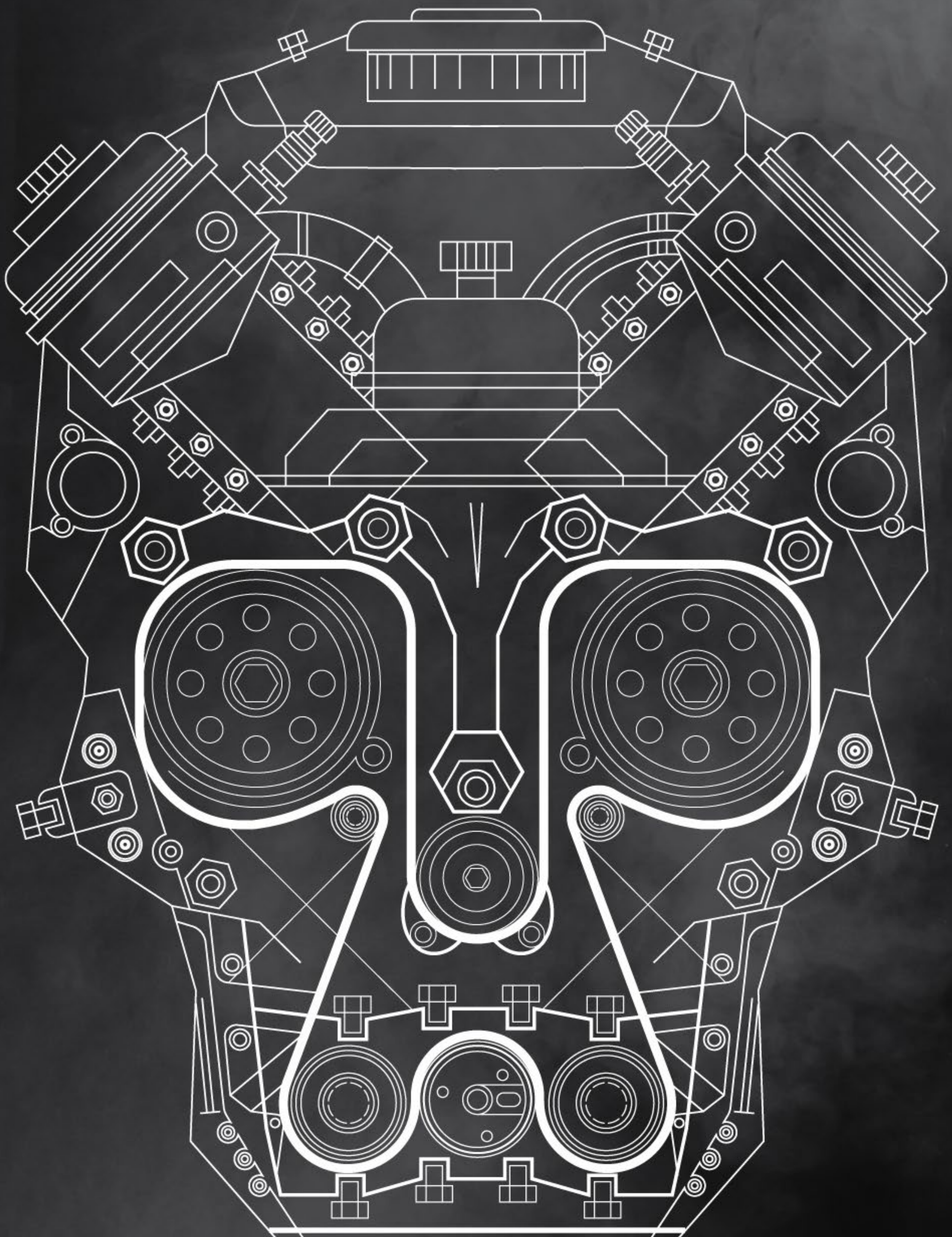
Cars with engines: can they ever be clean?



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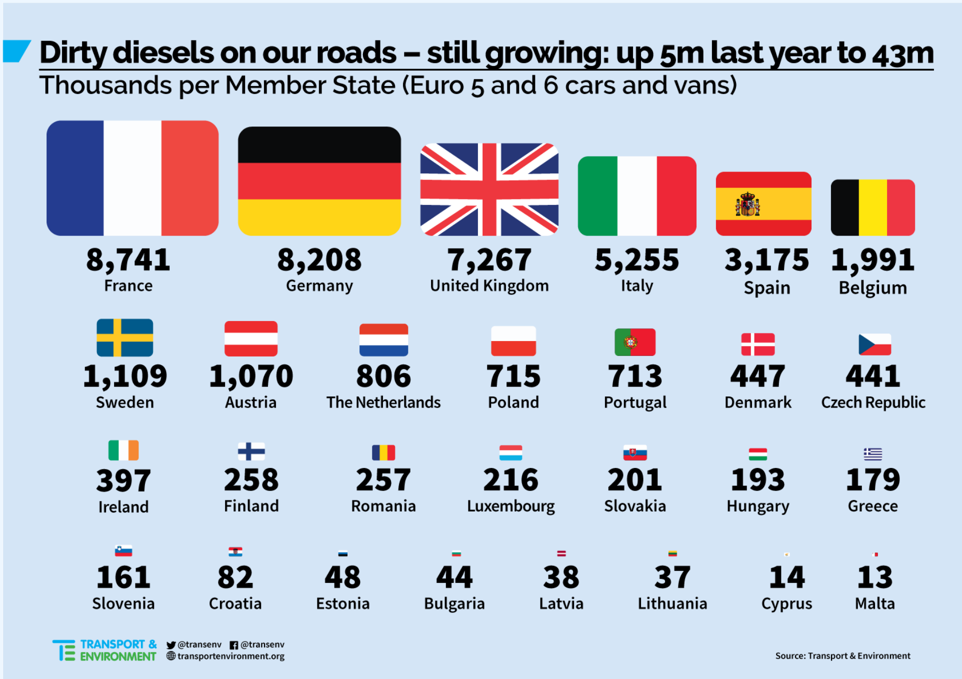
Executive summary

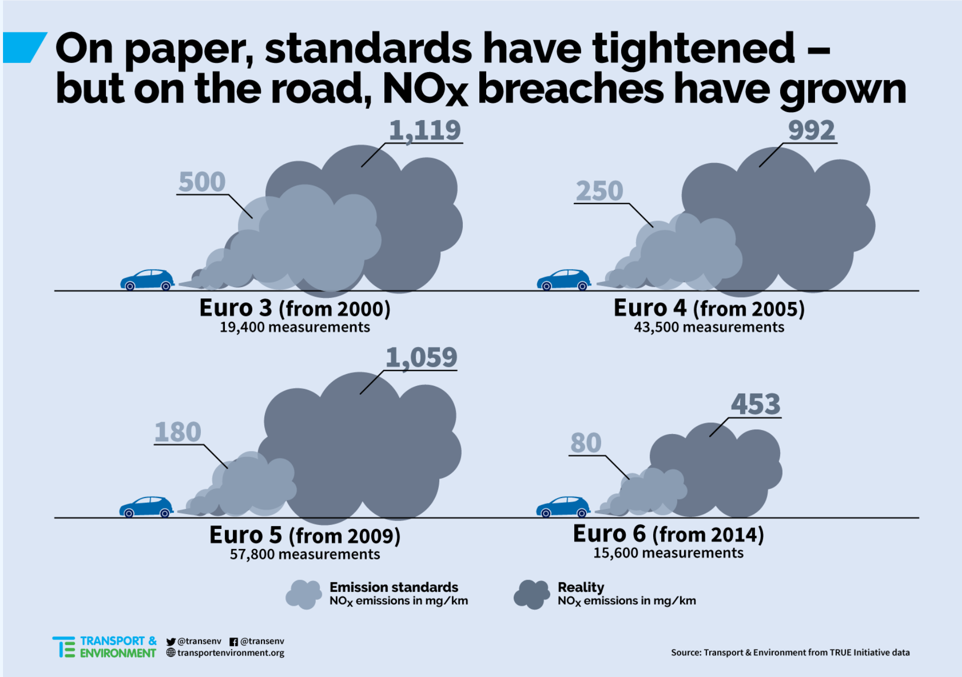
This report marks the third anniversary of the Dieselgate scandal. Whilst the scandal started with US regulators exposing cheating of nitrogen oxide emissions tests by Volkswagen, it quickly spread globally to affect almost every carmaker and every market in which diesel cars are sold. Subsequent work has shown that diesel emissions tests are not the only ones being manipulated – gasoline, CO_2 tests and even those affecting safety systems are manipulated.

When the scandal broke in 2015 there were 29 million grossly polluting diesel cars on the road. After 3 years, the number of dirty diesel cars and vans on the road today are still rising. This report estimates that there are now 43 million. This includes: 8.7 million in France; 8.2 million in Germany; 7.3 million in the UK and 5.3 million in Italy. Many of these cars are now being exported eastwards and ultimately will head to Africa. If Europe does not act, high emitting diesel cars will be polluting the air of cities around the world for decades and, in the process, shortening lives.



The report demonstrates that despite over 25 years of emissions legislation there has been minimal progress reducing diesel emissions of nitrogen oxides. New remote sensing data from over 700,000 real-world measurements of cars collected between 2011 and 2017 show petrol cars more than 12 years old and virtually all diesels are dirty, with almost no reduction in real-life NOx emissions recorded from diesel cars produced between 1996 and 2015.

The average NOx emissions from a Euro 2 to Euro 5 diesel cars is between 1,000mg/km and 1,150mg/km. The introduction of Euro 6 regulation in September 2014 has more than halved the emissions with measured real-world NOx emissions averaging with 450mg/km - but this is still over 5 times the allowed limit. This suggests banning only all older diesel cars is not equitable or justified as many Euro 6 models are no better than a Euro 2 vehicle on the road. 10% of the worst Euro 6 diesel cars on the road contribute 25% of the pollution from Euro 6 models. Cities should be banning all dirty models rather than polluting classes of vehicles and make use of remote sensing data and the TRUE Initiative database to do this. For petrol cars, there is a clear trend to many higher emitting vehicles as the vehicles age - but as with the diesels not all car models appear to degrade at a similar rate. This would suggest that there needs to be more effective targeting of older, higher emitting petrol cars.



Industry's claims that Dieselgate is history and new Euro 6 models complying with the new Real Driving Emissions (RDE) standard are clean is an incorrect generalisation. A small proportion of new models are clean, but many are not, particularly when driven by customers on the road. New T&E tests show a 2018 diesel Honda Civic meets the NOx limit when driven on the regulatory tests, but toxic emissions increase by a factor of 9 when driven on roads with more hills, with more typical accelerations and faster speeds that are still representative of a customer. Similarly, a Ford Fiesta's particulate emissions were more than twice the limit once driven in a way more typical of a customer despite being equipped with a gasoline particulate filter. A petrol Opel Adam also had much higher carbon monoxide emissions. Cars are being designed to pass a regulatory test rather than produce low emissions on the road. The test must be reformed to be far less restrictive how and where it can be driven.

Diesel Particulate Filter (DPF) tampering and the use of faulty and ineffective DPFs is a widespread problem throughout Europe,[1] significantly increasing real-world particle emissions from diesel vehicles. In this light, T&E has also undertaken a survey of more than 1,300 diesel taxis across 8 EU cities to see how well DPF – credited with making modern diesel exhausts soot-free – works in practice. This shows around 4% of Euro 5 and 6 vehicles are producing abnormally high particulate emissions - although DPFs are mandatory on all. Just 4% of cars without properly controlled particulate emissions result in a 75% increase in particulate emissions from all diesel vehicles. This illustrates that vehicle tampering and failures of exhaust treatment systems as the car ages will have a disproportionate impact on the overall emissions.

A further problem with the DPF is that these need to be cleaned (regenerated) on a regular basis. This is leading to the re-emission of many smaller and even more harmful particles of black carbon and sulphurated compounds. There are also concerns about many entirely unregulated pollutants such as benzene, carbonyl compounds, and Polycyclic Aromatic Hydrocarbons (PAH) such as carcinogens like benzo-alpha-pyrene. The report shows that cars with internal combustion engines were not clean in the past and are not clean today. Expectations that new Euro 6 limits and tests have fixed emissions problems from cars are not supported by the evidence and as a

[1] T&E, How to tackle the illegal diesel filter removal 'industry' in Belgium and beyond, July 2017 & BBC News, 'Thousands' driving without crucial diesel filters, October 2017

result the levels of air pollution will not improve as hoped. To clean up Europe's air and help millions of citizens suffering the health effects a seven-step programme is needed that includes:

1. action to clean up the 43 million dirty diesel cars and vans on the road today EU wide;
2. action to prevent the sale and use of grossly polluting cars that have not been properly fixed;
3. support for cities to design their urban vehicle access restriction policies as they see fit for local circumstances, public health and environment and help them target ALL grossly polluting cars using remote sensing;
4. have carmakers contribute to a Clean Air Fund to help cities across Europe meet the EU air quality standards – €10 for every new car sold would raise over €150 million per year;
5. reform of the RDE regulation to be more representative of the way cars are really used and driven;
6. vehicle emissions checked over entire lifetime, including independent third-party tests and strengthened periodic testing framework;
7. a new Euro 7 emissions limit.

This report comprehensively demonstrates not all new cars are clean even today and as the car ages the emissions will significantly worsen. Unless additional action is taken, our toxic urban air will persist. There remains significant potential to reduce emissions from combustion engines but this will require much stricter emission standards covering more pollutants, more realistic tests and a much more robust enforcement system throughout the vehicles' life. However, this report also shows that whilst ICE emissions can be lowered further, ICE vehicles will continue to emit toxic exhaust which will continue to adversely affect our health. Engined cars will also continue to emit carbon dioxide emissions. As a result, the transition to zero emission mobility will require a shift to zero emission technology and electromobility.

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List of abbreviations

AECC	Association for Emissions Control by Catalyst
BTEX	Benzene Toluene Ethylbenzene Xylene
CO	Carbon monoxide
CO_2	Carbon dioxide
CoC	Certificate of Conformity
DG	Directorate-General
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
DUH	Deutsche Umwelthilfe
EEA	European Environment Agency
EGR	Exhaust Gas Recirculation
EU	European Union
FIA	Fédération Internationale de l'Automobile
FNE	France Nature Environnement
GDI	Gasoline Direct Injection
GPF	Gasoline Particulate Filter
HC	Hydrocarbon
IARC	International Agency for Research on Cancer
ICCT	International Council on Clean Transportation
JRC	Joint Research Center
LNT	Lean NOx-Trap
NCAP	New Car Assessment Programme
NEDC	New European Driving Cycle
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides
NSC	NOx Storage Catalyst
PAH	Polycyclic Aromatic Hydrocarbon
PEMS	Portable Emissions Measurement System
PFI	Port Fuel Injection
PM	Particle Mass
PN	Particle Number
RDE	Real Driving Emissions
RS	Remote sensing
SCR	Selective Catalytic Reduction
T&E	Transport & Environment
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek
TRUE	The Real Urban Emissions
TWC	Three-Way Catalyst
UK	United Kingdom
UPC	Ultrafine Particle Counter
US	United States of America
US EPA	United States Environmental Protection Agency
WHO	World Health Organisation
WLTC	Worldwide harmonized Light vehicles Test Cycle
WLTP	Worldwide harmonized Light vehicles Test Procedure

1. Introduction

This report is launched on the third anniversary of the Dieselgate scandal. Whilst the scandal started with US regulators exposing cheating of diesel, nitrogen oxide emissions tests by Volkswagen. It quickly spread globally to affect almost every carmaker and every market in which diesel cars are sold. Subsequent work has shown that diesel emissions tests are not the only ones being manipulated: so are new laboratory tests for CO_2 emissions;[2] and even safety systems such as those for tyre pressure monitoring.[3] As the world's largest diesel car market, Europe was especially heavily affected by the scandal as illustrated on the first anniversary by Transport & Environment's report *Dieselgate: Who? What? How?* [4] which, alongside explaining how companies cheated, estimated there were 29 million dirty diesel cars on Europe's roads. Whilst US justice was fast and fair and consumers compensated; in Europe the scandal dragged on and companies went unpunished.

