which we had on-road NO_X values had enough entries in the Spritmonitor.de database to yield precise estimates. The minimum required sample size was determined to be 30 data points for a 95% confidence interval of less than ±5 percentage points of the real-world gap in CO_2 emission values. If a vehicle model did not meet these criteria, it was not included in the comparative analysis for CO_2 and NO_X. We averaged together CO_2 gap estimates from 2011 through 2015 because Spritmonitor.de data do not differentiate between models by Euro 5 and 6 legislation. Thus, CO_2 gap estimates for vehicle models are the same in the Euro 5 and Euro 6 charts.[10]

---

[9] The complete data set used for this analysis was acquired in April 2016.

[10] Between 2011 and 2015, type-approval values have decreased, on average, for diesel vehicles in the Spritmonitor database, thus contributing to the CO2 gap; however, this decrease only represents approximately 2 percentage points of the increase in the overall divergence between real-world and type-approved CO_2 values (see Tietge et al., 2016).

Table 1: Overview of testing protocols used by governments and independent organizations

		France	Germany	Wallonia (Belgium)	UK	Netherlands	DUH	TNO	ZDF	Emissions Analytics
On-road or on-track driving profile	NEDC speed trace	X	X		X	X			X	
	NEDC but with slightly modified speed trace		X		X	X				
	Two consecutive hot-start NEDC cycles with the engine running in between				X					
	NEDC but with cycles in reverse		X		X	X				
	If NEDC, cold or hot start?	cold	hot		hot	both (separate tests)			hot	
	If NEDC, preconditioning cycle?	no	no		unknown	unknown				
	RDE testing	X	X		X	X		X	X	
	Organization utilized its own pre-determined route: urban, rural and/or motorway driving						X	X		X
Chassis-dynamometer testing	Based on a “real-world” speed and road grade profile			X						
Measurement system	PEMS	X	X	X	X	X	X	X	X	X
	SEMS					X		X		
Test temperature	Range of ambient temperatures during testing (ºC)	min. 2 max. 21	min. 2 max. 22	18 (average laboratory temperature)	min. 4 max. 17	min. 1 max. 33	min. 20 max. 30	min. -3 max. 26	unknown	min. 2 max. 33

3. FACTORS INFLUENCING NO_X AND CO_2 EMISSIONS

Table A1 in the appendix lists the type of NO_x aftertreatment technology each vehicle in this analysis used, if any, when that information was available in the government reports. There are three primary emissions aftertreatment technologies that passenger cars use to control NO_x emissions: exhaust gas recirculation (EGR), the lean NO_x trap (LNT), and selective catalytic reduction (SCR). EGR is used in all Euro 5 and Euro 6 vehicles, and it is the primary NO_x control technology for Euro 5 passenger cars. Because of the limitations of EGR, LNT and SCR became popular with the introduction of stricter Euro 6 standards.

The latest Euro 6 cars, whose aftertreatment will be influenced by the RDE regulation, are equipped with technologies that address some of the deficiencies of pre-RDE aftertreatment designs. This includes combining LNT and SCR, as well as incorporating SCR-coated particulate filters, which are installed near the engine and are closely coupled with it (Eder, Kemmer, Lückert, & Sass, 2016; Knirsch, Weiss, Möhn, & Pamio, 2014).

A previous paper detailed the advantages and disadvantages of these NO_x control technologies (Yang, Franco, Campestrini, German, & Mock, 2015). A 2016 blog provided evidence that some manufacturers are unnecessarily turning off the EGR outside of NEDC testing conditions (German, 2016a). This is partly due to shortcomings of the technology itself (e.g., its inability to handle higher loads), but also to the way manufacturers calibrate the use of the EGR.

Manufacturers have considerable flexibility with how they design emissions strategies, such as how they calibrate a vehicle's engine and its aftertreatment. For example, a TNO study, where some of the data in this analysis originated, found that there is a considerable difference between the NO_x conversion efficiency of vehicle SCR catalysts during NEDC laboratory testing and on the road (Kadjik, van Mensch, & Spreen, 2015). There is no technical reason why conversion efficiency should be lower on the road for a given engine speed and load, so this suggests that the optimized SCR conversion strategy for the type-approval test is frequently not used on the road. The calibrated use of urea reagent (e.g., the timing of its injection to ensure that it mixes properly with exhaust gas) is one of the factors influencing SCR conversion rates. Consequently, it is possible that less-than-optimal SCR conversion rates are due to manufacturers calibrating engines to use less of this reagent than is necessary for the best conversion. Manufacturers may calibrate their engines this way for a few reasons: (a) the cars can have smaller reagent tanks that are easier to package in the vehicles, (b) car owners do not need to bother refilling reagent tanks, and (c) vehicles can go longer without maintenance when less reagent is used. Such calibration would also enable the use of smaller, less expensive SCR catalysts.

As for CO_2 emissions, there are several reasons for the gap between type-approval and real-world values. One of these is flexibility in road-load determination, for which vehicle manufacturers can generate favorable results, for example, by selecting specially prepared tires. Vehicle manufacturers are also able to take advantage of a large number of regulatory loopholes. Kühlwein (2016) found that for 19 diesel and gasoline passenger cars, the use of independently determined, realistic road loads instead of type-approval road loads increased CO_2 emissions under the NEDC test by an average of 7.2%.

There are other flexibilities and tolerances in the way chassis dynamometer testing is conducted. Over time, vehicle manufacturers have found ways to optimize this testing to their advantage. Kühlwein (2016) outlined these flexibilities in detail. In general, the gap between real-world CO_2 emissions and type-approval values is increasing; from 2001 to 2015, the gap has widened from 9% to 42% (Stewart, Hope-Morley, Mock, & Tietge, 2015; Tietge et al., 2016).

4. RESULTS

4.1 NO$_x$ EMISSIONS CONFORMITY FACTORS FROM INDIVIDUAL CAR TESTING[11]

Figure 1 illustrates Euro 5 and Euro 6 on-road NO$_x$ emissions with box plots of the distribution of NO$_x$ conformity factors from individual car tests. The CF is the ratio between the on-road NO$_x$ emissions for a car and the legal limit for NO$_x$ emissions of 180 mg/km for Euro 5 and 80 mg/km for Euro 6. The conformity factors are analyzed by manufacturer group and emissions standard, either Euro 5 or Euro 6. The boxplots show five key metrics of the distribution of measurements: the first and third quartile (25th and 75th percentiles) of the distribution, the median and the mean for each manufacturer, and outliers, which are displayed individually.

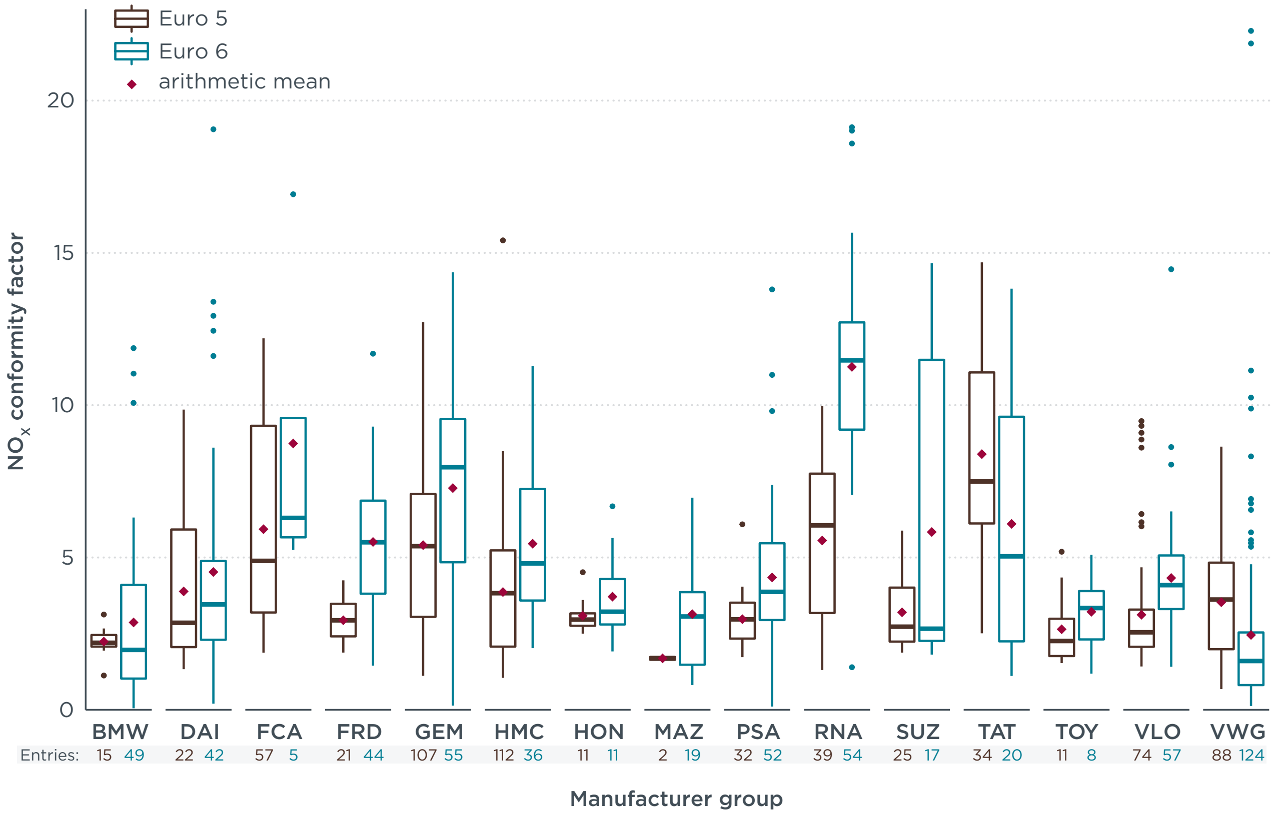

Figure 1: Boxplots of on-road NO$_x$ conformity factors of individual vehicle tests by manufacturer group and emissions standard.[12]

The figure shows that mean and median conformity factors increased for most manufacturer groups moving from the Euro 5 to the Euro 6 standard, although it should

---

[11] Parent companies (followed by other brands they own if they go by a different name) that are included in these findings: BMW: Mini; Daimler: Mercedes and Smart; Fiat Chrysler Automobiles: Alfa Romeo and Jeep; Ford; General Motors: Chevrolet and Opel/Vauxhall; Honda; Hyundai Motor Company: Hyundai and Kia; Isuzu; Mazda; PSA Group: Peugeot and Citroën; Renault-Nissan: Dacia, Mitsubishi, and Nissan; Ssangyong; Suzuki; Tata: Land Rover and Jaguar; Toyota; Volvo; and the Volkswagen group: Audi, Porsche, SEAT, and Škoda.

