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REASSESSMENT OF EXCESS NO_x FROM EUROPEAN DIESEL CARS FOLLOWING THE COURT OF JUSTICE OF THE EUROPEAN UNION RULINGS

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EXECUTIVE SUMMARY

Air pollution is the greatest environmental health danger in Europe. Diesel vehicles are a major contributor to poor air quality, largely due to high nitrogen oxides (NO_x) emissions. In Europe, 35,400 premature deaths were linked to on-road diesel vehicle emissions in 2015, or 14% of all air pollution-related premature deaths in the region.

The "Dieselgate" scandal in 2015 prompted government authorities and independent bodies to conduct extensive emissions testing of Euro 5 and Euro 6 diesel passenger cars, revealing that the issue of excess NO_x emissions was widespread across nearly all manufacturers. Vehicles showing compliant levels of NO_x during official laboratory testing had much higher emissions when operating on the road. Many manufacturers in Europe used calibration strategies that disabled or reduced the efficiency of emission control systems. These strategies were justified by manufacturers as being necessary to protect the engine, specifically to prevent clogging or slow its aging. Follow-up action by authorities was very limited, and many of these vehicles, now 5–13 years old, continue to operate today.

In December 2020, the Court of Justice of the European Union (CJEU) ruling in case C-693/18 clarified that under existing EU rules "only immediate risks of damage which create a specific hazard when the vehicle is driven… justify the use of a defeat device," and that clogging and aging prevention do not fall under this exemption. Additional CJEU rulings in July 2022 further clarified that defeat devices cannot be justified in any event if they operate throughout most of the year during normal driving conditions. Based on the proper interpretation set out by the CJEU, many emissions control calibration strategies implemented in diesel cars should now be considered defeat devices and prohibited under EU and UK laws, even for vehicles sold prior to the rulings.

The CJEU rulings provide a strong motivation for reinvestigating emissions control system calibrations and excess NO_x emissions of diesel cars. This report analyzes testing data and examines market surveillance interviews conducted by regulatory authorities to determine how many vehicle models likely have defeat devices under the CJEU definition. Results are analyzed by vehicle model and engine family against emission thresholds developed in this report which identify if a prohibited defeat device is likely or almost certainly present. These thresholds are based on expected engine behavior and testing data from other vehicle groups.

This analysis focuses on Euro 5 and Euro 6 diesel cars manufactured before the Real Driving Emissions (RDE) testing procedure was implemented beginning in 2017. Key findings of the analysis are:

"Suspicious" NO_x emission levels were found in 77%–100% of tests and vehicle averages, indicating the likely use of a prohibited defeat device. Figure ES-1 shows the summary of emission testing results reviewed in this study evaluated against the suspicious threshold defined by the ICCT. Of 1,400 total tests conducted under controlled settings by government authorities, 85% of tests on Euro 5 vehicles and 77% of tests on pre-RDE Euro 6 vehicles exceed the suspicious emissions threshold. Similar rates are observed for government tests conducted under real-world conditions. Results from independent real-world testing show that up to 100% of vehicle model averages exceed the suspicious threshold. Remote sensing data also show that up to 100% of engine family averages exceed the suspicious threshold.

"Extreme" NO_x emissions were found in 40%–75% of tests and vehicle averages, indicating that a prohibited defeat device is almost certainly present. The hatched section of Figure ES-1 shows emissions evaluated against the ICCT extreme threshold, set at three or four times the emissions limit for most tests in this analysis.

Approximately 42% of the 1,400 official government tests under controlled settings exceed the extreme threshold. Real-world testing by government authorities and independent bodies shows similar or higher rates of extreme emissions. Remote sensing data show that approximately 75% of engine family averages exceed the extreme threshold.

Over 200 unique vehicle models show high NO_x emissions above the "suspicious" threshold and over 150 unique vehicle models show NO_x emissions above the "extreme" threshold. As summarized in Figure ES-2, nearly all vehicle models tested by official government authorities show suspicious emissions in at least one test, and nearly 70% of vehicle models showed extreme emissions in at least one test. A large majority of vehicle models showed suspicious emissions in independent testing and remote sensing as well.

Strategies as described by manufacturers used in 66 unique vehicle models should now be considered prohibited defeat devices according to the latest CJEU rulings regarding the extremely limited circumstances in which the use of such defeat devices can be legally justified. Nearly 50 unique vehicle models alter emission control systems in low ambient temperatures, a strategy that was specifically ruled on in cases C-128/20, C-134/20, and C-145/20.