On the second anniversary, T&E published, *Diesel: the true (dirty) story*[5] that explained how Europe had through biased regulations and taxes Europe had consciously chosen to encourage the market for diesel cars and why its obsession was bad for the economy, its drivers and the environment. It showed that contrary to perceived wisdom that diesel cars are not actually lower carbon than gasoline versions if emissions are considered across the full lifecycle of the vehicle. In response to the scandal, the European Commission took steps to strengthen the system of testing and approval of cars and Volkswagen began the process of upgrading affected models but for most companies it was business as usual.

But in cities around Europe worries about the health effects of illegally high levels of toxic nitrogen dioxide caused by the cheating was creating pressure for action. In Germany, even Stuttgart, home of Mercedes-Benz and Munich, the base of BMW, are considering bans following a series of court cases brought by T&E member DUH. In London, the mayor announced an ultralow emissions zone; in Paris and Milan a proposed ban. Faced with an industry that will not take responsibility and clean up the dirty diesels still on the road, cities are taking the only action left available to them - keep them out of urban centres. Consumers understandably became worried about where they could drive their cars in the future and whether they would be sellable at a decent price. The ongoing scandal of cheating and high emissions resulting in many switching to cleaner cars. The market for new diesel cars has fallen from over 55% at its peak to just over 35% today.[6]

In the last 12 months, there has been some modest progress in penalising the cheats and tackling the cheating:

- Volkswagen Group has been fined €1bn;[7]
- The head of Audi has been locked up accused of manipulating evidence;[8]
- The European Commission brought legal action against Germany, Italy, Luxembourg and the UK over failures to enforce diesel emissions rules; and on 6 countries for failing to meet air pollution standards;[9]
- New real world tests have finally been introduced for all new cars (although this report questions how effective they will be);[10]

[2] T&E, Documents reveal: Commission scientists find car industry cheating emissions again, July 2018
[3] T&E, Failure of indirect tyre pressure monitoring systems puts drivers and road users at risk, November 2016
[4] T&E, Dieselgate: Who? What? How?, September 2016
[5] T&E, Diesel: the true (dirty) story, September 2017
[6] ACEA, Fuel types of new cars: diesel -15.5%, petrol +19.8%, electric +43.8% in second quarter of 2018, September 2018
[7] Reuters, Volkswagen fined one billion euros by German prosecutors over emissions cheating, June 2018
[8] Reuters, Head of Volkswagen's Audi arrested in Germany over diesel scandal, June 2018
[9] European Commission, Air quality: Commission takes action to protect citizens from air pollution, May 2018
[10] European Commission, New and improved car emissions tests become mandatory on 1 September, August 2017

- In Germany, 2 diesel summits resulted in German carmakers agreeing to clean up their cars in Germany [11] and pay into a clean air fund [12] - but cars everywhere else go unfixed and uncompensated and other carmakers continue to hide rather than take responsibility;
- Concerns are mounting in Central and Eastern European countries,[13] notably Bulgaria and Poland,[14] over increasing imports of polluting unfixed diesels as drivers in western cities attempt to get rid of them amidst ban announcements;
- Several carmakers, notably Fiat, Toyota and Volvo have announced plans to discontinue diesel car sales.[15]

But although countries across Central and Eastern Europe have raised concerns about a flood of second and third hand dirty diesels heading in their direction,[16] nothing is being done to tackle the legacy of dirty diesel cars. In fact, Chapter 2 of this report shows the problem is getting worse. It also includes a unique analysis of remote sensing data that looks at the real life NOx emissions from diesel and petrol cars that have been in circulation since the beginning of the 2000s.

Chapter 3, examines whether the industry claims diesel cars are getting cleaner is supported by the evidence (it is not); and Chapter 4 highlights a number of new and emerging issues that suggest high pollution emissions from the internal combustion engine is likely to continue for decades to come.

The last chapter considers what can be done to tackle the problems and reduce the pollution. Some carmakers are now shifting away from producing diesels but most continue to resist change and seek to redeem the reputation of diesel and regain the lost market share. But as long as tens of millions of grossly polluting diesel cars remain on the road, the Dieselgate scandal will not be over. Three years after the scandal came to light, it is time for EU and national regulators to act to help cities clean up the toxic air they continue to emit.

[11] Financial Times, German carmakers to upgrade 5m diesel vehicles to curb emissions, August 2017
[12] Reuters, Germany weighs joint fund with automakers to refit diesel cars: Spiegel, April 2018
[13] Handelsblatt Global, Eastern Europe's appetite for dirty old diesels, April 2018
[14] Deutsche Welle, Germany's dirty diesel cars en route for Eastern Europe, August 2017
[15] Financial Times (February 2018), Deutsche Welle (March 2018) and AutoExpress (May 2018) respectively
[16] T&E, Dirty diesels heading East, April 2018

2. The legacy of Dieselgate

Years of the Dieselgate emissions scandal demonstrated that diesel cars failed to meet European air pollution standards when driven on the road, with exhaust after-treatment systems often disabled or turned down. This chapter updates the number of dirty Euro 5 and 6 diesel cars and vans driven across Europe, building on the 2016 and 2017 figures presented in earlier reports. It also analyses the new remote sensing data to show that the on-road NOx emissions from diesel and petrol cars approved since 2000 continuously exceeded the limits. Finally, new modelling by T&E based on the remote sensing data quantifies the contribution of the 10% highest diesel emitters to the total amount of NOx emissions of the diesel fleet.

2.1. 2018 update of dirty diesel cars and vans

This is the third report T&E has issued on the anniversary of the 2015 Dieselgate scandal. For each, T&E has estimated the number of grossly polluting Euro 5 and Euro 6 cars and vans on European roads. In order to be considered as dirty, NOx results should be at least 2 times above the Euro standard limit for NEDC tests and at least 3 times above the Euro standard limit for Real Driving Emissions (RDE) tests and remote sensing measurements. The methodology used to build these numbers can be found in the Annex 1. The total has grown from 29 million two years ago;[17] to 37 million last year[18] and 43 million at present, i.e. one third of the EU diesel fleet.[19] Rather than the problem going away it is still getting worse.

Since our first Dieselgate anniversary report, the ranking of Member States have not changed a lot,[20] with France still being Europe's champion regarding the number of dirty diesel vehicles with about 8.7 million Euro 5 and 6 cars and vans. Germany closely follows with about 8.2 million and the UK with about 7.3 million. When numbers for Italy, Spain and Belgium are added, these 6 countries represent 80% of the whole EU dirty diesel fleet.

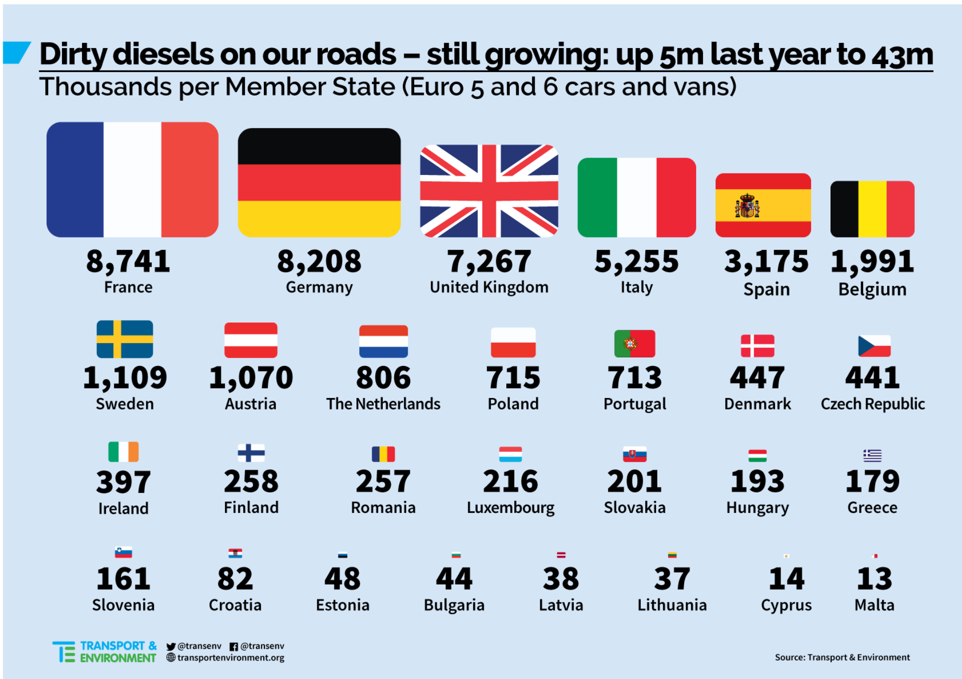

Figure 1 - Estimation of the number of dirty diesels covering the sales period 2010-2017

[17] T&E, Dieselgate: Who? What? How?, September 2016
[18] T&E, Diesel: the true (dirty) story, September 2017
[19] ACEA, Vehicles in use – Europe 2017, November 2017
[20] T&E, Dieselgate: Who? What? How?, September 2016

2.2. On-road emissions of Euro 3-6 diesels from remote sensing data

The recent Real Urban Emissions Initiative (TRUE), which includes the FIA Foundation, the ICCT, C40 Cities, Global NCAP and T&E, analysed a compilation from the CONOX project of over 700,000 instantaneous real world measurements on the emissions of passenger cars between 2011 and 2017.[21] The remote sensing technology was used in a range of European countries, including: France, Spain, Sweden, Switzerland and the UK.

Remote sensing (RS) technology optically measures emissions through the exhaust plume of a passing vehicle from the side or above the road. Compared to a Portable Emission Measurement System (PEMS) used for EU Real Driving Emissions tests (RDE), RS collects a snapshot of information on the emissions rather than making measurements over a comprehensive range of driving conditions. However, RS allows to collect data from hundreds of thousands of vehicles on the road in a cost-effective manner and within a relatively short timeline. The scope of measured vehicles is therefore much wider and gives a better idea of the range of emission behaviour from a large fleet sample, especially of older vehicles that are rarely tested using PEMS.

Alongside the measurements, number plate recognition allows to obtain the following reliable information for each individual vehicle: car manufacturer, fuel type, engine size and Euro standard. For a given brand, the same engine is usually used in several models. It is also common practice to use a given engine for several brands that belong to the same manufacturer group in order to benefit even more from economies of scale. In order to reflect this, the results are grouped per manufacturer, per fuel type (petrol, diesel) and per engine size. This classification of the results is done for each Euro standard. However, in order to make the average emission results accurate and representative, only vehicle groups including at least 30 measurements are included in this analysis.

The CONOX project collected data on several pollutants through RS but only NOx emissions have so far been analysed by the TRUE Initiative. Results discussed below cover diesel cars approved under Euro 3 to Euro 6 standards. It has to be noted that no Euro 6 car approved under WLTP and RDE regulations is included in the RS database given their recent introduction. All the results are from in-use vehicles in the fleet rather than brand new ones.

The main conclusion drawn from the dataset is that almost no reduction in real-life NOx emissions happened for diesel cars produced roughly between 1996 and 2015: 1,149mg/km on average for diesel cars approved under Euro 2 standard, the average of 1,119mg/km for Euro 3, 992mg/km for Euro 4 cars and 1,059mg/km for Euro 5 diesels. The introduction of the Euro 6 regulation in September 2014 did bring a reduction in absolute levels of real-world NOx emissions, with the average levels recorded of 453mg/km but this remains far above the allowed limit.

The RS database shows that the exceedance factors, or how much above the limit real-world NOx emissions, have consistently increased with the introduction of stricter EU NOx limits. On average, Euro 3 diesel cars emitted on the road more than twice as much NOx as what their respective standard. This figure goes up to 4 times for Euro 4 cars, and is around 6 times for Euro 5 and Euro 6. Given that the laboratory test used for type approval purposes was constant, this indicates with each Euro standard that car manufacturers, rather than improving the emissions, found other ways to meet the tighter NOx limits.

Furthermore, the dataset especially confirms that the divergence in performance between manufacturers has become wider: while the *maximum* exceedance is about 4 times the limit for Euro 3 diesel cars, this figure goes up to 10 times the limit for Euro 4 cars and is the highest, at almost 19 times, for Euro 5 and Euro 6 cars. According to the RS dataset, the best performing Euro 6 models are by Jaguar-Land Rover (still

[21] TRUE Initiative, Determination of real-world emissions from passenger vehicles using remote sensing data, June 2018

almost twice above the limit), while the four worst performers (Renault-Nissan, Subaru, Hyundai-Kia and Fiat-Chrysler) overshoot the limits by at least 12 times.