[12] The lower and upper hinges (the top and bottom of the box) represent the first and third quartile (25th and 75th percentiles) of the distribution. The thicker horizontal line in the box represents the median of the distribution. Orange diamonds represent the arithmetic mean. Whiskers (vertical lines extending from the box) extend to the smallest and largest values no further than 1.5 times the inter-quartile range outside the box, where the inter-quartile range refers to the distance between the first and third quartile. Outlying measurements are plotted as individual points. The number of measurements by emissions standard is presented underneath each manufacturer group. BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; GEM = General Motors; HON = Honda; HMC = Hyundai Motor Company; MAZ = Mazda; PSA = Groupe PSA; RNA = Renault-Nissan; SUZ = Suzuki; TAT = Tata (including Jaguar Land Rover); TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group.

be noted that all manufacturer groups reduced mean and median NO_x emission levels (in terms of mg/km) from Euro 5 to Euro 6. Volkswagen Group and Tata Motors are the only manufacturer groups that achieved a significant improvement in conformity factors. The boxplots also indicate a wide range in NO_x measurements, in part because of varying testing conditions and procedures.

Outlying points were not removed from the analysis under the assumption that they represent valid measurements. Outliers could represent trips with driving events where control strategies of aftertreatment systems lead to excess emissions; this interpretation of outlying measurements is also the reason for using the arithmetic mean, rather than a robust statistic such as median values, in other figures of this analysis.

Table 2 identifies the make and model of those individual outliers that fell on the upper end of the distribution. Seven of the 45 outliers are not identified for reasons pertaining to an organization's data publication permission.[13] The table shows that these outliers represent a range of conformity factors, from 3 to 22, which reflects the varying nature of the distribution of the individual measurements for these cars, although almost half of the outliers represent CFs of at least 10 (Table 2).

Table 2: Outliers from Figure 1. Outliers identified as individual points in Figure 1 are listed here. Seven of the 45 total outliers are not included for data publishing permission reasons.[14]

Source	Euro Standard	Group	Make	Model	Euro 6 Aftertreatment Technology, If Applicable	# of Outliers	NO_x CF/ Range of CFs
ZDF	Euro 5	BMW	BMW	BMW 3-series		1	3
EA	Euro 6	BMW	BMW	BMW 4-series	LNT	1	11
EA	Euro 6	BMW	BMW	BMW X3	LNT	1	12
UK	Euro 6	DAI	Mercedes	Mercedes A-Class	LNT	5	12-19
France	Euro 6	FCA	Fiat	Fiat 500	LNT	1	17
UK	Euro 6	FRD	Ford	Ford Focus	LNT	1	12
UK	Euro 5	HON	Honda	Honda CR-V		2	5, 7
UK	Euro 6	PSA	Peugeot	Peugeot 3008	SCR	3	10-14
Germany	Euro 6	RNA	Renault	Renault Kadjar	LNT	2	19
UK	Euro 6	RNA	Renault	Renault Megane	LNT	1	19
Wallonia (Belgium), UK	Euro 5	VLO	Volvo	Volvo V40		6	6-9
Netherlands	Euro 6	VLO	Volvo	Volvo XC90	unknown	3	8-14
DUH	Euro 6	VWG	Audi	Audi A3	LNT	1	5
EA	Euro 6	VWG	Audi	Audi A8	SCR	1	22
TNO	Euro 6	VWG	Audi	Audi Q7	SCR	1	6
Germany	Euro 6	VWG	Porsche	Porsche Macan	SCR	5	7-11
TNO	Euro 6	VWG	VW	VW Golf	unknown	1	6
TNO, EA	Euro 6	VWG	VW	VW Polo	LNT	2	5,7

---

[13] Some of these outliers are not disclosed because we are not allowed to release the car model for the individual outlier; we have permission only to include these outliers as a part of an average calculation for a manufacturer brand (so they are included in the calculations in Figures 4 and 5).

[14] BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; HON = Honda; PSA = Groupe PSA; RNA = Renault-Nissan; VLO = Volvo; VWG = Volkswagen Group.

Figure 2 illustrates the percentage of individual NO_x measurements from tested Euro 6 passenger cars that met the Euro 6 emission limit on the road (or when subject to a realistic speed trace on the chassis dyno), as well as those measurements with a CF of less than 2.1, which is the highest conformity factor allowed under the first regulatory step of the RDE (European Commission, 2016a). Figure 2 suggests that 10% of the Euro 6 vehicles that were tested would probably meet the Euro 6 limits on the road. Approximately one quarter had conformity factors that would probably meet the first implementation of RDE standards. The remaining 74% of the diesel passenger car measurements exceeded the RDE conformity factor. Measurements that exceeded the Euro 6 standard of 80 mg/km by an order of magnitude or greater (i.e., their on-road NO_x emissions exceeded 800 mg/km) amounted to 13%.

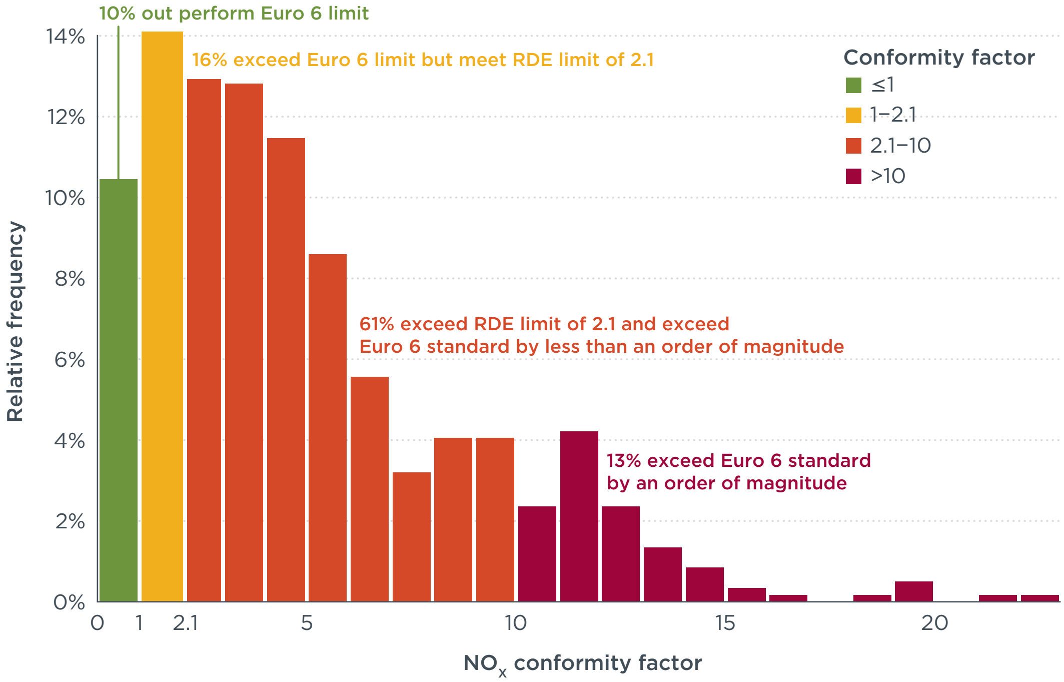

Figure 2: Histogram displaying individual NO_x measurements of Euro 6 cars tested by governments and independent organizations.[15]

In addition to the magnitude of conformity factors, the popularity of different car models also determines the real-world impact of excess emissions. Vehicles with NO_x CFs of less than 2.1 represented roughly 19% of the new diesel passenger cars sold in 2014 (based on data from Mock, 2015). On the other hand, vehicles with CFs greater than 8 were also some of the most popular, representing 14% of the new diesel passenger cars sold in 2014. Even if a high-emitting car is not very popular, the amount of NO_x all vehicles of its make and model emit on the road might match or surpass the emissions of more popular vehicles because its on-road NO_x values could be magnitudes greater than those of cleaner competitors.

Table 3 shows that many car models improved their NO_x conformity under Euro 6 compared with Euro 5.[16] On the other hand, a few cars had conformity factors that were

---

[15] These measurements are organized into four conformity factor groups: under 1 (= could meet the Euro 6 standard on the road), between 1 and 2.1 (= suggests compliance with the first step of RDE), and above and below 10 (= order of magnitude higher than Euro 6 laboratory standards). The bins are generally integer values, except for the 2.1 value. This means that the 1–2.1 bin is slightly larger than the others and therefore accounts for 16% of the measurements, even though the bar stops at 14%. These data also include more NO_x measurements than in Figures 1 and 2, which needed to be matched with real-world CO_2 values that were averaged from at least 30 entries, so some measurements were filtered out.

[16] This comparison is not possible for all vehicle models, because not all were tested or included in this overarching analysis for both Euro 5 and Euro 6.

more than three times greater under Euro 6 than under Euro 5: the BMW 1-series, the Mercedes-Benz B-Class, and the Peugeot 3008. For the 1-series and the Mercedes-Benz B-class, only one or two emissions measurements led to these results.

The mix of aftertreatment technologies used by top-performing vehicles, as shown in Table 3, suggests that no single aftertreatment technology is the best at reducing real-world NO$_X$ emissions, although several manufacturer groups, including Ford and the Volkswagen Group, have recently announced that they will be switching production of future vehicles to SCR, despite its higher cost (Howard, 2016).[17]

Table 3: Cars with lower conformity factors under Euro 6 than under Euro 5.[18]

		Euro 5		Euro 6		
Model	**Group**	**Number of measurements**	**NO$_X$ CF**	**Euro 6 Aftertreatment Technology**	**Number of measurements**	**NO$_X$ CF**
Audi Q3	VWG	3	3.46	unknown	1	0.60
Peugeot 208	PSA	8	3.12	SCR	1	0.68
VW Passat	VWG	11	3.29	unknown	15	1.31
Mitsubishi ASX	RNA	6	1.82	LNT	1	1.40
Skoda Superb	VWG	3	5.37	LNT	3	1.44
Audi A6	VWG	7	4.82	SCR	14	1.57
Seat Leon	VWG	2	1.89	LNT	1	1.62
VW Tiguan	VWG	3	4.70	unknown	1	1.76
Mercedes C-Class	DAI	2	2.89	SCR	21	2.59
Skoda Octavia	VWG	12	3.85	LNT	7	2.63
Land Rover Range Rover Evoque	TAT	2	5.60	SCR	6	2.73
Jaguar XF	TAT	5	4.90	SCR	2	2.93
Toyota Avensis	TOY	2	3.36	LNT	6	3.09
Volvo V60	VLO	2	5.12	unknown	5	3.39
Mercedes E-Class	DAI	5	6.73	SCR	5	3.43
Peugeot 308	PSA	4	4.07	SCR	25	3.54
Opel/Vauxhall Mokka	GEM	13	5.37	LNT	19	5.12
Opel/Vauxhall Insignia	GEM	7	10.88	SCR	10	9.01

Note: Vehicles sorted by Euro 6 conformity factor. Green highlights vehicles with average on-road CFs that are less than 1; yellow indicates those between 1 and 2; and red are those vehicles with CFs of more than 2 times the legal limit.

Figure 3 compares results from NEDC and RDE testing for Euro 5 and Euro 6 vehicles, charting results for those vehicles that were subjected to both on-road NEDC testing and RDE testing. When focusing on Euro 6 vehicles, the figure illustrates once more that nearly all tested cars were outside the blue box that represents the Euro 6 laboratory emissions limit of 80 mg/km. Furthermore, it becomes clear from the figure that this does not occur only during RDE testing. In fact, most Euro 6 cars exceeded the 80 mg/km limit when driven on the road following the NEDC test cycle. So even a small variation in test conditions, such as repeating the NEDC test on the road instead

---

[17] See Yang et al. (2015) for a comparison of NO$_X$ emissions performance for cars with LNT and SCR technologies during a Worldwide-Harmonized Light-Duty Test Cycle.