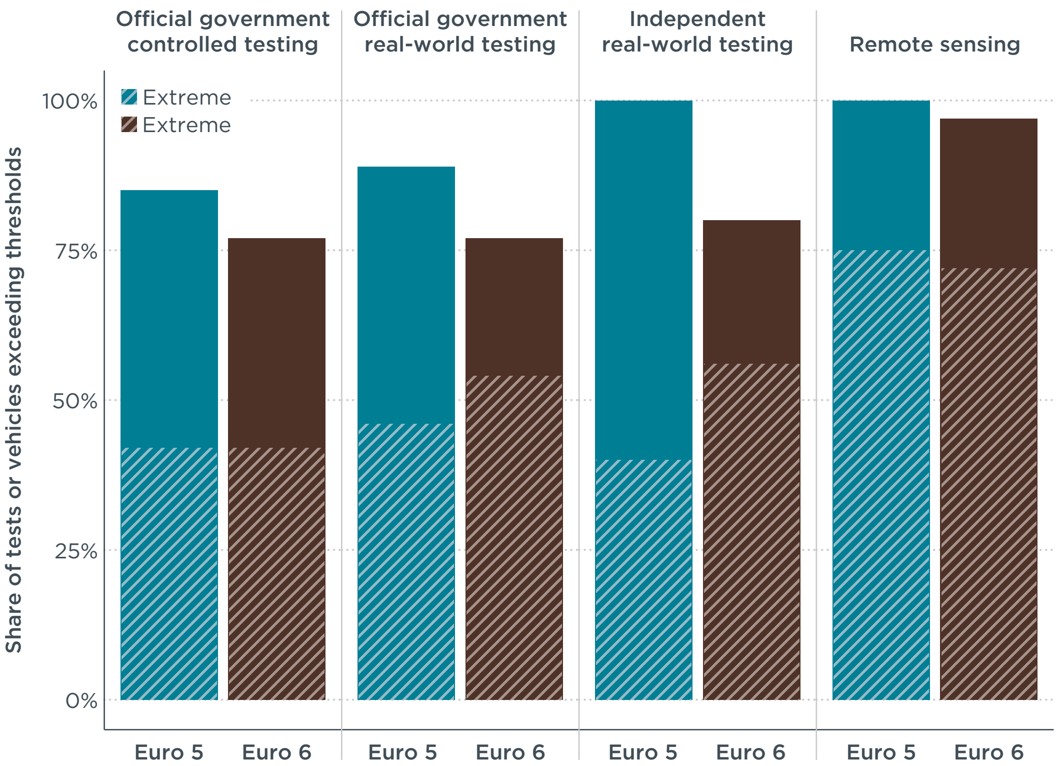
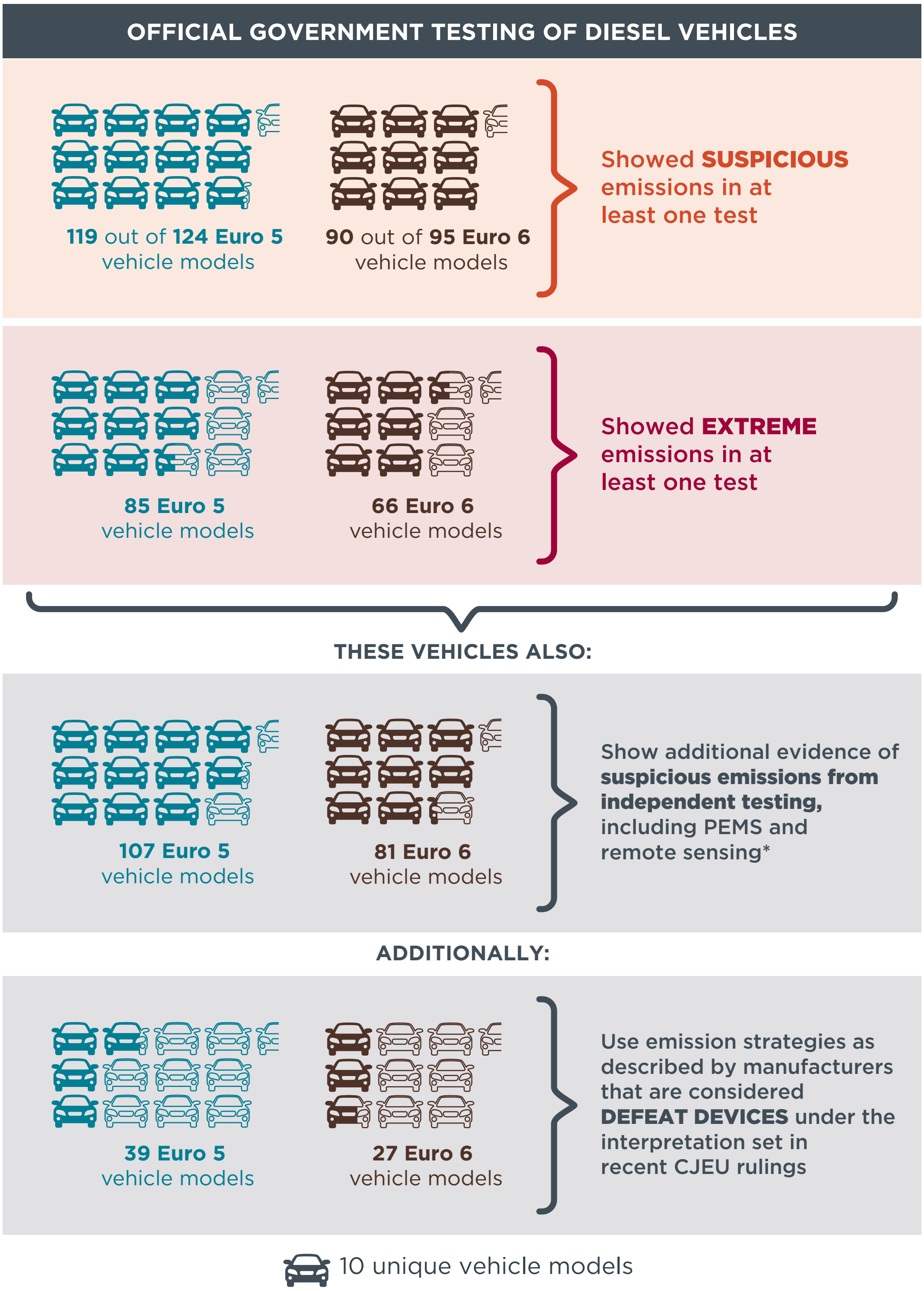