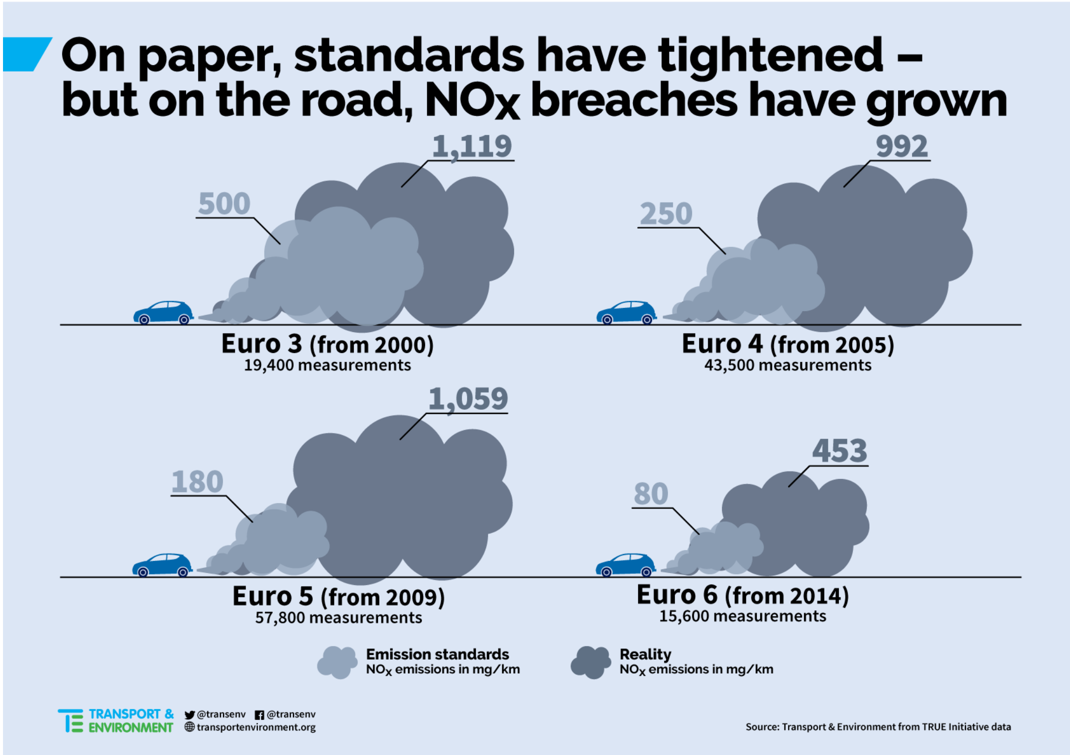

Figure 2 - Comparison of the average NOx emissions by Euro standard to their respective limit

The dataset from remote sensing also shows that the share of dangerous NO_2 pollutant, causing respiratory and other diseases, from NOx emissions of diesels increased from 16%-22% (Euro 1 to Euro 3) to 35% for Euro 6.

2.3. High diesel emitters

The remote sensing data demonstrates a very wide range of exceedances, especially for Euro 5 and Euro 6 diesel cars (from just 2-3 times above the limit to almost 19 times). The highest emitting models contribute a disproportionately large share of NOx emissions to polluted urban air across Europe. This section models the impact of these high emitters for diesel cars approved under Euro 4, 5 and 6 regulations. For each sample of measurements per Euro standard, high emitters are defined as being the 10% of cars with the highest NOx average emissions. The methodology used to determine the contribution of outliers to the total amount of NOx emissions emitted per the European diesel fleet annually can be found in Annex 2.

	Proportion of high outliers in the samples	Contribution of high outliers in the total annual fleet-average amount of NOx emitted	How many times high outliers emit above the NOx limit on average?	How much more high outliers emit compared to the average sample?
Euro 4	12%	20%	6.4	61%
Euro 5	9%	15%	9.5	63%
Euro 6	11%	25%	12.6	124%
Total	**10%**	**18%**	-	**73%**

Table 1 - Comparison of the proportion of outliers in the measured samples with their contribution to total annual mass of NOx emissions

Table 1 summarises the findings of the outlier modelling. For Euro 4 and Euro 5 diesel cars, the outliers emit about 60% more NOx than the average measured sample. This goes up to 124% for Euro 6 diesel cars, confirming that the worst performing Euro 6 vehicles have the highest exceedance compared to the emission limit of 80mg/km they should meet. Finally, when all Euro 4, 5 and 6 diesel cars are mixed together, high outliers emit almost 75% more than the average.

The results show that a relatively small amount of high emitting models representing the worst 10% of the cars on the road contributes disproportionately to the overall levels of NOx emitted by the diesel car fleet. This grows with stricter standards; notably, one-tenth of Euro 6 outliers is responsible for one quarter of the overall diesel fleet NOx, with the average contribution of the outliers at around one fifth. It is a strong indication that access policies (e.g. diesel bans, low emission zones) should be based on actual performance of vehicles, not their Euro class.

2.4. Real-world NOx emissions of petrol cars

The remote sensing data also provides insight into the real-world emissions of petrol cars, notably how NOx emissions have changed as standards became stricter. From Euro 3 to Euro 5 standards, NOx limits for petrol cars were about 3 times stricter than diesels (150, 80 and 60mg/km for Euro 3, 4 and 5 respectively) and remained unchanged when Euro 6 standard became law (60mg/km).

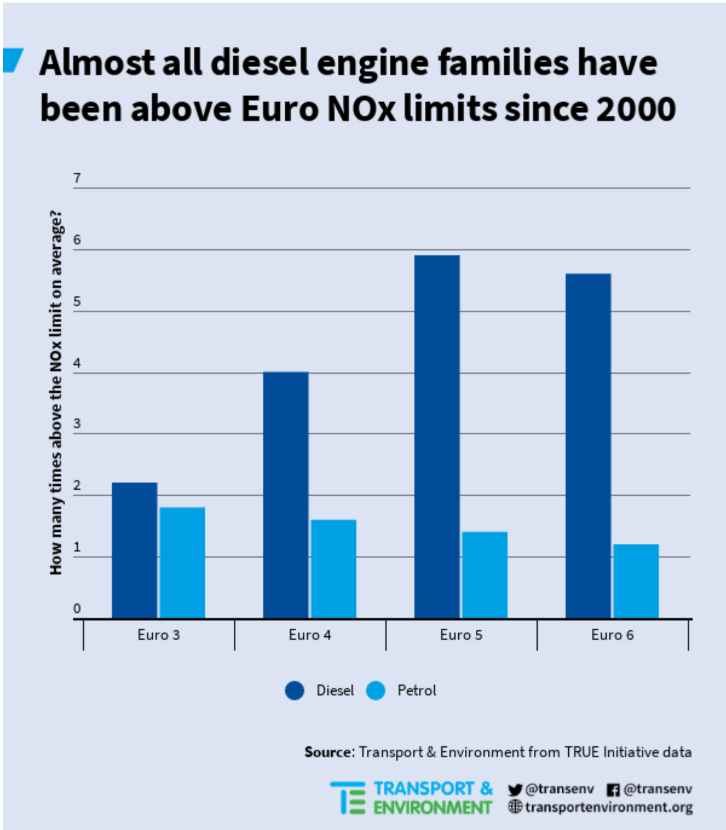

Figure 3 - Average exceedances of NOx emissions per Euro standard and per fuel type

As regards the Euro 6 petrol cars measured in the sample, the average NOx emissions are estimated to be slightly higher than the allowed limit on the road, 73mg/km instead of the limit of 60mg/km, a much smaller exceedance than diesels (22% for petrol compared to 466% for diesels). The level of exceedance for the worst performing Euro 6 petrol engines is over 3 times above the limit, against almost 19 times for the worst performing Euro 6 diesels.

An increase of NOx emissions from petrol cars is noticed when previous Euro standards are considered: 83mg/km, 131mg/km, 270mg/km and 582mg/km on average for cars approved respectively under Euro 5, Euro 4, Euro 3 and Euro 2 standards. All these cars have been equipped with the same after-treatment technology, i.e. three-way catalysts, that did not fundamentally change in this timeline, not even by gasoline direct injection, as most of these engines are still using stoichiometric air/fuel mixtures to avoid fitting more expensive after-treatment systems. In the end, this means that the increase of NOx emissions for older petrol cars is more likely to be an aging effect, coming from the catalyst system in particular.

2.5. Takeaways from remote sensing data

While the car industry claims that the problem of air pollution caused by dirty vehicles is solved thanks to the implementation of new laboratory and on-road tests, the largest legacy of the Dieselgate scandal remains untackled. The number of dirty diesel vehicles on EU roads continue to rise, standing at 43 million cars and vans when the 2017 sales are included, up from 29 million two years ago, a 48% increase.

The problem is confirmed by the recent remote sensing data analysed by the TRUE Initiative showing that real-world NOx emissions from diesel cars produced between 1996 and 2015 continuously exceeded the respective limits, on average emitting about 1,080mg/km. The introduction of Euro 6 regulation decreased this average value to 450mg/km, still significantly above the 80mg/km limit. The wide spectrum of exceedances between manufacturers is once again confirmed: ranging from 2-3 times in the best case scenario to almost 19 times the limit for the worst performing Euro 5 and 6 models, with the average exceedance around 6 times. The outliers modelling shows that only 10% of the high emitting diesels contribute to almost 20% of the total amount of NOx emissions from the diesel fleet.

The remote sensing dataset shows that petrol cars also have higher NOx emissions in real life than in laboratory. The absolute levels of NOx emissions are lower than for diesels with about 70-80mg/km on average for Euro 5 and 6 cars (against the limit of 60). Euro 2, 3 and 4 petrol cars have higher real-world NOx emissions (about 580mg/km, 270mg/km and 130mg/km respectively) which is likely to be an effect of the aging emission control systems, three-way catalysts.

Besides, the TRUE Initiative has also showed that ambient temperature has a smaller impact on petrols than diesels. While the results remain relatively constant for petrol engines, NOx emissions from diesels rise significantly below 10°C. This temperature is just above the European average, and also corresponds to the lower boundary of the thermal window, exposed in Dieselgate investigations, below which many diesel vehicles disable or turn down their exhaust gas recirculation (EGR) systems.

3. Are modern diesels clean?

Since the Dieselgate scandal in 2015 the EU has implemented a new on-road test, Real Driving Emissions (RDE) test, to check the level of emissions measured during the lab test are consistent with those measured in real life conditions on the road. The RDE regulation is an improvement on the obsolete NEDC lab tests used until 2017 as vehicles are tested in wider conditions, especially ambient temperatures and driving styles. However, concerns have been raised that manufacturers can still optimise their models to the new test conditions, and specifically the boundary conditions that define how and where the car is driven during the test. T&E has therefore commissioned emissions tests on three different vehicles using RDE compliant and non-compliant routes and driving styles to verify the NOx emissions performance under different conditions. This builds on earlier work by the ICCT.[22]

3.1. Results of RDE tests outside of regulatory boundaries

3.1.1. Scope of the testing campaign and selected vehicles

T&E commissioned Emisia[23] to perform on-road tests on three cars. Emisia is an independent tester based in Thessaloniki (Greece), linked with the Aristotle University of Thessaloniki and the Laboratory of Applied Thermodynamics. As the testing campaign is ongoing, this report presents the preliminary results of the NOx, PN and CO emissions. The results also do not include any correction of the results that is part of the RDE test. This is because T&E was interested in the real world emissions.

The selected vehicles were approved in line with both the WLTP and RDE test protocols that have been introduced for new types in September 2017.[24] The vehicle selection attempted to reflect different market segments and car manufacturers. The tested vehicles were:

- An Opel Adam I fitted with an indirect injection petrol engine (PFI);
- A Ford Fiesta VII fitted with a direct injection petrol engine (GDI);
- An Honda Civic X fitted with a diesel engine.

More details about their technical characteristics can be found in Annex 3. All models are Euro 6d-temp approved, meaning:[25]

- the “Euro 6” limits are the reference for pollutants (HC, CO, NOx, PM, PN);
- “d” refers to the fact that WLTP and RDE tests were used to measure the emissions during the type approval process. Note that RDE tests only check NOx and PN emissions on the road, while WLTP is used for CO_2 and all regulated air pollutants;
- “temp” refers to the temporary RDE conformity factor of 2.1 for NOx, and the margin of 0.5 for PN emissions.

Relevant limits are summarised in the Table 2 below.[26] Three on-road tests were performed:

- “RDE smooth”: an on-road test with a smooth driving style fully compliant with the RDE regulations;
- “RDE dynamic”: an on-road test with a dynamic driving style fully compliant with the RDE regulations, using the same route as the “RDE smooth” test;

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[22] The ICCT, Will the future RDE regulation be enough to restore trust in diesel technology?, August 2017
[23] EMISIA SA, Quotation n°18.RE.009.V2
[24] Official Journal of the European Union, Regulations n°2017/1151 & n°2017/1154
[25] Ibid.
[26] Official Journal of the European Union, Regulations n°715/2007, n°2017/1151, n°2017/1154

- "RDE extended": an on-road test with a dynamic style on a route that lied outside the boundary conditions as currently defined in the regulations, mainly altitude and altitude gain.

	Diesel		Petrol	
	Euro 6 limit	For RDE tests	Euro 6 limit	For RDE tests
NOx emissions (mg/km)	80	168 (CF = 2.1)	60	126 (CF = 2.1)
PN emissions (particles/km)	6 x 10^11	9 x 10^11 (Margin = 0.5)	6 x 10^11	9 x 10^11 (Margin = 0.5)
CO emissions (mg/km)	500	Not applicable	1,000	Not applicable

Table 2 - Summary of the Euro 6 limits that apply for WLTP and RDE tests regarding few pollutants

Both RDE smooth and RDE dynamic tests were performed once per car, while the RDE extended test was performed twice per car. The characteristics of the routes used and how they compare with the boundary conditions in the regulations can be found in Annex 4. All these on-road tests were done with the same PEMS equipment with a cold start engine. For the RDE smooth and RDE dynamic, the WLTP-measured CO_2 emission figures that are available in the Certificate of Conformity (CoC) were used to validate the tests, in line with the upcoming RDE 4 regulation.[27] However, all the emission results that are presented in the next sections are "raw" results, meaning direct measurements from the PEMS, without any correction, unlike the RDE regulation.

3.1.2. Pollutant results of the three tested cars

- Honda Civic X:

The Honda Civic diesel was equipped only with a lean NOx-trap (LNT) technology and NOx storage catalyst (NSC), rather than a SCR system to reduce NOx emissions at the tailpipe, emissions were therefore expected to be close to the limits. NOx-traps are cheaper and less complex to implement in terms of hardware and software than SCR systems but also much less effective in reducing NOx emissions, 70-80% for LNT, compared to 95% reduction possible for an SCR system[28]) when implemented properly. Many early Euro 6-approved cars used LNT as an option to respect the limit in the lab on NEDC, but the different national testing programmes in the aftermath of the Volkswagen emissions scandal and other independent tests has exposed the poor behaviour of this after-treatment technology in real-world conditions. The worst performing models from Fiat and Renault, are fitted with LNT and have the real-world NOx emissions in excess of 1,000mg/km, more than 12 times the Euro 6 limit.[29]

The results of the RDE compliant tests show that Honda's LNT technology performs well during a compliant RDE smooth test with emissions at 68mg/km, below the Euro 6 limit. For the RDE dynamic test, emissions rise to 162mg/km, just below the 168mg/km limit for Euro 6d-temp cars. However, if the car is driven outside of the boundary conditions, the NOx emissions increase to 1,450mg/km, almost 9 times the allowed limit

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[27] European Commission, Comitology Register, Meeting of the Technical Committee on Motor Vehicles (TCMV) on 03/05/2018, Version of the RDE 4th regulation proposal adopted by TCMV

[28] Timothy V. Johnson, Vehicular emissions control highlights of the annual Society of Automotive Engineers (SAE) international congress, Platinum Metals Review, Volume 57, Number 2, April 2013, pp. 117-122

[29] T&E, Dieselgate: Who? What? How?, September 2016

for RDE tests. When a regeneration of the LNT system occurred, the emissions rose to 2,025mg/km, which represents an increase of 40% simply due to the regeneration of the Diesel Particulate Filter (DPF).