[18] DAI = Daimler; GEM = General Motors; PSA = Peugeot; RNA = Renault; TAT = Tata; TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group.

of under laboratory conditions, often triggers suspiciously high deviations in NO_x emissions, thereby suggesting the use of defeat devices. This observation is in line with a 2016 study by scientists from the European Commission's Joint Research Centre. The study found that "insufficient driving dynamics and an overly narrow temperature range of NEDC testing may not be the root cause of the diesel-NO_x problem" and that "elevated on-road NO_x emissions can neither be explained by transient driving nor by the variability of ambient temperatures during on-road driving, but may instead be related to the use of defeat strategies" (Degraeuwe & Weiss, 2017). The researchers support this finding with analyses demonstrating that diesel cars show higher NO_x emissions on the road under NEDC-like conditions than during NEDC testing in the laboratory, controlling for dynamic conditions and ambient temperatures.

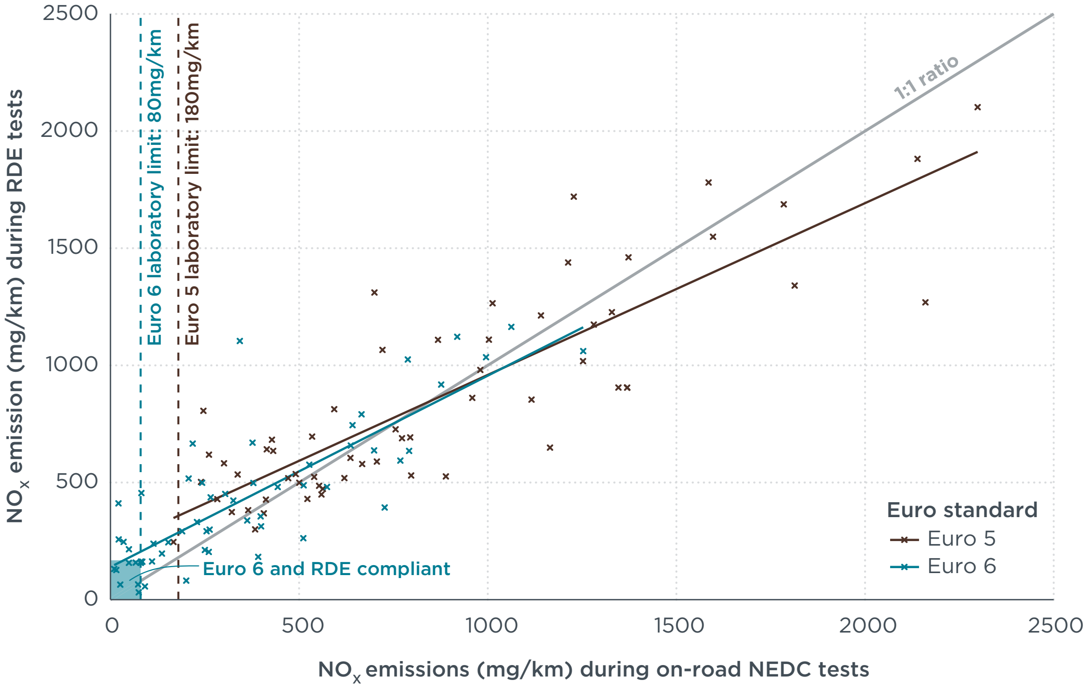

Figure 3: Comparison of results from on-road NEDC and RDE testing for Euro 5 and Euro 6 vehicles. This chart includes NO_x emission measurements from all Euro 5 and Euro 6 passenger cars for which both RDE and on-road NEDC data were available. Markers represent individual cars, with the average on-road NEDC measurement on the x-axis and the average RDE value on the y-axis.

4.2 COMPARING EURO 5 AND EURO 6 DIESEL PASSENGER AUTO EMISSIONS FOR ON-ROAD CO_2 AND NO_x

Figures 4 and 5 compare Euro 5 and Euro 6 diesel passenger car performance on the road across both CO_2 and NO_x. As explained in the methodology section, not all the passenger cars for which we have NO_x emissions values are included in these figures because there were not enough entries for all car models in the Spritmonitor.de database to meet the minimum sample size of 30 required for our analysis. The y-axis represents the real-world divergence in CO_2 emission values, or the difference between CO_2 values measured on the road and the type-approval value for each vehicle. The x-axis represents the NO_x conformity factor (CF). Corresponding identification numbers for each car can be found in Table A1 in the appendix.

Figure 4 shows that the two cars with the highest NO_x conformity factors under Euro 5 were the Opel/Vauxhall Insignia (ID #20), with a CF of 11 based on seven tests, and the Jeep Grand Cherokee (#9), with a CF of 10 based on 13 trials. The Nissan Qashqai (#45) had a conformity factor of 7.5 in 15 tests, making it another of the highest NO_x emitters. As for CO_2, the Mazda CX-5 (#32) was one of the highest emitters, with a divergence of 44%, although it was one of the lowest NO_x emitters. The second-highest CO_2 emitter was the Volvo V40 (#54) with a divergence of 42% and a NO_x conformity factor of 3. The Audi A6 (#59) and A1 (#58) and the Mercedes-Benz A-class (#3) had CO_2 divergences of 40%.

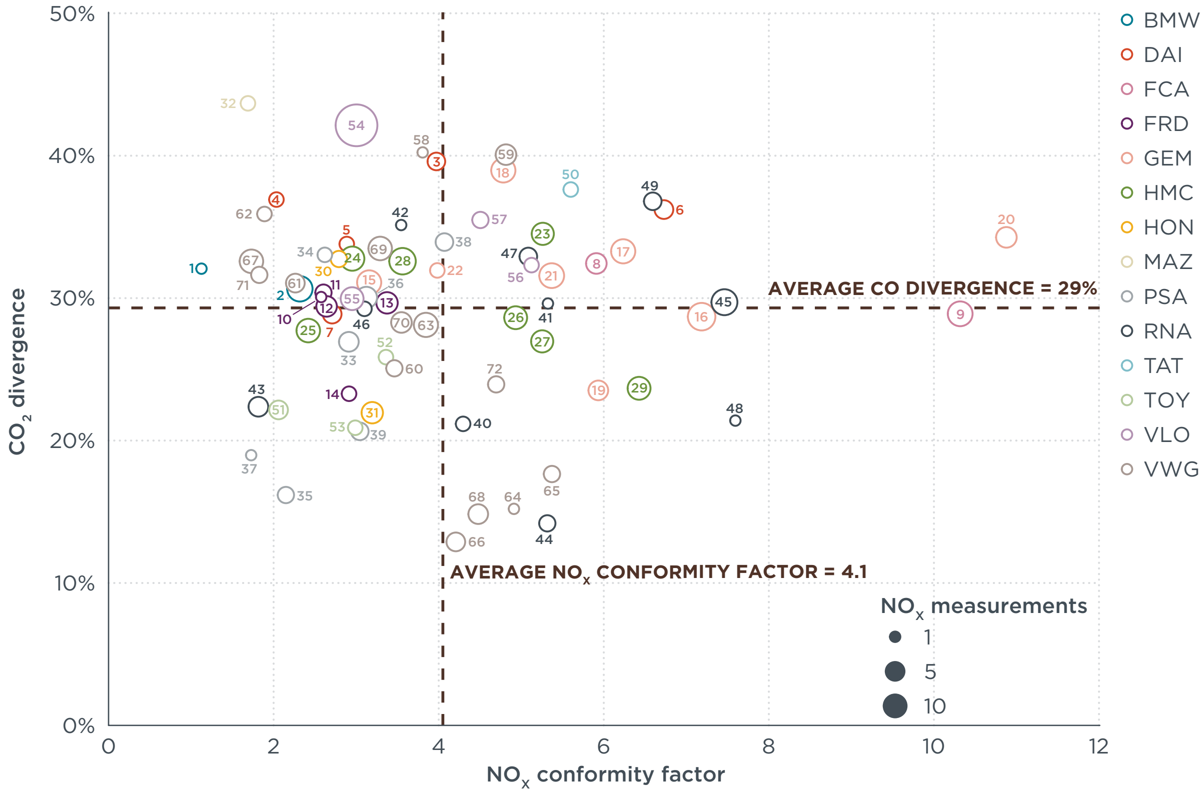

Figure 4: Euro 5 diesel passenger cars gap between real-world and type-approval CO_2 emission values vs. on-road NO_x emissions conformity factors.[19]

The cars that came the closest to meeting Euro 5 standards, i.e., those with conformity factors of less than 2, include the BMW 1-series (#1), Mazda CX-5 (#32), Mitsubishi ASX (#43), Peugeot 3008 (#37), SEAT León (#62), VW Sharan (#71), and VW Golf (#67) (Figure 4). For CO_2 emission values, the Peugeot 3008 (#37), Citroën C5 (#35), Škoda Yeti (#66), Škoda Superb (#65), Škoda Roomster (#64), and VW Golf Plus (#68) had divergences of less than 20%. The VW Golf (#68) outperformed many other Euro 5 cars for NO_x and CO_2, even though it is one of the vehicles with a known defeat device.

Figure 5 shows the same data for Euro 6 cars, in which CFs are based on a NO_x emissions limit of 80 mg/km rather than the Euro 5 limit of 180 mg/km. Here, compared with Euro 5 passenger cars, many more vehicles had CFs greater than 8: the Peugeot 3008 (#35); Mercedes A-Class (#8) and B-Class (#9); Alfa Romeo Giulietta (#12); Hyundai i20 (#23); Opel/Vauxhall Insignia (#20) and Zafira (#22); Dacia Sandero (#39); Nissan Qashqai (#41); and Renault Scénic (#45), Clio (#43), Captur (#42), and Mégane (#44). The Renault Mégane had the highest conformity factor for Euro 6 cars at 11.8.

---

[19] ID Numbers can be found in Table A1 in the appendix. Marker sizes are indicative of the number of measurements included in the NO_x conformity factor calculation (i.e., the larger markers represent more measurements). BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; GEM = General Motors; HON = Honda; HMC = Hyundai Motor Company; MAZ = Mazda; PSA = Groupe PSA; RNA = Renault; TAT = Tata; TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group.