PN emissions are quite low with a level of about 0.3-0.4 x 10^{11} particles/km on each test, underlining the efficiency of DPF. However, on the second RDE extended test, in which a regeneration occurred, the level of PN emissions rose to 6.1 x 10^{11} particles/km. This level is below the PN limit with the RDE margin, but demonstrates regeneration of after-treatment systems causes very high emissions for a short amount of time (in this case, about 16 times more PN than the RDE extended test without regeneration). The regeneration should be oxidising trapped particles fully and should not be increasing emissions.

- Ford Fiesta VII:

The 2018 model year of the Ford Fiesta VII is fitted with a typical after-treatment emission control system for a petrol engine, i.e. a three-way catalyst to reduce emissions of HC, CO and NOx, and a gasoline particulate filter (GPF) downstream to control PN emissions from the gasoline direct injection engine.

All three on-road tests carried out on the Fiesta confirm that three-way catalysts are efficient to control NOx emissions at the tailpipe. On the RDE smooth and dynamic tests, NOx emissions were about 20mg/km, regardless of the driving style, while it reached between 30 and 40mg/km on the RDE extended tests, still comfortably within the Euro 6 limit of 60mg/km.

The results of PN emissions on the two RDE compliant tests, produced results close or slightly below the allowed limit: 8.0 x 10^{11} particles/km and 9.1 x 10^{11} particles/km on the RDE smooth and RDE dynamic tests respectively (the limit is 9.0 x 10^{11} particles/km). But when driven outside of the boundary conditions, the PN emissions rose to 19 - 25 x 10^{11} particles/km, or between 2 and 3 times above the RDE limit. This suggests that the GPF has been sized and configured to just comply with the test and that higher emissions will occur during more dynamic driving.

The filtering efficiency of GPF technology is currently lower than that of diesel particle filters: around 60-80%[30] compared to over 99%.[31] This difference is not because GPF technology itself is not capable of filtering better, but because the current limit in the Euro 6 regulation does not incentivise the car industry to use more efficient filters. A GPF with a higher filtering efficiency would also lead to a higher back pressure in the exhaust line, making the engine less efficient as exhaust gases are slower to leave the tailpipe. Another plausible explanation is that Ford simply did not fit and implement the GPF in the most efficient way on its vehicle, something that was seen with DPFs' introduction with the Euro 5 regulation. Indeed, this current generation of the Ford Fiesta has been introduced on the market in 2017 just before the entry into force of WLTP and RDE regulations, meaning that the original versions sold were approved on NEDC, without the need to fit a GPF, which was added subsequently to already designed models.

Finally, the CO emissions measured were very low during the two RDE smooth and dynamic tests: 4-26mg/km, while the regulatory limit is 1,000mg/km. It should be underlined that even though CO emissions are measured during RDE tests, they are not checked for compliance on the road in the current scope of the RDE regulation.[32] However, during the outside the boundaries RDE test, Fiesta's CO emissions were significantly higher and even above the allowed limit, or between 469 and 1,028mg/km.

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[30] AECC, Gasoline Particulate Filter (GPF), How can the GPF cut emissions of ultrafine particles from gasoline engines?, November 2017
[31] AECC, Emissions control technologies to meet current and future European vehicle emissions legislation, August 2016
[32] Official Journal of the European Union, Regulations n°2017/1151, n°2017/1154

- Opel Adam:

Powered by a petrol engine with an indirect injection, the after-treatment emission control system fitted on the 2018 model year Opel Adam is a three-way catalyst without a GPF. This is since the current Euro 6 regulation does not impose a limit on PN emissions for indirect injection petrol engines (only GDIs). This means that GPFs will not be found for these powertrains.

While the three-way catalyst technology has been used for a long time on petrol cars, the one used on the Opel car has showed relatively high level of CO emissions during the two RDE compliant tests: 492mg/km with the smooth driving and 735mg/km with the dynamic driving. Both values are below the allowed limit but significantly higher than the levels measured on the Ford Fiesta with a similar catalyst technology. When driven outside of the boundary conditions on the third test, the CO emissions rose sharply with levels between 2,323 and 2,814mg/km, i.e. almost 3 times the allowed limit.

The PN emissions were in any case lower than the regulatory limit in all tests: between 1.3 and 2.7 x 10^{11} particles/km for the RDE smooth and dynamic tests respectively, and between 1.2 and 1.7 x 10^{11} particles/km for the RDE extended tests. As regards NOx emissions, the tested Adam confirmed the petrol's low emission levels, with the figures even lower than the Fiesta's results: 11-20mg/km for the RDE smooth and dynamic tests respectively and between 18mg/km and 27 mg/km for the RDE extended tests.

- Summary of the results:

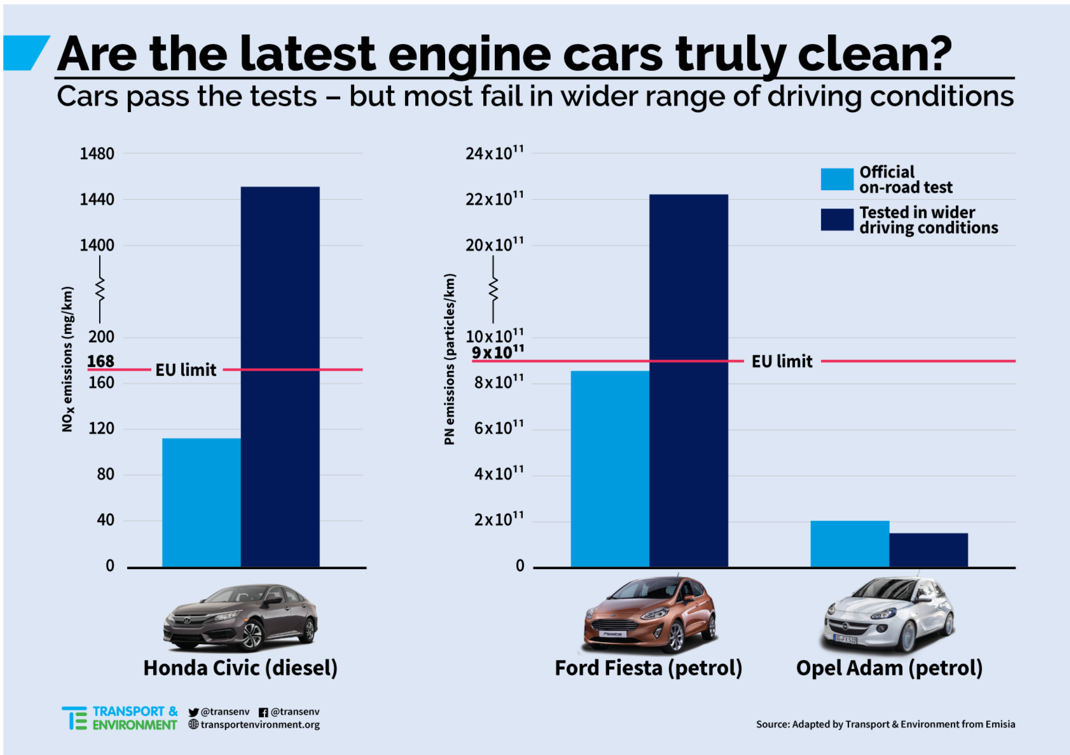

Figure 4 - Graphic representation of the NOx and PN test results for the diesel and petrol cars respectively

The Table 3 below summarises the pollutant results for the three tested cars on the different on-road tests. In a nutshell, the diesel Honda Civic respects the NOx limit with the temporary RDE conformity factor of 2.1 on compliant RDE smooth and dynamic tests, but NOx emissions skyrocket once driven outside on the RDE extended route. PN emissions are low though, unless a DPF regeneration is happening. Both tested petrol cars have low NOx emissions in any condition. However, the Ford Fiesta barely complies with the PN emission limit (with the PEMS margin) on RDE smooth and dynamic tests, despite its GPF, but PN emissions are more than twice the limit once driven on the RDE extended tests. Regarding the Opel Adam, CO emissions are way above the limit on the RDE extended tests but PN emissions are always below the limit in any condition.

	RDE smooth		RDE dynamic		RDE extended	
	NOx (mg/km)	PN (particles/km)	NOx (mg/km)	PN (particles/km)	NOx (mg/km)	PN (particles/km)
Ford Fiesta VII	17	8.0 x 10^11	24	9.1 x 10^11	30 - 40	19.4 - 24.8 x 10^11
Honda Civic X	68	0.28 x 10^11	162	0.35 x 10^11	1,449 - 2,025	0.37 - 6.1 x 10^11
Opel Adam I	11	1.3 x 10^11	20	2.7 x 10^11	18 - 27	1.2 - 1.7 x 10^11

Table 3 - Summary of NOx and PN emission results on the three cars tested on the road

3.1.3. RDE boundary conditions are too narrow

Since 2015, T&E has been developing an on-road test programme together with carmaker PSA Group, French NGO France Nature Environnement (FNE) and auditors Bureau Veritas. The test is similar to the RDE, but uses a wider range of boundary conditions and makes other changes to the test to ensure it is genuinely representative of the average driver of the model.[33] In 2017, as part of the work the collaborators published an in-depth report examining the results of about 400 tests from over 60 models from the PSA Group.[34]

The graphs below compare the 340 test results from the joint PSA-T&E programme with the driving style boundaries as currently defined in the EU RDE regulation. Figure 5 and Figure 6 focus on the upper limit and show the speed multiplied by the acceleration as a function of the vehicle speed. In order to be considered as valid, data points for the three phases (urban, rural, motorway) have to be below the limit (green line). The Figure 7 however focuses on the lower limit and show the relative positive acceleration as a function of the vehicle speed. In order to be considered as valid, data points for the three phases have to be above the limit (green line). It has to be noted that all tested models were driven by the PSA Group, not by T&E or FNE.

Figure 5 shows that for the urban part of the test, vehicles driven rather moderately based on real-world data are considered as dynamic by the RDE regulation. For the rural and motorway parts, the RDE regulation would consider most tests as borderline or even too aggressive for a quite significant proportion of the 340 tests. This means that the current EU regulation would exclude some driving behaviour which is representative of many EU drivers, as it would fall outside of the RDE boundary conditions.

This is again emphasized by Figure 6 that focuses on large vehicles from the PSA Group range. The green dots, representing valid tests according to the PSA-T&E test protocol, fall outside of the RDE upper limit. Even though these models represent a small proportion of PSA's sales and of the EU's fleet, they nonetheless represent a significant share of CO_2 emissions, since these models are powerful, heavy and often driven aggressively. Moreover, it has to be noted that the large vehicles from the PSA Group do not have the highest power-to-weight ratios compared to many other premium or luxury car models on the EU market. This clearly shows that the RDE boundary upper limit for acceleration/dynamic driving is far from being fully representative of regular drivers.

[33] The developed protocol is intended to match the average driving conditions of a PSA customer both in terms of driving style and type of road (urban, rural, motorway) driven. Among other criteria, an on-road test is considered valid if the average acceleration is representative of 30th to 70th percentile customers on the urban and rural sections of the trip, and 20th to 80th percentile customers for motorways.

[34] Groupe PSA, T&E, FNE & Bureau Veritas, Real-world fuel economy measurements: technical insights from 400 tests of Peugeot, Citroën and DS cars, September 2017

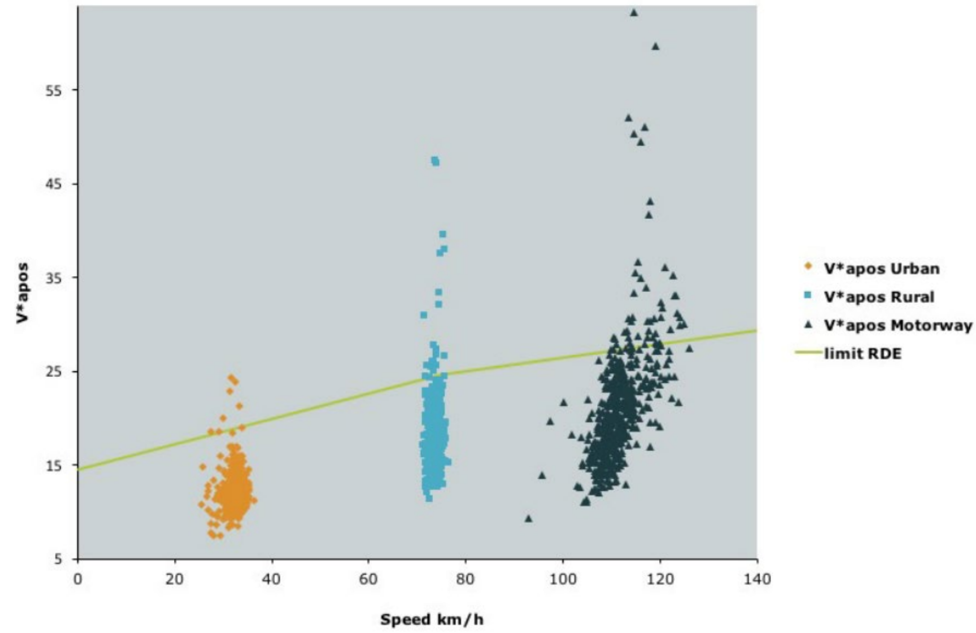

Figure 5 - Comparison of the driving conditions of 340 on-road tests done on PSA vehicles with the EU RDE upper limit

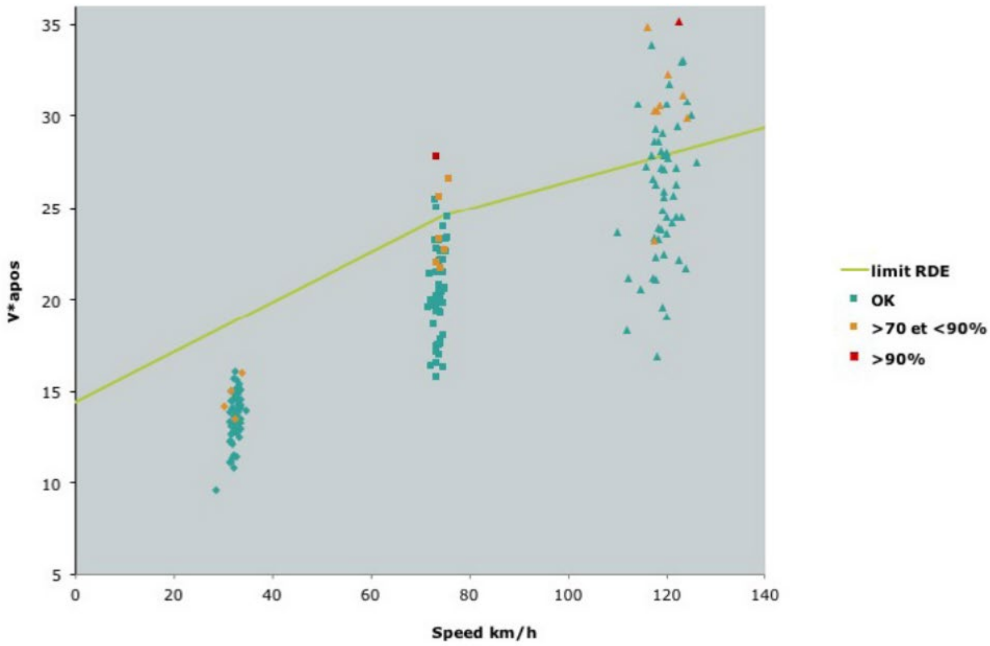

Figure 6 - Comparison of the driving conditions of on-road tests done on PSA's largest vehicles with the EU RDE upper limit

A comparison with the lower limit defined in the RDE regulation is shown in Figure 7. This shows that every test considered too passive by the PSA test protocol (orange and red dots) would be considered as valid by the regulation, with even some margin above the lower boundary. This indicates that the lower RDE limit is too low and does not filter the tests that are too passive and not representative of the real world. In the end, the driving style window defined in the EU regulation incentivises too smooth driving, rather than checking representative styles as both upper and lower limits set too low. Even though not all drivers will drive as dynamically as during our RDE extended tests presented in this report, it does not mean that none of them will do so.

The problem is further exacerbated in the last part of the RDE regulation dealing with in-use compliance, agreed earlier in 2018. This introduces further weakening by validating each RDE test against the WLTP laboratory one on the basis of CO_2 emissions. This means that RDE tests are pushed further away from real-world driving conditions, with even smoother driving styles being rewarded because of the link with WLTP and the test optimisation towards lower CO_2 emissions that this entails.[35]

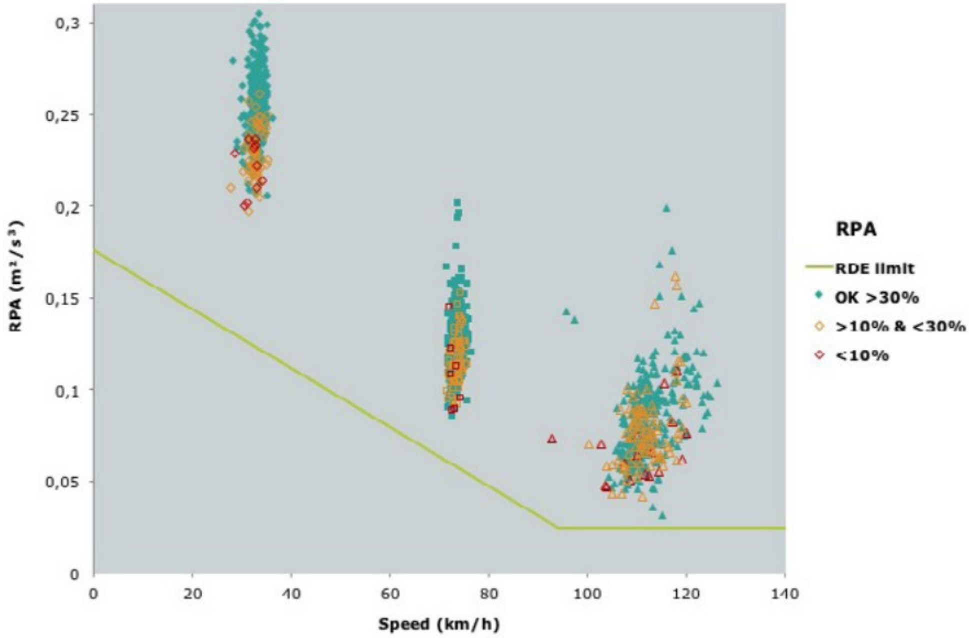

Figure 7 - Comparison of the driving conditions of 340 on-road tests done on PSA vehicles with the EU RDE lower limit

Similarly, the altitude boundary conditions are also restrictive. The first criterion is the cumulative positive altitude gain that is limited to 1,200m/100km in the regulation. The route used for the joint testing programme with PSA is close to the limit with a result of about 1,000m/100km. However, this route was designed around one of PSA's main technical centres in Western part of Paris, which is known as a rather flat area. The key conclusion is that the RDE is not representative of real world driving and that on the road most models will be driven more dynamically and on routes outside the RDE boundary conditions.

3.2. Effectiveness of DPFs on modern diesels

DPF tampering and the use of faulty and ineffective DPFs is a widespread problem throughout Europe, significantly increasing real-world particle emissions from diesel vehicles. Last year, in Belgium alone, tens of thousands of diesel vehicles were discovered with illegally removed and tampered DPFs.[36] Drivers tampering or removing the DPF on their diesel vehicle to avoid the cost of a DPF replacement are driving their car illegally, irresponsibly and significantly increase air pollution emissions.

To understand the proportion of vehicles that are driven with tampered or dysfunctional DPFs, T&E undertook a survey of over a thousand Diesels across 9 EU cities. Using an Ultra-fine Particle Counter (UPC), T&E recorded the concentration of Particulate Number (PN) at the side of the road while diesel vehicles passed. Taxi vehicles were exclusively recorded as the best proxy for Diesel vehicles. In each city, samples were taken at the airport in order to have sufficient taxi traffic which would pass within a single lane road or taxi bay. Vehicles that triggered a sharp and abnormally high increase in PN concentration relative to average concentration are likely to be driving with dysfunctional, tampered or removed DPFs. The data from Paris was regarded as invalid and has not been included in results due to extremely high levels of background PN, caused by departing air traffic. More details about the methodology can be found in the Annex 5.

[35] T&E, How to strengthen proposals for the RDE 4th package and WLTP 2nd act, April 2018
[36] T&E, How to tackle the illegal diesel filter removal 'industry' in Belgium and beyond, July 2017

Table 4 shows the results from each survey sample. Results show the sample size, the number of abnormally high emitting Euro 5-6 vehicles and their respective proportion in the sample. On average, across the 8 samples, 4% of total diesel vehicles sampled were Euro 5-6 and recorded abnormally high concentrations of PN emissions. An average of 4% is unusually high when considering Euro 5-6 new cars have been fitted with mandatory DPF filters since the 2011 round of Euro 5 standards. This figure in theory should be 0%. Thus, there is a discrepancy between what should be expected of Euro 5-6 diesels and our sample results. It is likely that these vehicles are driven with tampered or dysfunctional DPFs. Furthermore, no clear geographical divide between Eastern and Western countries can be concluded; however results are often dependent on the number of old diesel vehicles in the sample set, of which visibly more were sampled in Riga and Bucharest.

Sample site	Sample size	No. of high emitting Euro 5-6 vehicles	% of high emitting Euro 5-6 vehicles
Berlin (Tegel)	200	5	3%
Riga	102	7	7%
Warsaw (Chopin)	135	5	4%
Prague (Václav Havel)	196	5	3%
Bucharest (Henri Coandă)	134	4	3%
Rome (Fiumicino)	156	5	3%
Barcelona (El Prat)	226	14	6%
London (Gatwick)	154	7	5%
Total	**1,303**	**55**	**4%**

Table 4 – Number of measured vehicles and high emitted vehicles for each sample

Sample site	Average background PN concentration (particles/cm3)	Average PN concentration of whole sample (particles/cm3)	Average PN concentration of high emitting Euro 5-6 vehicles (particles/cm3)
Berlin (Tegel)	15,000	20,000	81,000
Riga	3,000	24,000	84,000
Warsaw (Chopin)	13,000	18,000	46,000
Prague (Václav Havel)	6,000	14,000	103,000
Bucharest (Henri Coandă)	3,000	14,000	43,000
Rome (Fiumicino)	3,000	13,000	74,000
Barcelona (El Prat)	4,000	14,000	70,000
London (Gatwick)	16,000	53,000	126,000
Average	**7,000**	**21,250**	**81,000**

Table 5 – Summary of results of PN concentrations for each sample

Table 5 shows the difference between the average background PN concentration, the average PN concentration and the average PN concentration of high emitting Euro 5-6 vehicles for each sample site. Background PN concentration represents the PN concentration in the air when no car passes. Average PN concentration is representative of steady, light traffic. The latter is therefore on average 3 times higher than background concentration, whilst the average abnormally high emitting vehicle triggers on average an increase of 4 times the PN concentration of light traffic and nearly 12 times the background PN concentration. Moreover, PN concentration reached as high as 143,000 particles/cm^3, 144,000 particles/cm^3 and 144,000 particles/cm^3 for Riga, Barcelona and Prague respectively for individual diesel vehicles. Therefore, these cars register PN emissions over 20 times the PN concentration of the background PN concentration and over 7 times the PN concentration of steady, light traffic (sample average).

Notably, results are variable for Warsaw, Bucharest and London. Warsaw and Bucharest recorded much lower averages for high emitting vehicles which results from much slower vehicles speeds of the recorded vehicles compared to the other sites. London had an outstandingly high average PN concentration due to overhead air traffic. Thus, the threshold PN concentration for abnormally high emitting cars is relatively higher.

Overall, the results show that DPF tampering and the use of dysfunctional DPFs seems to be a common situation around Europe: T&E found that an average of 4% of total sampled diesels are emitting abnormally high particulate emissions. This is an unacceptable proportion considering these vehicles have been fitted with a mandatory DPF. These vehicles are emitting on average 4 times the PN concentration of steady traffic and as much as 12 times the background PN concentration. According to Frank Kelly, professor of environmental health at King's College London, the removal of a DPF causes up to 20 times higher PN emissions than with an effectively operating filter.[37] This means just 4% of cars with ineffective DPF increase fleet emissions by 75%.

[37] BBC News, 'Thousands' driving without crucial diesel filters, October 2017

4. Conventional cars in the future: emerging evidence on unregulated pollutants

The previous chapters focused on some air pollutants covered by the Euro regulations - most particles, NOx and CO - and showed that diesel and petrol cars continue to exceed the emission limits when driven on the road, often on a large scale as is the case for diesel NOx emissions. But beyond the regulated pollutants there is emerging evidence to show that internal combustion engines and related processes directly or indirectly release many other harmful but yet unregulated pollutants. Relatively little research to date has been done to understand the scale of the problem, but this section summarises some of the evidence available to show the risks that are presently being ignored.

4.1. Diesel Particulate Filters and small particles

The World Health Organisation (WHO) classified diesel soot, or particles, as carcinogenic in 2016.[38] The introduction of diesel particulate filters (DPF) that has been necessary since 2011, has undoubtedly reduced the toxicity of diesel exhaust. But the shift to gasoline direct injection (GDI) engines and subsequent increase in particle emissions (notably in cars without GPFs) exacerbates the problem.

Whilst DPFs demonstrate high filtering efficiency (95% reduction of PM, over 99% reduction of PN[39]) they also overtime become clogged and need to be cleaned, or regenerated (whereby the particles are burnt off). Today the most common process is “active regeneration”, where the engine software activates a specific operation mode. This should happen when the vehicle is driven at high speed because high temperatures and exhaust flow are needed. Fuel injection parameters are changed to increase the exhaust temperature to burn the trapped particles. As a result, after-treatment is disabled during active regeneration, so diesel engines emit significantly more pollutants than during normal operation including NOx and probably other toxins.

Recent tests by two French public research institutes[40] investigated emissions during DPF regenerations on two Euro 5 cars on a chassis dynamometer in a lab. The results show a large increase of concentration of toxic particle emissions during a diesel filter regeneration. The emitted particles are composed of black carbon (at a concentration level of 400-500µg/m^3, about 8 times higher than during normal engine operation). Semivolatile material (at a concentration level of 80-150µg/m^3 was also emitted in much high amounts (between 6 and 24 times higher than during normal engine operation). The latter is composed mainly of ammonium bisulphate, sulphate and organic compounds (such as alkanes and cycloalkanes from the fuel used to create the higher exhaust temperature), as well as ammonium, sulphuric acid and traces of nitrates. Black carbon emissions are explained by the removal of the soot deposition on the DPF walls, called “soot cake”, used to improve DPF filtering efficiency, combined with the dropping filter efficiency during the regeneration process. Fuel and lubricant oil are identified as the sources of sulphur that is trapped during normal engine operation in the catalyst system before being released and transformed because of the high exhaust temperatures needed for the filter regeneration. The industry likes to portray regeneration as a process leading to full oxidation to CO_2 and NOx - this is not the case.

A second concern with DPF is that not all particles are effectively measured today. The current protocol used for the compliance with Euro PM and PN limits does not look at the entire range of particles. Notably, volatile and semivolatile particles are not counted at all, as well as the smallest solid ones that have a diameter below 23nm, or nanoparticles. These tiny particles are smaller than viruses and are similar in size

[38] WHO, International Agency for Research on Cancer, Agents classified by the IARC monographs, Vol. 1-122, July 2018
[39] AECC, Emissions control technologies to meet current and future European vehicle emissions legislation, August 2016
[40] Badr R’Mili, Antoinette Boréave, Aurélie Meme, Philippe Vernoux, Mickaël Leblanc, Ludovic Noël, Stéphane Raux and Barbara d’Anna, Physico-chemical characterization of fine and ultrafine particles emitted during Diesel Particulate Filter active regeneration of Euro 5 diesel vehicles, Environmental Science & Technology, Volume 52, Issue 5, March 6th 2018, pp. 3312-3319

to molecules.[41] The particles emitted during DPF regenerations are either in a nucleation mode (volatile particles with a diameter between 7 and 30nm for the tested vehicles) or in an accumulation mode (with a diameter bigger than 100nm).[42] Another study showed that about 75% of the number of particles emitted by Euro 5 diesel vehicles during DPF regeneration are particles with a size between 7 and 30nm.[43] This suggests the DPF may trap larger particles (that are regulated) but during regeneration it will re-emit some of these but in a smaller and more harmful size fraction.