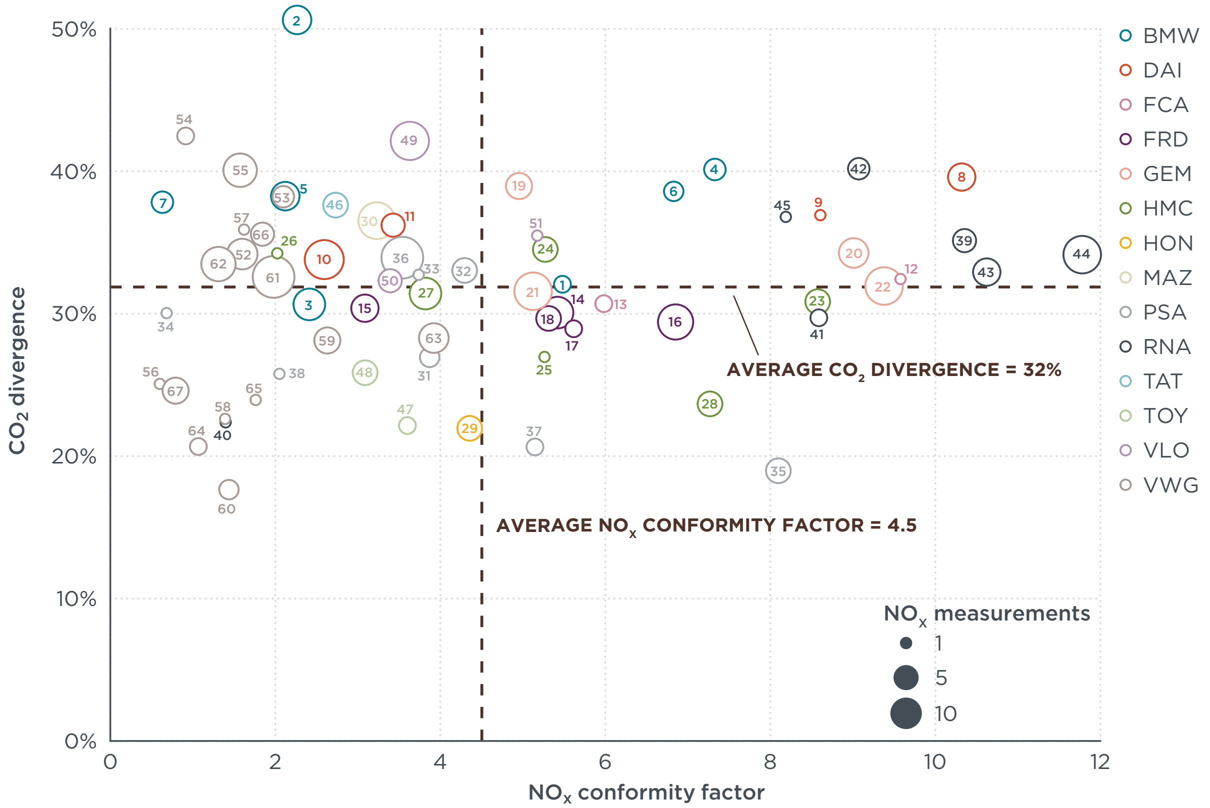

Figure 5: Euro 6 diesel passenger cars gap between real-world and type-approval CO_2 emission values vs. on-road NO_x emissions conformity factors.[20]

Despite the large number of cars with NO_x conformity factors greater than 8 compared with the tested Euro 5 cars, there were many more Euro 6 cars with conformity factors of less than 2. In fact, several cars had conformity factors of less than 1. This suggests that the NO_x emissions of these vehicles might meet Euro 6 standards on the road, showing that on-road compliance with the Euro 6 standard is possible given an appropriate application of aftertreatment technologies. The Škoda Fabia (#58), VW Touran (#67), Audi Q3 (#56) and A5 (#54), Peugeot 208 (#34), and Mini Countryman (#7) met Euro 6 standards on the road, while 10 more cars had CFs of less than 2: the Audi A3 (#52) and A6 (#55); Škoda Superb (#60); SEAT León (#57); VW Touareg (#66), Scirocco (#64), Tiguan (#65), Passat (#62), and Golf (#61); and Mitsubishi ASX (#40).

For CO_2 emissions, the Euro 6 and Euro 5 cars' performance was rated the same, reflecting use of the same CO_2 data, although the exact models included in the figures varied because different models were tested, as shown in Table A1. The cars with the highest and lowest CO_2 divergence values in Figures 4 and 5 also varied. Among Euro 6 vehicles, the highest CO_2 emitters were the Audi A6 (#55) and A5 (#54); BMW 2-Series (#2) and 4-series (#4); Renault Captur (#42); and Volvo V40 (#49). The vehicles with the lowest divergences were the Škoda Superb (#60) and Peugeot 3008 (#35).

---

[20] Marker sizes are indicative of the number of measurements included in the NO_x conformity factor calculation (i.e., the larger markers represent more measurements). BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; GEM = General Motors; HON = Honda; HMC = Hyundai Motor Company; MAZ = Mazda; PSA = Groupe PSA; RNA = Renault-Nissan; TAT = Tata (including Jaguar Land Rover); TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group.

4.3 EMISSIONS BY MANUFACTURER

Showing more broadly how car companies performed, Figures 6 and 7 record the NO_X and CO_2 performance by manufacturer for Euro 5 cars and Euro 6 cars.[21] Under Euro 5, Renault, Nissan, Alfa Romeo, and Jeep all had NO_X conformity factors of at least 6, while SEAT, Mazda, and Mitsubishi had some of the lowest CFs.

Land Rover was furthest out of NO_X conformity under Euro 5 with a CF of 9, but its performance dramatically improved under Euro 6, dropping to a CF of 2.7. The opposite occurred for Fiat, whose CF more than tripled between Euro 5 and Euro 6. Although Volkswagen admitted to the use of a defeat device in some of its Euro 5 cars, it had a NO_X CF of 2 under Euro 6, relatively low compared with its competitors. Mini, SEAT, and Mitsubishi also had low conformity factors under Euro 6, although only one Mitsubishi car, an ASX, and one SEAT car, a León, were tested.

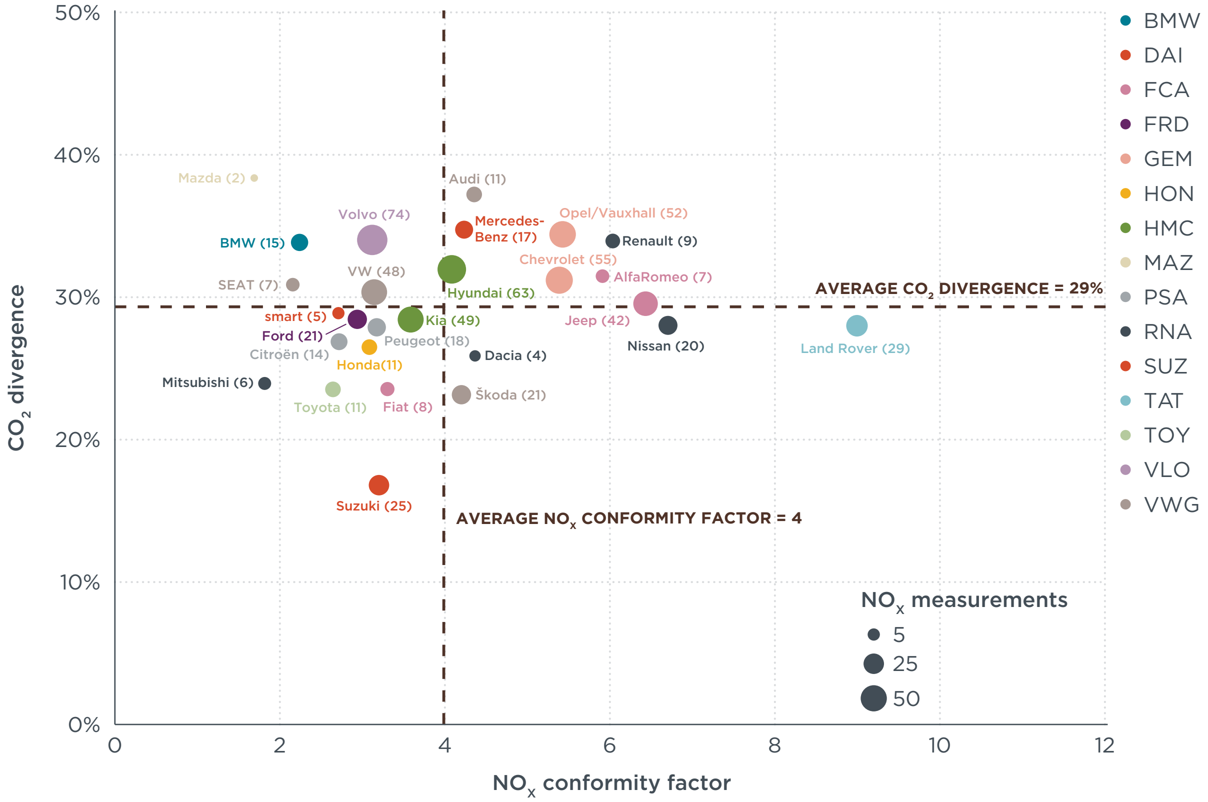

Figure 6: Euro 5 diesel passenger car gap between real-world and type-approval CO_2 emission values vs. on-road NO_X emissions conformity factors by brand.[22]

---

[21] Manufacturer groups (with the manufacturers that they own following) included in Figures 6 and 7: BMW: BMW and Mini; Daimler: Mercedes and Smart; Fiat: Alfa Romeo, Fiat, and Jeep; Ford; General Motors: Chevrolet and Opel/Vauxhall; Honda; Hyundai Motor Company: Kia and Hyundai; Mazda; Groupe PSA: Peugeot and Citroën; Renault-Nissan: Dacia, Mitsubishi, Nissan, and Renault; Suzuki; Tata: Land Rover; Toyota; Volvo; and the Volkswagen group: Audi, SEAT, Škoda, and VW.

The manufacturers included in these figures are slightly different from those whose car models were included in Figures 4 and 5 because the criteria for including the Spritmonitor.de CO_2 data (minimum sample size of 30 entries) was based on manufacturer brand, not model.

[22] Marker sizes are indicative of the number of measurements included in the NO_X conformity factor calculation (i.e., the larger markers represent more measurements). Colors indicate the brands belonging to: BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; GEM = General Motors; HON = Honda; HMC = Hyundai Motor Company; MAZ = Mazda; PSA = Groupe PSA; RNA = Renault-Nissan; SUZ = Suzuki; TAT = Tata; TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group.

Figure 7: Euro 6 diesel passenger car gap between real-world and type-approval CO_2 emission values vs. on-road NO_x emissions conformity factors by brand.[23]

As for CO_2, Suzuki, Škoda, Toyota, Mitsubishi, and Fiat recorded some of the smallest CO_2 emission value divergences. The highest CO_2 divergences belonged to Mazda, Audi, BMW, Mini, Volvo, Chevrolet, Opel/Vauxhall, Renault, and Mercedes-Benz (Figures 6 and 7).

When assessing the emissions data in terms of manufacturer groups, NO_x conformity factors were similar under both standards, with Renault-Nissan, Fiat Chrysler Automobiles, and General Motors at the higher end of NO_x conformity factors (Figures 6 and 7). Under Euro 6, all Renault-Nissan brands, excluding recently acquired Mitsubishi, had NO_x conformity factors of at least 6. Under Euro 6 standards, the Volkswagen Group (Volkswagen, SEAT, Škoda, and Audi) had CFs ranging from 2 to 3. All of the Volkswagen Group brands improved in performance from Euro 5 to Euro 6. BMW also had some of the lowest NO_x conformity factors under both Euro 5 and Euro 6, which is consistent with a previous study assessing on-road NO_x emissions (Yang et al., 2015). The Mini Countryman's CF of 0.6 helped BMW achieve a relatively low Euro 6 overall CF of 3.