The French researchers show that nucleating particles are emitted as long as the filter regeneration is happening, i.e. during almost 10 minutes on the two vehicles tested. Nucleating particles are composed of ammonium bisulphate and sulphate, sulphuric acid and organic compounds, while the bigger particles are made of organic compounds. Soot is emitted later in the regeneration process after a few minutes once the soot cake is being removed and burnt.[44] A Greek study from the Aristotle University also confirmed the similar bimodal particle size distribution (nucleation/accumulation), the increase of small nucleating volatile particles (5-10nm) in particular and a general increase in particle concentration during a DPF regeneration.[45]

European Commission's scientific body (Joint Research Centre or JRC) also investigated the small sub-23nm solid particles on different engine technologies, by testing vehicles and by undertaking literature reviews. Based on their lab tests done on several Euro 5 and Euro 6 diesel and petrol cars (either with direct or indirect injection systems), the results clearly show that all engine technologies emit sub-23nm particles,[46] a trend that was further confirmed by JRC's literature review[47] and by another recent study.[48]

However, emissions of sub-23nm particles vary according to the engine technology. For diesel cars, the proportion of such nanoparticles, smaller than 23nm, compared to particles bigger than 23nm, is below 20-30%, while petrol vehicles with direct injection (GDI) tend to emit more of them (between 35% and 50%). For gasoline cars with indirect injection (PFI), sub-23nm particles account for between 75% and 150% of total emissions.[49] Today, in normal operation, GDI engines on average emit more particles than diesels with DPF. As a result the absolute numbers of nanoparticles are higher for petrol engines. A previous investigation done by the JRC indicated that for PN emission levels below 10^{11} particles/km that are

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41 T&E, Gasoline particulate emissions: The next auto scandal?, October 2016

42 Badr R'Mili, Antoinette Boréave, Aurélie Meme, Philippe Vernoux, Mickaël Leblanc, Ludovic Noël, Stéphane Raux and Barbara d'Anna, Physico-chemical characterization of fine and ultrafine particles emitted during Diesel Particulate Filter active regeneration of Euro 5 diesel vehicles, Environmental Science & Technology, Volume 52, Issue 5, March 6th 2018, pp. 3312-3319

43 Cédric Louis, Yao Liu, Patrick Tassel, Pascal Perret, Agnès Chaumond and Michel André, PAH, BTEX, carbonyl compound, black-carbon, NO_2 and ultrafine particle dynamometer bench emissions for Euro 4 and Euro 5 diesel and gasoline passenger cars, Atmospheric Environment, Volume 141, September 2016, pp. 80-95

44 Badr R'Mili, Antoinette Boréave, Aurélie Meme, Philippe Vernoux, Mickaël Leblanc, Ludovic Noël, Stéphane Raux and Barbara d'Anna, Physico-chemical characterization of fine and ultrafine particles emitted during Diesel Particulate Filter active regeneration of Euro 5 diesel vehicles, Environmental Science & Technology, Volume 52, Issue 5, March 6th 2018, pp. 3312-3319

45 Stavros Amanatidis, Leonidas Ntziachristos, Barouch Giechaskiel, Alexander Bergmann and Zissis Samaras, Impact of selective catalytic reduction on exhaust particle formation over excess ammonia events, Environmental Science & Technology, Volume 48, Issue 19, October 7th 2014, pp. 11527-11534

46 Barouch Giechaskiel, Urbano Manfredi and Giorgio Martini, Engine Exhaust Solid Sub-23 nm Particles: I. Literature Survey, SAE International Journal of Fuels and Lubricants 7(3), 2014, pp. 950-964

47 Barouch Giechaskiel, Joonas Vanhanen, Minna Väkevä and Giorgio Martini, Investigation of vehicle exhaust sub-23 nm particle emissions, Aerosol Science and Technology, Volume 51, Issue 5, 2017, pp. 626-641

48 Anthi Liati, Daniel Schreiber, Yadira Arroyo Rojas Dasilva and Panayotis Dimopoulos Eggenschwiler, Ultrafine particle emissions from modern gasoline and diesel vehicles: An electron microscopic perspective, Environmental Pollution, Volume 239, August 2018, pp. 661-669

49 Barouch Giechaskiel, Joonas Vanhanen, Minna Väkevä and Giorgio Martini, Investigation of vehicle exhaust sub-23 nm particle emissions, Aerosol Science and Technology, Volume 51, Issue 5, 2017, pp. 626-641

achieved by diesel cars with DPF,[50] the proportion of sub-23nm particles was higher than 100%[51] but this was not confirmed by JRC's later analyses.

JRC's latest testing programme compares emissions of solid and all particles (including volatile and semivolatile fractions not regulated today). The results show that for diesel and GDI cars, fractions are similar. But, for PFI vehicles, the proportion of all sub-23nm particles goes up between 130% and 180%. This means that petrol cars with indirect injection engines emit a significant amount of volatile or semivolatile particles of a very small size, below 6nm.[52]

JRC also looked at PN emissions in tests low temperatures, at -7°C. In the 2014 paper, GDI vehicles had PN emission levels 3 times higher at -7°C than with ambient temperatures, and the fraction of sub-23nm went from 30-40% to 60-100%.[53] As regards PFI technology, the influence of cold start at ambient temperatures evaluated on the NEDC urban phase showed particle emissions 20 times higher than during the extra-urban phase, noting than most of the PN emissions happened during short moments of acceleration.[54]

Recent research from a Swiss public research institute recently tested seven Euro 6 cars (three petrol and four diesel) on a chassis dynamometer and found that small particles are present in both diesel and petrol exhaust in three different forms: soot (the main solid particle caused by combustion of fuel with carbonaceous compounds); ash (that are metal particles); and ash-bearing soot.[55] The authors found ultrafine ash particles are more dominant than ultrafine soot for diesel engines, while the amounts are more or less the same for petrol cars, either with a direct or an indirect injection system. These particles can be released during a DPF regeneration because of the soot cake being burnt but also after DPF regenerations, as the filtering efficiency drops. The researchers concluded that more research on these ash particles should be done in order to understand better their impact on human health, as sizes of ash particles were found to be in the order of few nanometres (4-7nm on diesel engines).

The research demonstrates that serious and dangerous particles are emitted by diesel and petrol engines that today are not captured by the EU regulations. It is already possible to extend the size of particles down to 10nm using current measurement technology.[56] However, the smallest nanoparticles will remain untackled in the future and continue to be an important risk for human health.[57]

The introduction of RDE regulation is expected to increase the use of SCR technologies needed to effectively reduce NOx emissions from diesel cars in real-world driving conditions. This catalyst system uses urea (ammonia) in order to react with NOx so that it is transformed into water and inoffensive nitrogen gas. However, the dosing of urea is key to ensure proper functioning of SCR system: too little urea will cause some NOx not to be captured, but too much urea leads to ammonia slips, releases through the exhaust. Ammonia is toxic for humans. Research by the Aristotle University shows ammonia slip can also result in formation of new non-volatile particles emissions at the tailpipe despite the DPF. Notably, the

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[50] As confirmed by the results from the on-road tests presented in section 3.1

[51] Barouch Giechaskiel, Urbano Manfredi and Giorgio Martini, Engine Exhaust Solid Sub-23 nm Particles: I. Literature Survey, SAE International Journal of Fuels and Lubricants 7(3), 2014, pp. 950-964

[52] Barouch Giechaskiel, Joonas Vanhanen, Minna Väkevä and Giorgio Martini, Investigation of vehicle exhaust sub-23 nm particle emissions, Aerosol Science and Technology, Volume 51, Issue 5, 2017, pp. 626-641

[53] Barouch Giechaskiel, Urbano Manfredi and Giorgio Martini, Engine Exhaust Solid Sub-23 nm Particles: I. Literature Survey, SAE International Journal of Fuels and Lubricants 7(3), 2014, pp. 950-964

[54] Barouch Giechaskiel and Giorgio Martini, Review on engine exhaust sub-23 nm solid particles, 2014

[55] Anthi Liati, Daniel Schreiber, Yadira Arroyo Rojas Dasilva and Panayotis Dimopoulos Eggenschwiler, Ultrafine particle emissions from modern gasoline and diesel vehicles: An electron microscopic perspective, Environmental Pollution, Volume 239, August 2018, pp. 661-669

[56] Barouch Giechaskiel, Joonas Vanhanen, Minna Väkevä and Giorgio Martini, Investigation of vehicle exhaust sub-23 nm particle emissions, Aerosol Science and Technology, Volume 51, Issue 5, 2017, pp. 626-641

[57] Barouch Giechaskiel, Urbano Manfredi and Giorgio Martini, Engine Exhaust Solid Sub-23 nm Particles: I. Literature Survey, SAE International Journal of Fuels and Lubricants 7(3), 2014, pp. 950-964

concentration of particles doubles when ammonia escapes the SCR system compared to when there is no ammonia injection. This phenomenon was noticed both at low and high loads, and through the entire range of particle sizes as concentration of solid particles bigger than 23nm increased by 129% and those of total particles smaller than 23nm increased by 67%.[58]

As of today, levels of pollutant and CO_2 emissions happening during a DPF regeneration, as well as the distance interval between two consecutive DPF regeneration events, are measured in laboratory in order to calculate "Ki factors" that are used to correct the emissions measured during the type-approval WLTP test. These Ki factors determined in the laboratory are also used for RDE tests in order to take into account regeneration events. This is contrary to the purpose of RDE tests as these factors are not representative of real life conditions or driving.

4.2. New harmful unregulated pollutants

In addition to particles, which damaging effect on health and environment is widely acknowledged, there is emerging evidence that conventional engines emit other unregulated toxins the damaging impact of which is only just beginning to be understood. Of particular concern are a group of volatile organic compounds, known collectively as **BTEX**, naturally present in crude oil and also used in the process to transform crude oil into refined fuels.[59] BTEX is a family of monocyclic aromatic hydrocarbons that include **benzene, toluene, ethylbenzene and xylenes**, with benzene being classified as carcinogenic by the WHO,[60] while the other compounds are known for their toxicity and impact on human health.[61]

Research done by French public research institutes on three Euro 5 diesel cars and one Euro 5 GDI car, mainly tested on Artemis cycles showed that benzene was the dominant constituent of BTEX (60%) found in diesel exhaust (respectively 180-703µg/km and 79-262µg/km on urban cycles with cold and hot start), while xylenes are more prominent (60%) in petrol exhaust (respectively about 20,650µg/km and about 110µg/km on urban cycles with cold and hot start).[62] A study from a Portuguese and Spanish university found even higher levels of xylene emissions on a Euro 5 PFI car on urban Artemis cycles: respectively about 145,000µg/km and 31,000µg/km with cold and hot engine starts. This study confirms the findings that xylene is the main BTEX component in petrol exhaust (about 50%).[63]

As regards newer Euro 6 vehicles, the same French public research institutes find that ethylbenzene is predominant (45-75%) for the diesel car on urban Artemis cycles: about 3,130µg/km and 215µg/km for cold and hot start respectively. Xylene remains the major compound measured for the GDI car on urban Artemis cycles (70%): 289µg/km and 12µg/km and about 2,340µg/km for cold and hot start respectively.[64] These results clearly underline the strong influence of cold start on BTEX emissions. Besides, with Euro 6 standard, diesel BTEX emissions seem to increase compared to the older Euro 5 model: twice more on hot urban Artemis cycle. For the GDI engine technology, emissions decreased by 8 times on hot urban cycle.

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[58] Stavros Amanatidis, Leonidas Ntziachristos, Barouch Giechaskiel, Alexander Bergmann and Zissis Samaras, Impact of selective catalytic reduction on exhaust particle formation over excess ammonia events, Environmental Science & Technology, Volume 48, Issue 19, October 7th 2014, pp. 11527-11534

[59] Queensland Government, Department of Environment and Science, Management and regulation, BTEX chemicals

[60] WHO, International Agency for Research on Cancer, Agents classified by the IARC monographs, Vol. 1-122, July 2018

[61] US EPA, Health effects notebook for hazardous air pollutants

[62] Cédric Louis, Yao Liu, Patrick Tassel, Pascal Perret, Agnès Chaumond and Michel André, PAH, BTEX, carbonyl compound, black-carbon, NO_2 and ultrafine particle dynamometer bench emissions for Euro 4 and Euro 5 diesel and gasoline passenger cars, Atmospheric Environment, Volume 141, September 2016, pp. 80-95

[63] Célia A. Alves, Diogo J. Lopes, Ana I. Calvo, Margarita Evtyugina, Sónia Richa and Teresa Nunes, Emissions from light-duty diesel and gasoline in-use vehicles measured on chassis dynamometer test cycles, Aerosol and Air Quality Research, Volume 15, Issue 1, February 2015, pp. 99-116

[64] Simon Martinet, Yao Liu, Cédric Louis, Patrick Tassel, Pascal Perret, Agnès Chaumond and Michel André, Euro 6 unregulated pollutant characterization and statistical analysis of after-treatment device and driving-condition impact on recent passenger-car emissions, Environmental Science & Technology, Volume 51, Issue 10, May 16th 2017, pp. 5847–5855

All in all, regarding Euro 5 cars, GDI engines tend to emit much more BTEX on urban cycles with a cold started engine but diesels emit more once the engine is warm. The only tested Euro 5 PFI car had very high emissions levels both with a cold and hot engine. For Euro 6 vehicles, the tested diesel car clearly emitted more than the petrol one, in both Artemis urban cycles with cold and warm started engines. The influence of cold start is worrying as this occurs mainly in urban areas, which already face air pollution issues.

Another emerging concern are **carbonyl compound** emissions, a family of chemical compounds composed of one or more carbon atom double-bonded to an oxygen atom. Among this group, **formaldehyde** is classified as carcinogenic by the WHO, while **acetaldehyde** is considered as possibly carcinogenic.[65] On the tested Euro 5 vehicles, formaldehyde and acetaldehyde represent the main components, or more than 75% of the total mass of carbonyl compounds, emitted by both diesel and petrol vehicles.[66] This trend is confirmed for the Euro 6 GDI car. For the Euro 6 diesel car **acetone** was mainly measured on urban phases (55-60%).[67] Diesel cars, either Euro 5 or 6, showed higher levels than petrol in general with, once again, a strong influence of cold start on the total emissions measured on urban Artemis cycles: 139-1,259µg/km for diesels with cold start, while petrols had a level of 21-80µg/km. Once the engine is warm, emissions go down to 78-464µg/km for diesels and 27-41µg/km for petrols.

A further area of concern are **polycyclic aromatic hydrocarbons**, or **PAH**s. These chemical compounds are released from various combustion processes, including internal combustion engine exhausts. According to the WHO, some PAHs are genotoxic, either acting as direct mutagens or carcinogens, or as precursors for carcinogens.[68] Since 2014, the EU Air Quality Directive limits the annual mean concentration in the ambient air of carcinogenic **benzo-alpha-pyrene** (an indicator for PAH) at a level of 1ng/m^3. Almost a quarter of the European citizens living in urban areas in 2015 was exposed to concentrations of benzo-alpha-pyrene higher than the yearly limit according to the European Environment Agency (EEA). 94% of the measurement stations reporting exceedances are in urban and suburban locations. Exceedance are mainly reported in Central and Eastern Europe with median values above the limit in Poland, Croatia, Bulgaria, Slovenia and Hungary. However, exceedances were also reported in large parts of Northern Italy and Southern Austria and in some few places in France, Germany, Spain and the UK.[69]

A recent Swiss study showed that showed that formation and emission levels of PAHs and PN are linked. The more PN a vehicle emits, the more PAH it will emit as well. Thus, it appears that PAH emissions are a bigger issue for GDI cars than diesels.[70] Three Euro 5 and two Euro 6 GDI cars were tested on WLTCs with a cold and hot started engine and compared to a Euro 5 diesel car. PAH emissions from GDIs reached a level of 108-490µg/km and 18-103µg/km on cold and hot WLTC test respectively, while the Euro 5 diesel car had emissions of 25µg/km and 6µg/km on cold and hot WLTC test respectively. Given the high genotoxicity of carcinogenic benzo-alpha-pyrene and the large proportions of **naphthalene** emissions (respectively 67% and 39% on cold and hot WLTC tests), the authors concluded that PAH emissions coming from GDI petrol

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[65] WHO, International Agency for Research on Cancer, Agents classified by the IARC monographs, Vol. 1-122, July 2018

[66] Cédric Louis, Yao Liu, Patrick Tassel, Pascal Perret, Agnès Chaumond and Michel André, PAH, BTEX, carbonyl compound, black-carbon, NO_2 and ultrafine particle dynamometer bench emissions for Euro 4 and Euro 5 diesel and gasoline passenger cars, Atmospheric Environment, Volume 141, September 2016, pp. 80-95

[67] Simon Martinet, Yao Liu, Cédric Louis, Patrick Tassel, Pascal Perret, Agnès Chaumond and Michel André, Euro 6 unregulated pollutant characterization and statistical analysis of after-treatment device and driving-condition impact on recent passenger-car emissions, Environmental Science & Technology, Volume 51, Issue 10, May 16th 2017, pp. 5847–5855

[68] Maria Muñoz, Regula Haag, Peter Honegger, Kerstin Zeyer, Joachim Mohn, Pierre Comte, Jan Czerwinski and Norbert V. Heeb, Co-formation and co-release of genotoxic PAHs, alkyl-PAHs and soot nanoparticles from gasoline direct injection vehicles, Atmospheric Environment, Volume 178, April 2018, pp. 242-254

[69] EEA, Air quality in Europe - 2017 report, EEA report n°13/2017, October 2017

[70] Maria Muñoz, Regula Haag, Peter Honegger, Kerstin Zeyer, Joachim Mohn, Pierre Comte, Jan Czerwinski and Norbert V. Heeb, Co-formation and co-release of genotoxic PAHs, alkyl-PAHs and soot nanoparticles from gasoline direct injection vehicles, Atmospheric Environment, Volume 178, April 2018, pp. 242-254

cars are comparable and as dangerous as diesel engines without a DPF, which exhaust gases are classified as carcinogenic by the WHO.[71]

The French public research institutes described earlier in this section also investigated PAH emissions from Euro 5 and 6 petrol and diesel cars.[72,73] While noting similar or lower levels of PAH emissions than the Swiss study, the authors confirmed that engine cold start on urban cycle resulted in highest PAH emissions, except for the Euro 6 diesel car which had higher emission values during the hot urban phase.