The results for Renault-Nissan align with a previous finding that a Renault vehicle was one of the highest NO_x emitters (Yang et al., 2015). It is possible that the Nissan and Renault vehicles' engines have similar conformity factors because Renault acquired Nissan in 1999, and Nissan primarily uses Renault engines for its diesel vehicles. It is also likely that Nissan follows a similar emissions calibration strategy. Mitsubishi, on the other hand, most likely has not yet harmonized its calibration strategy with that of Renault-

---

[23] Marker sizes are indicative of the number of measurements included in the NO_x conformity factor calculation (i.e., the larger markers represent more measurements). Colors indicate the brands belonging to: BMW = BMW; DAI = Daimler; FCA = Fiat Chrysler Automobiles; FRD = Ford; GEM = General Motors; HON = Honda; HMC = Hyundai Motor Company; MAZ = Mazda; PSA = Groupe PSA; RNA = Renault-Nissan; SUZ = Suzuki; TAT = Tata; TOY = Toyota; VLO = Volvo; VWG = Volkswagen Group.

Nissan because it was only recently acquired. Increased collaboration is likely over time (The Economist, 2016).

The German premium car manufacturer groups had generally poor performance on CO_2, and both the Volkswagen Group and Renault-Nissan were inconsistent in their CO_2 emission values across subsidiaries. This inconsistency may be because type-approval departments vary across subsidiaries and the subsidiaries include varying proportions of vehicle segments, which can affect CO_2 performance.

5. MANUFACTURERS' RESPONSES

Manufacturers have responded to the findings included in this analysis to varying degrees, ranging from issuing statements making excuses for high emission measurements to making voluntary recalls. Several manufacturers have attributed high NO_x emissions to reductions in the engine EGR rate for "engine protection reasons" outside certain ambient temperature conditions. Renault, for example, said in response to the French government's report that to protect the EGR system's effectiveness, engine-out NO_x emissions need to be higher at ambient temperatures below 17°C and above 35°C (Jacqué & Van Eeckhout, 2016). As reported in the appendix of the French government report, other manufacturers cited: (a) reduced EGR rate once the engine is hot; (b) preconditioning before testing that differs from what is done for laboratory testing, causing the LNT not to purge itself; (c) differences between starting testing in first gear as opposed to second, which is legally allowed during laboratory testing; and (d) potential LNT sulfur poisoning (Ministère de l'environnement, 2016).

From an engineering perspective, it is unclear how ambient temperatures explain on-road performance because outside temperature does not directly affect the temperature of engine components or emission control calibration (Muncrief et al., 2016). In fact, several manufacturers have made recalls or announced vehicle software changes after initially stating that an ambient temperature window is necessary for protecting the engine.

In a February 2016 press release, Fiat Chrysler Automobiles said it was voluntarily "updating … Euro 6 calibrations with new data sets to improve emission performance in real driving conditions," and was accelerating "programs to expand application of Active Selective Catalytic Reduction technology" (Fiat Chrysler Automobiles, 2016). Nevertheless, in May 2016, the German government filed a complaint with the European Commission against Fiat, asserting that four Fiat vehicles (Doblò, Jeep Renegade, and two new 500Xs) used illegal defeat devices (Bundesministerium für Verkehr und digitale Infrastruktur, 2016). The European Commission concluded mediation of this case in March 2017. A spokesperson for the responsible committee said the two sides "have found a common understanding on the need for Fiat to take measures," although no information was provided on whether the Fiat 500X or the two other models had an illegal defeat device (Teffer, 2017).

In Spring 2016, Suzuki announced a voluntary recall because some of its models with Fiat engines failed emissions testing during the same investigation. The company said that only models with the 1.6-liter diesel direct injection system engine from Fiat were affected (Holder, 2016; Panait, 2016).

Renault recalled 15,800 Captur diesel cars and announced software fixes for 700,000 other vehicles in January 2016 (Stothard, 2016).[24] A few months later, it issued a press release stating that it would "double the operating range at full efficiency of the EGR systems without impacting the reliability and safety of engine and vehicle operation under customer driving conditions" in its Euro 6b cars, and that it would enhance performance of the LNT trap by increasing the "frequency and efficiency of [trap] purges … with a more robust system in order to better manage the wide range of different driving conditions." New models would include these features while existing models would implement them progressively, the company said (Groupe Renault, 2016). Since January 2017, the French judiciary branch has been investigating "suspected cheating," although Renault stated that "vehicles are not equipped with cheating software affecting anti-pollution systems" (Chassany, 2017).

---

[24] This analysis found that the Euro 6 Renault Captur had a CF of 7.

As for Nissan, the South Korean Ministry of Environment charged that the Euro 6 Qashqai, which this analysis showed was a relatively high NO_X emitter, used a defeat device after the car failed emissions testing, and Nissan recalled 800 vehicles, although they denied any wrongdoing (Jin, 2017).

The Volkswagen Group, including Audi and Porsche, Daimler's Mercedes-Benz, and PSA's Opel (formerly owned by General Motors until March 2017) said in April 2016 that, in total, they would recall 630,000 vehicles in Germany to fix the temperature setups (Behrmann, 2016). In August 2016, Germany's KBA approved another Volkswagen plan to fix software in 460,000 diesel vehicles, applying to vehicles with 1.2-liter EA189 TDI engines, such as the Volkswagen Polo (Korosec, 2016). Additionally, in November 2016, Volkswagen confirmed that U.S. and European investigators were looking into irregularities related to CO_2 emission levels in some Audi automatic-transmission vehicles (Schmitt, 2016).

In July 2017, German Transport Minister Alexander Dobrindt accused Porsche of using a defeat device in the Porsche Cayenne (an SUV not included in this assessment), forcing Volkswagen to recall 22,000 of the vehicles that were sold in Europe (Jennen, Buergin, & Behrmann, 2017). In the same month, Audi offered a voluntary software update for 850,000 diesel cars with V6 and V8 TDI engines in "close consultation with Germany's Federal Motor Transport Authority (KBA)," to "reduce overall emissions, especially in urban areas" (Audi AG, 2017). Daimler also voluntarily recalled more than 3 million Mercedes-Benz Euro 5 and Euro 6 diesel cars in July 2017, extending a service action that was already in place for 250,000 compact cars and V-class vans to nearly every modern Mercedes diesel vehicle (Behrmann, 2017). Further, in August 2017, during a summit with authorities and diesel car manufacturers in Germany, BMW agreed to update the software in 300,000 of its cars. In total, during this announcement in August, these three car manufacturer groups agreed to update the software in 5.3 million cars (Saarinen, 2017).

Before selling Opel to PSA, General Motors also modified the emissions-control system software on the 2014 Opel Zafira Tourer, which has an engine that is also used in several other Opel vehicles, including the Astra, another car included in this analysis (Gordon-Bloomfield, 2016). Opel acknowledged that this model had engine software that switched off exhaust treatment systems under certain circumstances but maintained that this was legal (Carrel, 2016). In March 2017, the French Competition, Consumer Affairs and Prevention of Fraud department (DCCCRF) said that its investigation into Opel "did not bring to light any evidence of fraud" (Balibouse, 2017). However, as German (2016b) pointed out, there are well-known, widely available fixes for the situations that Opel explained as justifications for shutting off the aftertreatment system.

In February 2017, the PSA group, after the DCCCRF decided to send the findings of its investigation to a public prosecutor, said in a statement that the company "[sets] engine parameters according to real-life driver behavior" (PSA Group, 2017). As German (2017) explained, it is difficult for PSA to legally justify changing emissions-control calibrations based on real-life driver behavior.

Citing "collapsing consumer confidence in car testing," PSA has collaborated with Transport and Environment and France Nature Environment, two environmental NGOs, to measure and publish real-world fuel consumption data for 58 models. The data were collected from trials on public roads under real-life driving conditions (e.g. with air conditioning on) using PEMS. The collaborators said they also planned to release NO_X emissions values in late 2017 (Transport & Environment, 2017).

As for responses to the divergence between real-world and type-approval CO_2 values, the German Association of the Automotive Industry acknowledged that laboratory testing utilizes an “obsolete measuring procedure that no longer adequately reflects the reality of today’s models or road traffic” (Rotter, 2016). The European Automobile Manufacturers’ Association (ACEA), which represents BMW, DAF Trucks, Daimler, Fiat Chrysler Automobiles, Ford, Hyundai Motor Company, Iveco, Jaguar, Land Rover, Opel, PSA, Renault, Toyota, the Volkswagen Group, and Volvo, stated in response to the KBA and U.K. Department for Transport’s reports that “these announcements highlight the known differences between laboratory test cycles and real-life driving conditions, with actual emissions varying depending on conditions met on the road and on driver behavior” (McLaughlin, 2016).

These manufacturers have yet to show whether their recalls will have a significant or measureable impact on NO_X and CO_2 emissions in the real world.

6. CONCLUSIONS

Before 2015 and the discovery of Volkswagen's use of an illegal defeat device in all of its diesel cars in the United States, few had systematically reviewed on-road NO_x emissions.[25] Since then, many independent organizations and governments have conducted studies. This paper aggregates these results for the first time, adding large-scale CO_2 emissions data as well as data that ICCT purchased from a commercial provider, to provide an initial perspective of the state of on-road emissions performance of diesel passenger cars.

This assessment of several government reports shows that, on average, on-road NO_x and CO_2 emissions from diesel passenger cars are much higher than laboratory emission standards and type-approval values. NO_x emissions' conformity factors for Euro 5 cars (those subject to a legal NO_x limit of 180 mg/km) ranged from just over 1, indicating that on-road emissions could almost meet laboratory testing standards, to 11, signaling that on-road emissions were 11 times as high as the laboratory standard.

Several Euro 6 vehicles subject to a legal limit of 80 mg/km had conformity factors for NO_x emissions that were below 1, meeting the Euro 6 emission limit on the road. However, the histogram of CFs in Figure 2 showed that only 10% of the Euro 6 vehicles that were tested would probably meet the Euro 6 limit on the road. Approximately one quarter of Euro 6 cars had CFs that would probably meet the requirements of the first step of RDE standards, with a NO_x conformity factor of 2.1. The highest Euro 6 CF was almost 12.

Both Euro 5 and Euro 6 cars had an average CF roughly 4 times greater than the legal limit for NO_x (Figures 4 and 5). Overall, General Motors and Renault-Nissan cars, particularly the Opel Insignia and Nissan Qashqai, had some of the highest NO_x conformity factors for both Euro 5 and Euro 6. Under Euro 5, other high NO_x conformity factors belonged to Fiat Chrysler Automobiles (Jeep) and Tata Motors (Land Rover), although Tata Motors' CF was lower under Euro 6. The lowest NO_x conformity factors under both Euro 5 and Euro 6 belonged to Mitsubishi, specifically the ASX, and BMW. Under Euro 6, several brands belonging to Volkswagen had CFs of less than 2.