In a nutshell, these two studies underline once again the influence of cold start engines in the levels of PAH emissions, an additional unregulated pollutant that is released in already dirty urban air. Even if both diesel and GDI engines emit such pollutants, it appears that PAH are mainly an issue for petrol cars.

4.3. Takeaways of the emerging evidence

The introduction of particulate filters on diesel cars (DPF, since 2011 for all of them) allowed an important reduction of particle emissions, either in their mass or overall number. However, as DPFs need to be emptied on a regular basis, the use of active regeneration causes the emission of mostly smaller particles in size (below 30nm) but also of a different nature: black carbon rather than soot, organic compounds from the fuel used to heat up the exhaust, and sulphurated compounds as a consequence of this higher exhaust temperature.

More generally, the current EU regulations do not cover these smallest particles that have a diameter below 23nm and are particularly harmful to health as they can penetrate deep into human tissue. Several studies, including from JRC, showed that both diesel and petrol engines are concerned by this issue but at different scale. GDI engines emit the biggest amount of these nanoparticles, especially at cold temperatures below 0°C. The introduction of GPF in the new RDE regulation is expected to help reduce this problem, especially given the better filtration efficiency of gasoline particulate filters.[74] However, a proper fitting of this after-treatment device is needed in order to make sure that particle emissions are effectively reduced on the road under wide driving conditions. As regards the PFI petrol engines, these emit a sizeable proportion of sub-23nm particles, especially volatile ones. However, the RDE PN limit does not currently apply to these engines meaning there is no requirement to fit GPF that would reduce those nano emissions.

A growing number of studies look at other harmful unregulated pollutants that are released by all internal combustion engines, especially during cold start operation in urban areas where air pollution is already a huge problem. This section looks in particular at BTEX (benzene, toluene, ethylbenzene and xylenes), carbonyl compounds and PAH (polycyclic aromatic hydrocarbons). Even though the number of vehicles tested to date is rather limited, and more research is needed, clear trends are emerging. While PAH emissions, including carcinogenic benzo-alpha-pyrene, are more of a concern for GDI petrol cars, diesels emit larger quantities of carbonyl compounds, including carcinogenic formaldehyde. Regarding BTEX emissions that include carcinogenic benzene, it is a bigger problem for new Euro 6 diesel vehicles than for older Euro 5 cars, while PFI and GDI emit much more than diesel, especially when the engine is cold. Overall the levels for GDIs are lower than diesels when the engine is warm.

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[71] WHO, International Agency for Research on Cancer, Agents classified by the IARC monographs, Vol. 1-122, July 2018

[72] Cédric Louis, Yao Liu, Patrick Tassel, Pascal Perret, Agnès Chaumond and Michel André, PAH, BTEX, carbonyl compound, black-carbon, NO_2 and ultrafine particle dynamometer bench emissions for Euro 4 and Euro 5 diesel and gasoline passenger cars, Atmospheric Environment, Volume 141, September 2016, pp. 80-95

[73] Simon Martinet, Yao Liu, Cédric Louis, Patrick Tassel, Pascal Perret, Agnès Chaumond and Michel André, Euro 6 unregulated pollutant characterization and statistical analysis of after-treatment device and driving-condition impact on recent passenger-car emissions, Environmental Science & Technology, Volume 51, Issue 10, May 16th 2017, pp. 5847–5855

[74] AECC, Gasoline Particulate Filter (GPF), How can the GPF cut emissions of ultrafine particles from gasoline engines?, November 2017

In conclusion, it is clear that conventional engines due to the chemical and physical properties of combustion processes will never be truly clean as long as they are driven by petrol or diesel fuel. Despite the claims from the car industry that new laboratory and on-road tests have solved the problem, many harmful and carcinogenic but yet unregulated pollutants are emitted by both diesel and petrol cars, without any solution to tackle them. When tailpipe emissions are considered, only a shift to powertrains driven on electricity can be a true sustainable solution.

5. Conclusions and policy recommendations

On the third anniversary of the Dieselgate scandal, it is sobering that rather than a reduction in the number of dirty diesel cars and vans on the road this report shows their numbers are still rising. T&E estimate there are now 43 million grossly polluting diesel vehicles on the road (that emit at least 3 times more NOx on the road than allowed in EU standards). 3 years ago the figure was just 29 million. The problem is greatest in France with 8.7 million dirty diesels, with Germany, the UK and Italy close by, with 8.2 million, 7.3 million and 5.3 million respectively. But many of these cars are now being exported eastwards[75] and ultimately will head to Africa. If Europe does not act, these cars will continue to pollute the air for decades shortening lives.

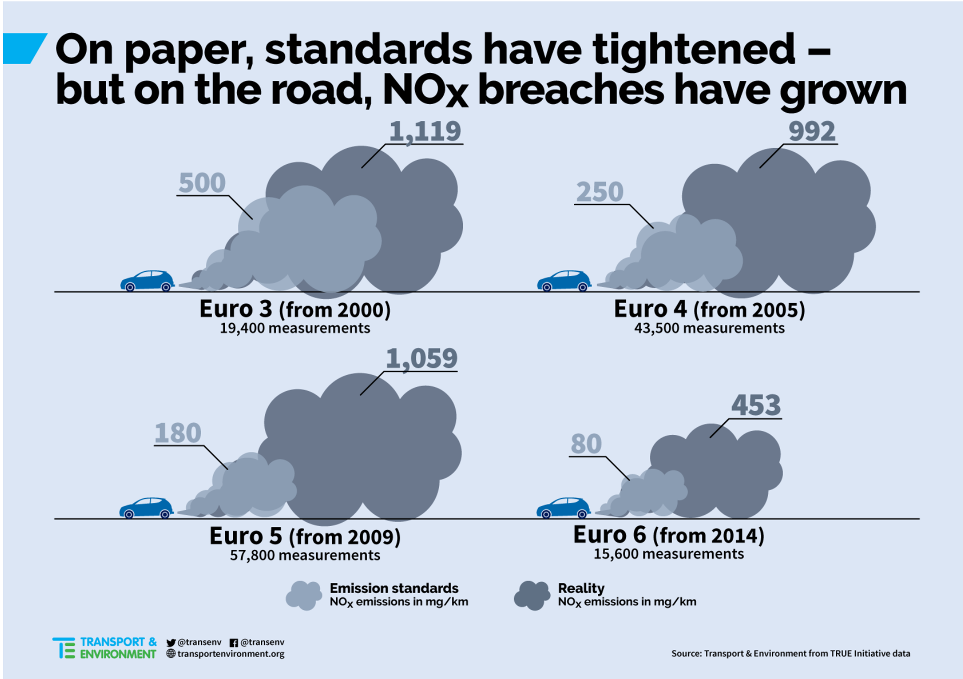

Figure 8 - Average real-world NOx emissions per Euro standard compared to the respective limits

This report shows that the failure of Euro 5 and 6 standards and regulations highlighted through the Dieselgate scandal in fact followed similar failures of earlier Euro standards. It is shameful there has been no meaningful real world reduction in NOx emissions from Euro 2 to 5 diesel cars (between 1996 and 2015). Whilst standards got stricter on paper, the scale of exceedances of limits increased sharply. Whilst a quarter of Euro 2 diesel cars complies with the NOx standard on the road, no car between Euro 3 and Euro 6 was found to meet the limits based upon remote sensing data. On average, Euro 3 diesel cars emit more than twice as much NOx as what their respective standard with the exceedance increasing to four times for Euro 4 cars, and is around six times for Euro 5 and Euro 6.

Remote sensing data also shows there are a small proportion of diesel vehicles within every Euro class have disproportionately high NOx emissions - e.g. almost 13 times the limit on average for some of the worst-performing Euro 6 cars. On average, the 10% of highest diesel emitters are responsible for almost 20% of the total NOx emissions by cars.

In contrast to car industry's claim that emission exceedances are a problem of the past and that the new RDE-compliant diesels and petrol cars are clean, the report presents new, alarming evidence, that shows cars continue to be optimised to perform well in the tests and emit far more when in the hands of customers. The road tests performed outside of the new RDE test boundary conditions show emissions substantially higher than within the agreed test conditions. Notably NOx emissions on a diesel Honda Civic were 9 times higher than when tested in a way consistent with the RDE test conditions. Particle number emissions from a Ford Fiesta were more than twice higher in the tested outside the RDE test conditions; and an Opel Adam produced alarmingly high carbon monoxide emissions.

[75] T&E, Dirty diesels heading East, April 2018

The results of the tests demonstrate even if a car achieves very low emissions during an RDE test when driven by a typical owner it may become a gross emitter. The passive driving and flat roads required for an RDE test to be compliant are unrealistic and carmakers are designing cars to pass the test and not to deliver low emissions of the road. There is a significant risk the Euro 6 standard and new RDE test will fail in the same way the NEDC test and Euro standards 2-5 did.

The remote sensing data also highlights that as the vehicles age the emissions increase significantly. This trend is particularly notable for petrol cars: compared to the average Euro 5 and 6 petrol cars, NOx emissions increase by more than 3 times for 12 year-old cars and more than 7 times for 15 year-old cars.

The focus of the Dieselgate scandal has been NOx emissions leading to high levels of toxic nitrogen dioxide. The Euro 6 limit has also regulated particle numbers, but there is emerging evidence that a range of unregulated pollutants are also creating a hazard to health. Notably, very small particles are not covered by the regulations and neither are hazardous materials including benzene, carbonyl compounds and Polycyclic Aromatic Hydrocarbons (PAH) including benzo-alpha-pyrene.

5.1. Seven steps to cleaner city air

There are seven key steps to fixing our toxic urban air by reducing vehicle emissions:

1. A comprehensive EU-wide programme is needed to clean up the 43 million of dirty diesel cars and vans on the road today. Progress to date is piecemeal and slow. The Volkswagen repair programme edges forward slowly, but most other carmakers appear to have made minimal progress through voluntary action. In Germany, German carmakers have committed to clean up their dirty diesel cars and pay into a fund to support cleaner air; but in the rest of the EU there is no such commitment or action. A consistent EU-wide approach is needed.

2. A mix of hardware and software solutions are needed to clean up the dirty diesels still on the road. The effectiveness of these fixes must be independently certified to ensure significant emission reductions are achieved in the real-world as claimed by carmakers. Consumers should be compensated for any reduction in fuel efficiency. Where fixes are not possible, not carried out by the manufacturers, or cars are not made available by customers these vehicles must be removed from circulation so they cannot be driven until repaired. The system of Periodic Technical Inspection must check upgrades have been implemented successfully and it should also be illegal to knowing sell or export a car that has not been properly upgraded.

3. Cities should be free to design their urban vehicle access restriction policies as they see fit the local circumstances, public health and environment. Yet the head of the car industry association said recently, "We seem to go back to the Middle Ages where the cities were defining how things needed to be done, undermining the single or internal market."[76] Cities are being demonised for trying to protect the health of citizens and ensure they meet legally binding ambient air pollution standards. The car industry opposes bans; they will not clean up the dirty cars on the road; and they will not contribute towards the costs of other measures to improve urban air quality. Bans of dirty diesels are one of the few solutions available to cities. However, this analysis has shown that there are high and low emitting models in every euro-class. Rather than arbitrarily banning specific euro-classes cities should make use of remote sensing data. Linked to a camera for number plate recognition it is possible to identify grossly polluting cars and to require these to be repaired, have the emissions controls upgraded, or banned from the city. In this way cities can target specific models and make the exclusions more effective and fairer.

[76] Reuters, EU carmakers offer conditional 20 percent CO_2 cut by 2030, 13/09/2017

4. Carmakers should contribute to a local Clean Air Fund to help cities across Europe meet the EU air quality standards. €10 for every new car sold would raise over €150 million per year. Such a sum of money would help cities invest in cleaner buses and taxi fleets, fund remote sensing equipment, and pay for recharging infrastructure for zero emission vehicles, bike sharing, or new shared, on-demand app-based mobility programmes to encourage car sharing. If the car industry will not undertake hardware upgrades on polluting models they should pay to clean up the air in other ways.

5. The current RDE regulation should be reformed to make its more representative of the way cars are really used and driven. At present the test boundary conditions are too restrictive and unrepresentative. The proportion of urban driving should be increased along with the vertical altitude gain. The temperature thresholds should be widened; the cars should be driven more dynamically and there should be no adjustment for driving dynamics except to include an appropriate minimum and maximum factor. The PN test should include all particles. The expectation should be for the emissions to be within legal limits for at least 225 thousand kilometres for a diesel - a typical lifetime use. In its current form the Euro 6 is no more likely to be effective than previous euro-standards.

6. Instead of relying on narrowly prescribed tests on pre-sale vehicles, compliance with EU emission standards should be based on vehicle performance over its lifetime. Notably, independent third parties should have clear powers to perform in-use compliance tests on vehicles on the road in line with the RDE regulation, and vehicle authorities obliged to act in case of emission exceedances. The EU system of periodic technical inspections should be strengthened to allow for effective controls over vehicles lifetime, including ensuring that ageing emission control systems on older vehicles continue to deliver emission reductions on the road as long as vehicles are in operation.

7. The currently biased Euro standards that allow diesel to emit more NOx emissions than petrol should be reformed. The EU should swiftly restore technology neutrality and agree the new Euro 7 emission standards to pave the way for a level playing field among all fuels. Euro 7 standards should ensure that by 2025 diesel cars emit equivalent levels of NOx to state-of-the-art petrol cars on the road; the levels should be set at a level that would enable the WHO air pollution guidelines to be met across cities throughout Europe.