As for real-world CO_2 emissions, vehicles had CO_2 emission values exceeding type-approval standards by just over 10% to just over 40% (Figures 4 and 5). The average divergence between type-approval CO_2 values and real-world emission values was about 30%.[26] The lowest divergences among car brands belonged to Škoda, Toyota, Fiat, Suzuki, and Mitsubishi. The manufacturers with the highest divergences were Mazda, Audi, BMW, Mini, Volvo, Chevrolet, Opel/Vauxhall, Renault, and Mercedes-Benz (Figures 6 and 7).

This assessment provides an overarching perspective on the NO_x and CO_2 emissions of some of the most popular diesel cars. This is possible in part because of the large sample size that aggregating the data provides, although we openly recognize that the data making up this assessment result from a range of testing conditions (e.g., differing engine loads and ambient temperature, hot or cold starts).

---

[25] Ligterink, Kadijk, van Mensch, Hausberger, & Rexeis (2013) and Weiss, Bonnel, Hummel, Provenza, & Manfredi (2011) analyzed emissions from diesel passenger vehicles in Europe. Franco, Sánchez, German, & Mock (2014) also aggregated real-world NO_x emissions in the EU and the United States.

[26] The 30% value refers to the average CO_2 gap for Euro 5 and Euro 6 diesel vehicles built between 2011 and 2015. This average is lower than most recent estimates of 40% for vehicles built in 2015 because the gap has been growing over time (see Tietge et al., 2016).

The findings in this study along with analyses from our previous publications highlight several steps that should be taken to reduce on-road NO_x and CO_2 emissions from passenger diesel cars:

1. PROVIDING TRANSPARENT, ACCESSIBLE DATA:

Since the discovery of Volkswagen's illegal defeat device in 2015, government agencies in various European states carried out vehicle emissions testing, providing data that has helped generate a systematic overview of emission levels of the most popular diesel vehicles. This testing should be the beginning of a long-term monitoring program of real-world vehicle emissions. It is important to ensure that all data collected during future testing campaigns, not only for NO_x but also for CO_2 and other emissions, are made publicly available within a reasonable time. Disclosing the data allows independent third parties to confirm the findings and helps rebuild consumer and public trust. The vehicle emissions testing should be continued on a regular basis, carried out by government agencies and/or independent technical services. To ensure full objectivity of the testing programs, trial vehicles should be independently sourced and financed, rather than provided by manufacturers, and testing should not be funded by manufacturers.

2. IMPROVING TEST PROCEDURES:

The introduction of RDE testing in Europe is a first step toward improving vehicle testing standards in Europe, but, unless a high level of ambition is adopted, it will fall far short of completely addressing high NO_x emissions on the road (Miller & Franco, 2016). As part of a further development of the RDE test procedure, legislation needs to ensure that on-road testing does not apply only to prototype vehicles, as is the case today, but that it is extended to production vehicles that are randomly selected for in-service conformity testing. Furthermore, a broad market surveillance program for on-road emission levels of new vehicles needs to allow not only type-approval authorities but also third parties to independently carry out vehicle emissions testing. Finally, CO_2 emissions are still not covered in the RDE testing procedure. They are currently measured only under laboratory conditions, not on the road. As we have pointed out in earlier studies, including CO_2 in future on-road testing regulations is imperative for ensuring that production vehicles meet declared values (Tietge et al., 2016).

3. PROPERLY ENFORCING CURRENT AND FUTURE EMISSION STANDARDS:

Even the most advanced testing procedures are effective only if they are properly enforced. The emissions testing results collected by government agencies during recent months provide a wealth of information, and, in many cases, strong indications of illegal defeat devices. It is the responsibility of type-approval authorities to ensure that vehicles comply with standards and follow up by ordering recalls that would remove identified defeat devices and ensure a significant reduction in vehicle emissions. In addition, and in particular where a retroactive fix is not possible, it is the responsibility of type-approval authorities to issue fines as a warning that the use of defeat devices and exceeding emission limits will not be tolerated. In addition to the national type-approval authorities, the European Commission could take a stronger role in coordinating vehicle emissions testing and legal actions, as suggested in the currently debated overhaul of the EU type-approval framework directive (European Commission, 2016b).

These key steps could greatly reduce on-road CO_2 and NO_x emissions from diesel passenger vehicles and could help rebuild consumer trust in declared emission values.

REFERENCES

Anenberg, S. C, Miller, J., Minjares, R., Du, L., Henze, D. K., Lacey, F., ... Heyes, C. (2017). Impacts and mitigation of excess diesel-related NO_x emissions in 11 major vehicle markets. *Nature, 545,* 467–471. doi:10.1038/nature22086

Audi AG. (2017). *For the future of the diesel engine: Audi starts free retrofit program for up to 850,000 cars* [Press Release]. Retrieved from https://www.audi-mediacenter.com/en/press-releases/for-the-future-of-the-diesel-engine-audi-starts-free-retrofit-program-for-up-to-850000-cars-9144

Balibouse, D. (2017, March 20). French watchdog clears GM's Opel of cheating on diesel emissions. *Reuters.* Retrieved from http://www.reuters.com/article/us-france-opel-diesel-idUSKBN16R0M1

Behrmann, E. (2016, April 22). Carmakers in Germany to recall 630,000 for emissions, Bild says. *Bloomberg News.* Retrieved from https://www.bloomberg.com/news/articles/2016-04-22/carmakers-in-germany-to-recall-630-000-for-emissions-bild-says

Behrmann, E. (2017, July 18). Daimler will recall 3 million diesel cars across Europe to fix emissions. *Bloomberg News.* Retrieved from https://www.bloomberg.com/news/articles/2017-07-18/daimler-to-recall-3-million-diesel-cars-on-emissions-concerns

Bundesministerium für Verkehr und digitale Infrastruktur. (2016, August 31). Unregelmäßigkeiten in der Abgasnachbehandlung an Fahrzeugen des Herstellers „Fiat-Chrysler-Automobiles“ (FCA)- Maßnahmen gemäß Artikel 30 der Richtlinie 2007/46/EG. [Letter to Maurizio Vitelli, Ministero delle Infrastutture dei Trasporti]. Robert-Schuman-Platz 1, Bonn, Germany.

Carrel, P. (2016, May 18). Germany asks Opel for more information in Zafira emissions probe. *Reuters.* Retrieved from http://www.reuters.com/article/us-volkswagen-emissions-germany-opel-idUSKCN0Y92GI

Chassany, A-S. (2017, January 13). Renault investigated by French judges over diesel emissions. *Financial Times.* Retrieved from https://www.ft.com/content/9768e92e-d985-11e6-944b-e7eb37a6aa8e

Degraeuwe, B., & Weiss, M. (2017). Does the New European Driving Cycle (NEDC) really fail to capture the NO_x emissions of diesel cars in Europe? *Environmental Pollution, 222,* 234–241. doi:10.1016/j.envpol.2016.12.050

The Economist. (2016, May 12). Nissan and Mitsubishi make an alliance. Retrieved from https://www.economist.com/news/business-and-finance/21698734-assembling-cars-easier-joining-together-companies-make-them-nissan-and

Eder, T., Kemmer, M., Lückert, P., & Sass, H. (2016). OM 654- Launch of a new engine family by Mercedes-Benz. *MTZ Worldwide, 77,* 60–67. doi:10.1007/s38313-015-0097-4

European Commission. (2016a). *Amending Regulation (EC) No. 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)* (Document no. 32016R0646).

European Commission. (2016b). *European Commission tightens rules for safer and cleaner cars* [Press Release]. Retrieved from http://europa.eu/rapid/press-release_IP-16-167_en.htm

Fiat Chrysler Automobiles. (2016). *FCA on real driving emissions* [Press Release]. Retrieved from https://www.fcagroup.com/en-US/media_center/fca_press_release/FiatDocuments/2016/february/FCA_on_Real_Driving_Emissions.pdf

Franco, V., Sánchez, F., German, J., & Mock, P. (2014). Real-world exhaust emissions from modern diesel cars. Retrieved from http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars

German, J. (2016a). "The emissions test defeat device problem in Europe is not about VW." Retrieved from http://www.theicct.org/blogs/staff/emissions-test-defeat-device-problem-europe-not-about-vw

German, J. (2016b). "Opel's admissions of defeat device calibrations." Retrieved from http://www.theicct.org/blogs/staff/opels-admissions-defeat-device-calibrations

German, J. (2017). "Why are EU manufacturers claiming their defeat devices are not defeat devices?" Retrieved from http://www.theicct.org/blogs/staff/why-are-eu-automakers-claiming-defeat-devices-are-not-defeat-devices

Gordon-Bloomfield, N. (2016, January 19). After Dieselgate, Renault, General Motors rush to fix non-compliant diesel cars in Europe. *Transport Evolved.* Retrieved from https://transportevolved.com/2016/01/19/after-dieselgate-renault-general-motors-rush-to-fix-non-compliant-diesel-cars-in-europe/

Groupe Renault. (2016). *Groupe Renault reduces its nitrogen oxide emissions on its diesel Euro 6b vehicles in customer driving conditions* [Press Release]. Retrieved from http://media.renault.com/global/en-gb/renaultgroup/Media/PressRelease.aspx?mediaid=76775

Holder, J. (2016, April 28). Mercedes-Benz joins Audi, Suzuki and Vauxhall in diesel recall in UK. *Autocar.* Retrieved from https://www.autocar.co.uk/car-news/motoring/mercedes-benz-joins-audi-suzuki-and-vauxhall-diesel-recall-uk

Howard, B. (2016, May 6). Ford switches to better, costlier SCR emissions treatment for its next diesel. *Extreme Tech.* Retrieved from http://www.extremetech.com/extreme/227973-ford-diesel-another-automaker-switches-to-better-costlier-scr-emissions-treatment

Jacqué, P., & Van Eeckhout, L. (2016, January 19). Renault constraint de s'expliquer sur les failles de son moteur diesel. Retrieved from http://www.lemonde.fr/economie/article/2016/01/19/devant-lacommission-royal-renault-revele-les-failles-de-son-moteur-diesel_4849711_3234.html

Jennen, B., Buergin, R., & Behrmann, E. (2017, July 27). Porsche's Cayenne recalled by Germany over diesel cheating concerns. *Bloomberg News.* Retrieved from https://www.bloomberg.com/news/articles/2017-07-27/germany-orders-mandatory-recall-of-porsche-cayenne-over-software

Jin, H. (2017, February 9). South Korean court rules against Nissan in emissions case. *Reuters.* Retrieved from http://www.reuters.com/article/us-nissan-southkorea-idUSKBN15O0EW

Kadjik, G., Ligterink, N., van Mensch, P., & Smokers, R. (2016). *NO_x emissions of Euro 5 and Euro 6 diesel passenger cars—test results in the lab and on the road.* Retrieved from https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/overview-of-reports-measuring-the-emissions-of-passenger-cars-and-vans/

Kadjik, G., van Mensch, P., & Spreen, J. (2015). Detailed investigations and real-world emission performance of Euro 6 diesel passenger cars. Retrieved from https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/overview-of-reports-measuring-the-emissions-of-passenger-cars-and-vans/

Korosec, K. (2016, August 15). German regulators approve Volkswagen diesel emissions fix. *Fortune.* Retrieved from http://fortune.com/2016/08/15/german-regulators-approve-volkswagen-diesel-emissions-fix/

Knirsch, S., Weiss, U., Möhn, S., & Pamio, G. (2014). New generation of the Audi V6 TDI Engine, Part 2: thermodynamics, application, and exhaust cleaning. *MTZ Worldwide, 75,* 22–27.