5.2. Final remarks

Three years since the Dieselgate scandal erupted more new dirty diesel have driven onto the road than have been repaired. Carmakers have made minimal progress to clean up the millions of dirty cars on Europe's roads. Instead, the carmakers have poured money and resources into proving their technology is clean using new but still ineffective tests. This is a desperate attempt to protect the collapsing diesel market in Europe and maximise profits by selling old combustion technology.

This report has presented a range of evidence that shows not all new cars are clean even today. It also shows as the car ages the emissions will significantly worsen. Our toxic urban air will not be fixed in a decade's time as the oil industry claim.[77] Instead the problem will have persisted as real world emissions will continue to be too high because:

[77] FuelsEurope, Urban air quality and traffic emissions: how Euro 6d and emission control technology will address the problem, February 2018

1. Inadequate tests that mean real world emissions are much higher than those measured in tests in the lab or on the road;
2. Degradation of exhaust treatment systems on all models as they age;
3. Of high emissions from cars with faulty or tampered exhaust treatment systems;
4. A failure to clean up the 43 million dirty cars on the road from the Dieselgate legacy.

The physics and chemistry of fuel combustion and limitations imposed by the cost and size of exhaust treatment systems mean the internal combustion engined car will never be truly clean and so long as they burn fossil fuels they will never be carbon free. A shift to zero emission mobility would require transitioning to to zero emission vehicles and electromobility. Thanks to technological progress in the last years this is now technically possible and environmentally and economically desirable.

6. Annexes

Annex 1 – Methodology to estimate the number of dirty diesel vehicles on Europe's roads

Registration figures are taken from the databases published by the European Environment Agency (EEA) to monitor the CO_2 emissions from brand new cars and vans, since 2010 and 2012 respectively.[78] Besides, the former database published by European Commission's DG Clima is also used in order to cover car sales from 2008 and 2009 but only with figures at EU level.[79] Data from the ICCT's Pocketbook allow to determine what the annual distributions of vehicle sales between Euro 5 and 6 standards are, at the EU level but also at the scale of Member States.[80]

Regarding NOx emissions, T&E has been collecting test results from the national investigations that were on-going after the exposure of the Dieselgate scandal, including France, Germany, the Netherlands, Spain and the UK. T&E's database is regularly updated and also include public data from Emissions Analytics through its EQUA AQ Index[81] and reports from TNO,[82] a public Dutch research institute. All results from these sources consist of on-road Real Driving Emissions (RDE) tests with an on-board Portable Emissions Measurement System (PEMS), but also NEDC tests made on chassis dynamometer in a lab or outside on a road or a test track. Complementary information has been added thanks to the CONOX remote sensing database analysed by the TRUE Initiative,[83] which is explained in further detail in the section 2.2.

Results were grouped by type of vehicle (cars or vans), by Euro standard and by engine family, knowing that powertrains are shared within groups of car manufacturers, even sometimes between competitors. For instance, the 1.5-litre dCi diesel engine developed by Renault is used by the Renault-Nissan Alliance (including Dacia, Infiniti, Nissan and Renault), but also by Mercedes-Benz in its entry level models. To be considered as dirty, NOx emission results for an engine family should be at least 2 times above the Euro standard limit for NEDC tests and at least 3 times above the Euro standard limit for RDE tests and remote sensing measurements.

Only brand new vehicles are counted. It is assumed that the vehicles registered in one Member State stays in the same country and no deregistration has been taken into account.

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[78] EEA, Monitoring of CO_2 emissions from passenger cars & Monitoring of CO_2 emissions from vans, April-May 2018
[79] European Commission, DG CLIMA, Reducing CO_2 emissions from passenger cars, Monitoring of CO_2 emissions - Decision 1753/2000 (repealed), 2009: Excel summary tables
[80] ICCT, European vehicle market statistics 2017/2018, November 2017
[81] equaindex.com
[82] TNO, Traffic & Transport, Automotive research at TNO, Clean Mobility, Overview of reports measuring the emissions of passenger cars and vans
[83] TRUE Initiative, Determination of real-world emissions from passenger vehicles using remote sensing data, June 2018

Annex 2 – Methodology to model the contribution of high diesel outliers in total NOx emissions

The methodology used for this modelling exercise is summarised with the Figure 9 below and explained further into details below the graph.

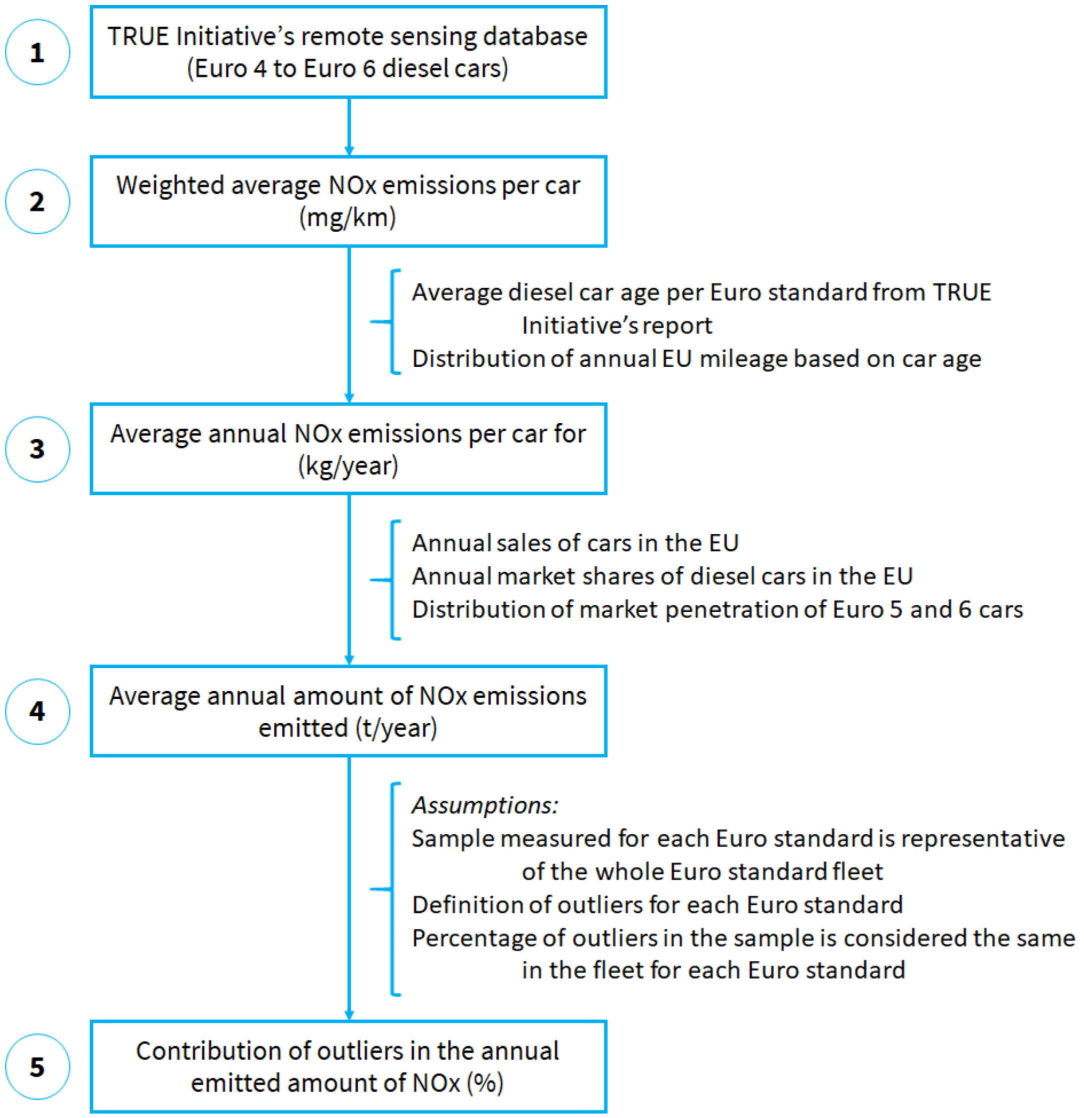

Figure 9 - Modelling and assumptions to estimate diesel outliers' contribution to annual NOx emissions from the EU diesel fleet

The results, based on the CONOX remote sensing data analysed by the TRUE Initiative, cover more than 100,000 measurements from diesel cars type approved under Euro 4 to Euro 6 standards using the NEDC laboratory test procedure. The sample of measurements covers a wide range of more than 250 diesel engine families sold by more than 20 groups of manufacturers. As specified in the TRUE Initiative's report, only engine families with more than 30 measurements were kept for the evaluation of emissions, to ensure consistency.[84]

A weighted average of NOx emissions per car (in mg/km) is calculated from the average values and the number of measurements per engine family for each Euro standard. The same calculation has been made

[84] TRUE Initiative, Determination of real-world emissions from passenger vehicles using remote sensing data, June 2018

with outliers. For each sample of measurements per Euro standard, high emitters are defined as being the 10% of cars with the highest NOx average emissions. However, as the number of measurements varies for each engine family, the definition of 10% was rather taken as a target.

Then, in order to convert the distance-specific figures per car (mg/km) into an annual amount of NOx emitted, information about mileage is needed. TRACCS, an EU project funded by DG Clima, gives the distribution of average annual EU mileage based on vehicle age and per car segment.[85] Statistics from ACEA about the mix of sales of new cars per segment were taken[86] but, in order to complete the picture, information regarding the average age is needed. The TRUE Initiative's report presents for each Euro standard the average age of the sample of cars per fuel type.[87] It was assumed that these average values are representative of the average age of the diesel car fleet.

In order to estimate the size of the fleet, statistics from the ICCT and the EEA are used to calculate the total number of diesel cars sold in the EU from 2001 to 2017.[88] The ICCT's Pocketbook also includes information about the market penetration in the EU of Euro 5 and 6 cars,[89] which have been used as a model for the market penetration of Euro 4 cars as well. The combination of these information allows the estimation of the distribution of annual diesel car sales per Euro standard. It has to be noted that no deregistration was assumed.

Finally, the diesel car fleet size per Euro standard calculated above is used in order to estimate the average annual amount of NOx emitted by the diesel fleet per Euro standard. It is assumed that the samples measured during the remote sensing campaign in several countries are representative of the EU fleet for each Euro standard. Besides, it is also assumed that the proportion of outliers determined in each sample is the same in the respective EU diesel fleets for each Euro standard.

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[85] TRACCS, Project overview
[86] ACEA, Statistics, Trends in new car registrations, Segments by body
[87] TRUE Initiative, Determination of real-world emissions from passenger vehicles using remote sensing data, June 2018
[88] ICCT, European vehicle market statistics, 2017/2018, November 2017 & EEA, Monitoring of CO_2 emissions from passenger cars, April 2018
[89] ICCT, European vehicle market statistics, 2017/2018, November 2017

Annex 3 - Technical specifications of the three tested cars

Model	Opel Adam I	Ford Fiesta VII	Honda Civic X
Car segment	A (Mini)	B (Small)	C (Lower medium)
Fuel type	Petrol with indirect injection (PFI)	Petrol with direct injection (GDI)	Diesel
Engine architecture	In-line 4 cylinder Naturally aspirated	In-line 3 cylinder Turbocharged	In-line 4 cylinder Turbocharged
Engine size	1398cm³	998cm³	1597cm³
Engine power	64kW	74kW	88kW
Transmission	Manual	Manual	Manual
Euro standard	Euro 6d-temp	Euro 6d-temp	Euro 6d-temp
After-treatment system	TWC	TWC + GPF	DOC + DPF + LNT
First date of registration	July 2018	July 2018	March 2018

Source: Adapted by Transport & Environment from Emisia

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As WLTP and RDE regulations apply for new models since September 2017 and all new cars sold since September this year, the tested cars were registered very recently. However, in line with the testing protocol defined with the French NGO France Nature Environnement, the carmaker PSA Group and the auditors Bureau Veritas, a minimum mileage of 1,000 km was ensured before starting the testing campaign.[90]

[90] T&E, The PSA Group, NGOs T&E and FNE, and Bureau Veritas publish the protocol for measuring real-world fuel consumption, October 2016

Annex 4 – Characteristics of the RDE routes

		Boundaries defined in the regulation	Route for RDE smooth and dynamic tests	Route for RDE extended test
Distance	Urban	>16km	27km	27km
Distance	Rural	>16km	27km	20km
Distance	Motorway	>16km	21km	17km
Trip composition	Urban	29%-44% of total distance	36%	43%
Trip composition	Rural	23%-43% of total distance	36%	31%
Trip composition	Motorway	23%-43% of total distance	28%	26%
Average speeds	Urban	15-40km/h	28km/h	17km/h
Average speeds	Rural	60-90km/h	75km/h	75km/h
Average speeds	Motorway	>90km/h	106km/h	123km/h
Payload	-	≤90% of maximum vehicle weight	Yes (Driver + PEMS)	Yes (Driver + PEMS)
Altitude	Moderate conditions	0-700m	7-122m	-
Altitude	Extended conditions	700-1,300m	-	35m-894m
Altitude difference	-	Altitude difference between start & finish ≤100m	54m	1m
Cumulative altitude gain	-	1,200m/100km	594m/100km	2,255m/100km
Ambient temperature	Moderate conditions	0-30°C	-	22-30°C
Ambient temperature	Extended conditions	-7°C to 0°C & 30°C to 35°C	25-32°C	-
Stop percentage	-	6%-30% of urban time	21%	3.5%
Maximum speed	-	145km/h (allowed up to 160km/h)	133km/h	150km/h

Source: Adapted by Transport & Environment from Emisia data and European regulations

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Annex 5 – Methodology to measure PN concentrations

A TSI P-Trak Ultrafine Particle Counter (UPC) 8525 was used to record Particulate Number (PN) readings of diesel vehicles from a 2 metre proximity at the side of the road. Only taxi vehicles were recorded as the best proxy for diesel vehicles, unless taxis are easily identifiable as hybrid cars. All samples were taken from the city airports to ensure a high concentration of taxi vehicles and to increase consistency between sample sites. The UPC measures PN with a diameter of less than 0.1µm (or 100nm) and records the PN concentrations per cubic centimetre (cm^3). PN concentration was taken at a rate of once every second. In order to achieve consistency between each sample, the particle reader was placed at the side of a road, approximately 1-3 metres from the passing vehicle at exhaust level (40 cm from ground). Sample sites at each airport were chosen on a selection of criteria, including the high frequency of taxi vehicles occupying a single lane and where the vehicles were accelerating. Vehicles in the Warsaw and Bucharest samples had significantly slower speeds and thus contribute to lower PN peaks.

Only individual vehicles that triggered a sharp increase of PN concentration of at least 20,000 particles/cm^3 above the average sample PN concentration were regarded as abnormally high emitting vehicles. Multiple vehicles, or traffic that caused a steady increase in PN concentration to 20,000 particles/cm^3 above the average were not scored as abnormally high emitting vehicles. Euro 5-6 vehicles were identified based on the model style.