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

Ligterink, N., Kadijk, G., van Mensch, P., Hausberger, S., & Rexeis, M. (2013). Investigations and real world emission performance of Euro 6 light-duty vehicles. TNO Report 2013 R11891 (pp. 1–53).

McLaughlin, C. (2016). *ACEA statement on national emissions test results* [Press Release]. Retrieved from http://www.acea.be/press-releases/article/acea-statement-on-national-emissions-test-results

Miller, J., & Franco, V. (2016). Impact of improved regulation of real-world NO_x emission from diesel passenger cars in the EU, 2015-2030. Retrieved from http://www.theicct.org/rde-passenger-car-nox-impacts-eu

Ministère de l'environnement, de l'énergie et de la mer. (2016). Rapport final de la commission indépendante mise en place par la Ministre Ségolène Royal après la révélation de l'affaire Volkswagen. Accessible at http://www.ladocumentationfrancaise.fr/rapports-publics/164000480/

Mock, P. (Ed.) (2015). European vehicle market statistics—Pocketbook 2015/16. Retrieved from http://eupocketbook.theicct.org/

Mock, P. (2017). Real-driving emissions test procedure for exhaust pollutant emissions of cars and light commercial vehicles in Europe. Retrieved from http://www.theicct.org/RDE-test-procedure-exhaust-gas-pollutant-emissions-cars-and-LCVs

Mock, P., German, J., Bandivadekar, A., & Riemersma, I. (2012). Discrepancies between type-approval and "real-world" fuel consumption and CO2 values—assessment for 2001-2011 European passenger cars. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_EU_fuelconsumption2_workingpaper_2012.pdf

Muncrief, R., German, J., & Schultz, J. (2016). Defeat devices under the U.S. and EU passenger vehicles emissions testing regulations. Retrieved from http://www.theicct.org/briefing-defeat-devices-us-eu-vehicle-emissions-regulations

Official Journal of the European Union. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.109.01.0001.01.ENG

Panait, M. (2016, April 29). Suzuki recalls 1.6 diesel-engined cars due to excessive NO_x emissions. *Autoevolution.* Retrieved from https://www.autoevolution.com/news/suzuki-recalls-16-diesel-engined-cars-due-to-excessive-nox-emissions-107011.html

PSA Group. (2017, February 9). PSA Group's position concerning the DGCCRF investigation. *Business Wire.* Retrieved from http://www.businesswire.com/news/home/20170209005979/en/PSA-Groups-Position-DGCCRF-Investigation

Rotter, E. (2016). *VDA on ICCT* [Press Release]. Retrieved from https://www.vda.de/en/press/press-releases/20161117-vda-on-icct.html

Saarinen, M. (2017, August 3). BMW, Mercedes and VW agree on emissions software update for 5.3m cars. *Auto Express.* Retrieved from http://www.autoexpress.co.uk/car-news/vw-emissions/100356/bmw-mercedes-and-vw-agree-on-emissions-software-update-for-53m-cars

Schmitt, B. (2016, November 13). And now, CO2gate: Audi puts Volkswagen in even deeper trouble. *Forbes*. Retrieved from https://www.forbes.com/sites/bertelschmitt/2016/11/13/and-now-co2gate-audi-puts-volkswagen-in-even-deeper-trouble/#5a555dc35177

Stewart, A., Hope-Morley, A., Mock, P., & Tietge, U. (2015). *Quantifying the impact of real-world driving on total CO_2 emissions from UK cars and vans*. Retrieved from Element Energy, http://www.element-energy.co.uk/2015/09/element-energy-study-into-real-world-vehicle-emissions-and-new-test-cycles-published/

Stothard, M. (2016, January 2016). Renault to correct vehicles' emissions through software change. *Financial Times*. Retrieved from https://www.ft.com/content/3b2ad64e-be8e-11e5-846f-79b0e3d20eaf?mhq5j=e2

Teffer, P. (2017, March 17). Much remains unclear after German-Italian spat on Fiat. *Euobserver.* Retrieved from https://euobserver.com/dieselgate/137281

Tietge, U., Díaz, S., Mock, P., German, J., Bandivadekar, A., & Ligterink, N. (2016). *From Laboratory to Road: A 2016 update of official and 'real-world' fuel consumption and CO_2 values for passenger cars in Europe.* Retrieved from http://www.theicct.org/laboratory-road-2016-update

Transport & Environment. (2017). *PSA publishes real-world fuel consumption data for 1,000 Peugeot, Citroën and DS Cars* [Press Release]. Retrieved from https://www.transportenvironment.org/press/psa-publishes-real-world-fuel-consumption-data-1000-peugeot-citro%C3%ABn-and-ds-cars

United Kingdom Parliament. House of Commons Transport Committee. (2016). *Volkswagen emissions scandal and vehicle type approval: Third Report of Session 2016-17* (HC 69). London: Order of the House. Retrieved from https://publications.parliament.uk/pa/cm201617/cmselect/cmtrans/699/699.pdf

Untersuchungsausschuss, Deutscher Bundestag. (2016). Kraftfahrt-Bundesamt widerspricht VW. Retrieved from https://www.bundestag.de/ausschuesse18/ua/5untersuchungsausschuss#url=L3ByZXNzZS9oaWIvMjAxNjExLy0vNDc5NzA0&mod=mod441658

U.S. Environmental Protection Agency. (2017). *Learn about Volkswagen violations.* Retrieved from https://www.epa.gov/vw/learn-about-volkswagen-violations

Weiss, M., Bonnel, P., Hummel, R., Provenza, A., & Manfredi, U. (2011). On-road emissions of light-duty vehicles in Europe. *Environmental Science & Technology, 45,* 8575–8581. doi:10.1021/es2008424

Yang, L., Franco, V., Campestrini, A., German, J., & Mock, P. (2015). *NO_x control technologies for Euro 6 diesel passenger cars.* Retrieved from http://www.theicct.org/nox-control-technologies-euro-6-diesel-passenger-cars

APPENDIX

DATA SOURCES

DUH: Zimmerli, Y., Güdel, M., Comte, P., et al. (2015). NO_X-Emissionsmessung von einem Personenwagen Opel Zafira Diesel, Euro 6b auf dem Rollenprüfstand. *Deutsche Umwelthilfe (DUH) report.* October 2015

Comte, P., Zimmerli, Y., Czerwinksi, J. (2016). NO_X-Emissionsmessung von einem Personenwagen Fiat 500X 2.0 MJ 4*4, Euro 6 auf dem Rollenprüfstand. *Deutsche Umwelthilfe (DUH) report.* February 2016

Zimmerli, Y., Güdel, M., Comte, P., Czerwinski, J. (2015). NO_X-Emissionsmessung von einem Personenwagen Renault Espace Diesel, Euro 6b auf dem Rollenprüfstand. *Deutsche Umwelthilfe (DUH) report.* November 2015

Deutsche Umwelthilfe. (2016). NO_X-und CO_2-Messungen an Euro 6 Pkw im realen Fahrbetrieb: Messergebnisse. September 2016.

France: Ministère de l'environnement, de l'énergie et de la mer. (2016). Rapport final de la commission indépendante mise en place par la Ministre Ségolène Royal après la révélation de l'affaire Volkswagen. Accessible at http://www.ladocumentationfrancaise.fr/rapports-publics/164000480/

Germany: Bundesministerium für Verkehr und digitale Infrastruktur. (2016). Bericht der Untersuchungskommission „Volkswagen." April 2016. Accessible at http://www.bmvi.de/SharedDocs/DE/Publikationen/LA/bericht-untersuchungskommission-volkswagen

Netherlands: Dutch Vehicle Authority (RDW). (2016). RDW emission test programme: Results of indicative tests for the presence of an unauthorised defeat device. September 2016. Accessible at https://www.rdw.nl

TNO: Kadijk, G., Mensch, P. van, Spreen, J. S. (2015). TNO 2015 R10702: "Detailed investigations and real-world emission performance of Euro 6 diesel passenger cars." May 2015. Accessible at http://repository.tudelft.nl/view/tno/uuid%3A40da980a-4c03-4b70-a9b1-240f9ea395f5/

Heijne, V., Kadijk, G., Ligterink, N., et al. (2016). TNO 2016 R11177: "NOx emissions of fifteen Euro 6 diesel cars: Results of the Dutch LD road vehilce emission testing programme 2016." October 2016. Accessible at https://www.rijksoverheid.nl/documenten/rapporten/2016/10/14/tno-2016-r11177-nox-emissions-of-fifteen-euro-6-diesel-cars-results-of-the-dutch-ld-road-vehicle-emission-testing-programme-2016.

UK: Department for Transport. (2016). Vehicle Emissions Programme data. July 2016. Accessible at https://www.gov.uk/government/publications/vehicle-emissions-testing-programme-conclusions

Wallonia (Belgium): Di Antonio, Carlo. (2016). Affaire VW: Résultats de l'évaluation des rejets atmosphériques par les véhicules légers diesel. *Ministre wallon de l'Environnement report*. June 2016. Accessible at http://diantonio.wallonie.be/resultats-de-l-evaluation-des-rejets-atmospheriques-par-les-vehicules-legers-diesel-en-wallonie

ZDF: Comte, P., Zimmerli, Y., Güdel, M., Czerwinski, J. (2015). Emissionsmessungen an einem BMW 320d Touring (Euro 5a) auf dem Rollenprüfstand und auf der Strasse. *Zweite Deutsche Fernsehen (ZDF) report.* November 2015.

Comte, P., Zimmerli, Y., Güdel, M., Czerwinski, J. (2015). Emissionsmessungen an einem VW Passat 2.0 TDI (Euro 5a) auf dem Rollenprüfstand und auf der Strasse. *Zweite Deutsche Fernsehen (ZDF) report.* November 2015.

Comte, P., Zimmerli, Y., Güdel, M., Czerwinski, J. (2015). Emissionsmessungen an einem Mercedes-Benz C 200 CDI (Euro 5a) auf dem Rollenprüfstand und auf der Strasse. *Zweite Deutsche Fernsehen (ZDF) report.* November 2015.

Table A1: Cars included in Figures 1 through 7. All Euro 5 and Euro 6 cars are fitted with exhaust gas recirculation (EGR); other aftertreatment technologies under Euro 6 are noted, with LNT = lean NO_x trap; SCR = selective catalytic reduction. An asterisk (*) before an aftertreatment technology means the aftertreatment technology is likely, not confirmed, based on the aftertreatment technology the manufacturer uses for its other passenger cars. If a car was included in Figure 4 or 5, its ID # is included in this table. As explained in the Methodology section, not all cars are included in these figures because of the minimum number of entries that was necessary for using the CO_2 data from Spritmonitor.

Names of car manufacturer groups:
BMW = BMW
DAI = Daimler
FCA = Fiat Chrysler Automobiles
FRD = Ford
GEM = General Motors
HON = Honda
HMC = Hyundai Motor Company
MAH = Mahindra Group
MAZ = Mazda
PSA = Groupe PSA
RNA = Renault-Nissan
SUZ = Suzuki
TAT = Tata
TOY = Toyota
VLO = Volvo
VWG = Volkswagen Group

Data Sources:
DUH = Deutsche Umwelthilfe
EA = Emissions Analytics
F = France
G = Germany
N = Netherlands
TNO = The Netherlands Organisation for Applied Scientific Research
UK = United Kingdom
W = the Walloon government in Belgium
ZDF = German television network

Group	Model	ID # if included in Figure 4 (Euro 5)	Euro 5 Data Source	ID # if included in Figure 5 (Euro 6)	Aftertreatment Technology (LNT or SCR) under Euro 6	Euro 6 Data Source
BMW	**BMW 1-series**	1	F	1	unknown	F
BMW	**BMW 2-series**			2	LNT	EA, G
BMW	**BMW 3-series**	2	EA, G, ZDF	3	LNT	DUH, EA, F, UK
BMW	**BMW 4-series**			4	LNT	EA
BMW	**BMW 5-series**			5	LNT	DUH, EA, G, TNO
BMW	**BMW X3**			6	LNT	EA
BMW	**BMW X5**				SCR	DUH, UK
BMW	**Mini Countryman**			7	LNT	UK
DAI	**Mercedes A-Class**	3	EA, F	8	LNT	DUH, F, UK
DAI	**Mercedes B-Class**	4	W	9	LNT	F
DAI	**Mercedes C-Class**	5	EA, ZDF	10	SCR	DUH, EA, G, TNO
DAI	**Mercedes E-Class**	6	UK	11	SCR	DUH, EA
DAI	**Mercedes S-Class**		EA		SCR	EA, F, G
DAI	**Mercedes V-Class**				SCR	G
DAI	**Smart Fortwo**	7	G			
FCA	**Alfa Romeo Giulietta**	8	EA, G, W	12	unknown	F
FCA	**Fiat 500L**		F, W			
FCA	**Fiat 500X**				LNT	DUH, F
FCA	**Panda**		EA, G			
FCA	**Jeep Cherokee**		F, G			
FCA	**Jeep Grand Cherokee**	9	N			
FCA	**Jeep Renegade**			13	*LNT	DUH
FCA	**Jeep Wrangler Unlimited Van**		N			
FRD	**Ford C-MAX**	10	W	14	LNT	F, G
FRD	**Ford Fiesta**	11	EA	15	LNT	TNO
FRD	**Ford Focus**	12	EA, F, G	16	LNT	DUH, TNO, UK
FRD	**Ford Kuga**			17	LNT, SCR	DUH, F
FRD	**Ford Mondeo**	13	EA, UK, W	18	LNT, unknown if SCR also	DUH, F, UK
FRD	**Ford S-MAX**	14	EA			
GEM	**Chevrolet Aveo**		N			
GEM	**Chevrolet Captiva**	15	N			
GEM	**Chevrolet Cruze**	16	EA, G, N, W			
GEM	**Chevrolet Orlando**	17	N			
GEM	**Opel/Vauxhall Antara**		N			
GEM	**Opel/Vauxhall Astra**	18	EA, G, UK, W	19	LNT	DUH, EA, F
GEM	**Opel/Vauxhall Corsa**	19	EA, UK			
GEM	**Opel/Vauxhall Insignia**	20	EA, UK	20	SCR	G, UK
GEM	**Opel/Vauxhall Mokka**	21	N, W	21	LNT	DUH, F, N, UK
GEM	**Opel/Vauxhall Zafira**	22	EA	22	SCR	DUH, EA, F, G, TNO

Group	Model	ID # if included in Figure 4 (Euro 5)	Euro 5 Data Source	ID # if included in Figure 5 (Euro 6)	Aftertreatment Technology (LNT or SCR) under Euro 6	Euro 6 Data Source
HMC	**Hyundai H-1**		N			
HMC	**Hyundai i20**			23	LNT	EA, G
HMC	**Hyundai i30**	23	EA, UK, F	24	LNT	DUH, UK
HMC	**Hyundai i40**	24	N, W			
HMC	**Hyundai ix20**	25	N			
HMC	**Hyundai ix35**	26	G, UK			
HMC	**Hyundai Santa Fe**	27	EA, UK	25	unknown	DUH
HMC	**Hyundai Tuscon**				LNT	DUH, F
HMC	**Isuzu D-Max**		N			
HMC	**Kia Ceed**	28	EA, N			
HMC	**Kia Optima**		N, W		LNT	EA
HMC	**Kia Rio**			26	LNT	F
HMC	**Kia Sorento**			27	unknown	N
HMC	**Kia Sportage**	29	EA, F, UK, W	28	LNT	EA, UK
HMC	**Kia Venga**		N, W			
HON	**Honda Civic**	30	EA			
HON	**Honda CR-V**	31	EA, UK	29	LNT	F, UK
HON	**Honda HR-V**				LNT	G
MAH	**Ssangyong Korando**		EA			
MAZ	**Mazda 2**				EGR only	F
MAZ	**Mazda 6**			30	EGR only	EA, F, G, UK
MAZ	**Mazda CX-5**	32	EA			
PSA	**Citroën Berlingo**		W			
PSA	**Citroën C3**		EA, F			
PSA	**Citroën C4**	33	W, UK	31	*SCR	EA
PSA	**Citroën C4 Picasso**	34	EA, F	32	SCR	EA, F
PSA	**Citroën C5**	35	F, W			
PSA	**Citroën Cactus**				SCR	TNO
PSA	**Citroën DS4**		W			
PSA	**Citroën DS5**				SCR	EA
PSA	**Peugeot 2008**			33	*SCR	DUH
PSA	**Peugeot 208**	36	F, UK, W	34	SCR	F
PSA	**Peugeot 3008**	37	EA	35	SCR	F, UK
PSA	**Peugeot 308**	38	EA	36	SCR	EA, F, G, TNO
PSA	**Peugeot 5008**	39	EA, F	37	SCR	F
PSA	**Peugeot 508**			38	SCR	F
PSA	**Peugeot 807**		F			
RNA	**Dacia Duster**	40	EA, F			
RNA	**Dacia Lodgy**	41	W			
RNA	**Dacia Sandero**	42	W	39	LNT	G
RNA	**Mitsubishi ASX**	43	EA, G	40	LNT	F
RNA	**Nissan Juke**	44	EA, W			

Group	Model	ID # if included in Figure 4 (Euro 5)	Euro 5 Data Source	ID # if included in Figure 5 (Euro 6)	Aftertreatment Technology (LNT or SCR) under Euro 6	Euro 6 Data Source
RNA	**Nissan Qashqai**	45	EA, UK, W	41	LNT	DUH, F
RNA	**Nissan X-Trail**	46	EA			
RNA	**Renault Captur**			42	LNT	F
RNA	**Renault Clio**	47	EA, F, W	43	LNT	TNO
RNA	**Renault Espace**				LNT	F
RNA	**Renault Kadjar**				LNT	F, G
RNA	**Renault Kangoo**		F			
RNA	**Renault Laguna**	48	F			
RNA	**Renault Megane**			44	LNT	TNO, UK
RNA	**Renault Scénic**	49	EA, F, W	45	*LNT	DUH
RNA	**Renault Talisman**				LNT	F
SUZ	**Suzuki Swift**		N			
SUZ	**Suzuki SX4**		N			
SUZ	**Suzuki Vitara**				LNT	G, N
TAT	**Jaguar XE**				SCR	EA, G, UK
TAT	**Jaguar XF**		EA		SCR	EA
TAT	**Land Rover Discovery**		EA			
TAT	**Land Rover Freelander**		EA, UK			
TAT	**Land Rover Range Rover**		EA, G			
TAT	**Land Rover Range Rover Sport**		EA, UK			
TAT	**Land Rover Range Rover Evoque**	50	EA	46	SCR	EA, G
TOY	**Toyota Auris**	51	G	47	LNT	DUH, F
TOY	**Toyota Avensis**	52	EA	48	LNT	F, UK
TOY	**Toyota Verso**	53	EA			
TOY	**Toyota Yaris**		F, W			
VLO	**Volvo C30**		W			
VLO	**Volvo S60**				LNT	EA, F
VLO	**Volvo S80**				LNT	EA
VLO	**Volvo V40**	54	EA, N, UK, W	49	LNT	F, N, TNO
VLO	**Volvo V50**	55	N			
VLO	**Volvo V60**	56	EA, W	50	unknown	G
VLO	**Volvo XC60**	57	EA	51	unknown	DUH
VLO	**Volvo XC90**				unknown	N
VWG	**Audi A1**	58	F			
VWG	**Audi A3**			52	LNT	DUH, G, UK
VWG	**Audi A4**			53	SCR	DUH, EA
VWG	**Audi A5**			54	SCR	EA
VWG	**Audi A6**	59	EA, G	55	SCR	DUH, EA, G
VWG	**Audi A8**				SCR	EA

Group	Model	ID # if included in Figure 4 (Euro 5)	Euro 5 Data Source	ID # if included in Figure 5 (Euro 6)	Aftertreatment Technology (LNT or SCR) under Euro 6	Euro 6 Data Source
VWG	**Audi Q3**	60	EA, F	56	unknown	DUH
VWG	**Audi Q7**				SCR	EA, F, TNO
VWG	**Porsche Cayenne**		F			
VWG	**Porsche Macan**				SCR	G
VWG	**SEAT Alhambra**	61	EA, W			
VWG	**SEAT León**	62	EA	57	LNT	F
VWG	**Škoda Fabia**			58	LNT	F
VWG	**Škoda Octavia**	63	EA, UK, W	59	LNT	DUH, EA, UK
VWG	**Škoda Roomster**	64	W			
VWG	**Škoda Superb**	65	EA	60	LNT	EA
VWG	**Škoda Yeti**	66	EA, W			
VWG	**VW Beetle**		EA, G			
VWG	**VW Caddy C20**				unknown	EA
VWG	**VW Golf**	67	EA, F, G	61	unknown	DUH, EA, F, G, TNO, UK
VWG	**VW Golf Plus**	68	G, W			
VWG	**VW New Beetle**		W			
VWG	**VW Passat**	69	EA, G, ZDF	62	unknown	DUH, EA, G, TNO
VWG	**VW Polo**	70	F, G, W	63	LNT	EA, TNO
VWG	**VW Scirocco**			64	LNT	EA
VWG	**VW Sharan**	71	F, W			
VWG	**VW Sportsvan**				LNT	G
VWG	**VW Tiguan**	72	EA, F	65	unknown	DUH
VWG	**VW Transporter**				unknown	EA
VWG	**VW Touareg**			66	SCR	G
VWG	**VW Touran**			67	SCR	DUH, EA, G, TNO