Figure ES-1. Share of Euro 5 and pre-RDE Euro 6 vehicle tests or vehicle model/engine family averages exceeding the "suspicious" threshold by data source. Due to the different formats of the various data sources, the official market surveillance summary shows the share of overall tests, the independent testing summary shows the share of vehicle model averages, and remote sensing summary shows the share of engine family averages exceeding the thresholds.



* Remote sensing results are grouped by engine family. This number includes all vehicle models for which their engine family average show suspicious emissions.

Figure ES-2. Summary of Euro 5 and pre-RDE Euro 6 diesel vehicle models showing suspicious and extreme emissions

Actions to address excess diesel NO_x emissions have been limited to date. Only some manufacturers have performed recalls and fixes, and the impact of these fixes is unclear as many vehicles have not been retested or the testing results have not been released publicly. Limited data that do exist indicate that updates were not successful in reducing emission levels below the regulatory limit.

With a clarified definition of defeat devices and the rules prohibiting their use from recent CJEU rulings, EU Member State and UK market surveillance authorities now have a clear basis on which to take action to address excess NO_x emissions. Evidence from this report suggests that such action would impact a large share of Euro 5 and pre-RDE Euro 6 diesel cars. Based on these findings, the following steps are recommended:

EU Member States and the United Kingdom should exercise their authority and take corrective action for vehicles with prohibited defeat devices. The CJEU has made it clear that the instances in which the use of defeat devices can be justified are extremely limited. This report identifies vehicles showing extremely high NO_x emissions that almost certainly employ defeat devices based on testing results and manufacturer statements. For these and other vehicles for which there is already sufficient evidence of use of prohibited defeat devices, EU Member States and the United Kingdom should require manufacturers to take immediate corrective action.

EU Member States and the United Kingdom should conduct additional market surveillance and perform more detailed investigations for vehicles with suspected defeat devices. In cases where official government testing, independent testing, or remote sensing data show suspicious emissions but lack conclusive evidence of a prohibited defeat device, market surveillance authorities should conduct follow-up investigations.

EU Member States and the United Kingdom should evaluate emissions performance after recalls and updates. Authorities should ensure that the updated vehicle model no longer contains prohibited defeat devices and emits less than the regulatory limits for all or nearly all remaining in-use vehicles. The testing should include real-world driving conditions and evaluate the durability of emission control systems over the vehicle's entire useful life. Emissions data and information on impacts to fuel economy and vehicle durability should be provided to the public in a timely manner. The extent of uptake of updates and fixes among vehicles still on the road should be closely monitored.

The European Commission and the United Kingdom should update the vehicle certification process to regulate real-world emissions more effectively. The RDE requirements have helped to lower real-world emissions but fail to include certain driving conditions, such as those beyond pre-defined positive elevation and dynamic criteria. Future vehicle certification should require testing over a wider range of real-world conditions. In-service conformity requirements, currently set at 5 years or 100,000 km (whichever comes first), should be updated to reflect typical vehicle lifetime.

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BACKGROUND

Emissions testing following the “Dieselgate” scandal in 2015 raised awareness of excess nitrogen oxides (NO_x) emissions from Euro 5 and Euro 6 diesel vehicles. Studies conducted by European Member States and independent organizations revealed that average on-road emissions were 4.1 times the emissions limit for Euro 5 diesel passenger cars and 4.5 times for Euro 6 (Baldino et al. 2017). An analysis of 700,000 remote sensing measurements collected across multiple European cities between 2011 and 2017 found that no Euro 5 and Euro 6 engine families had average emissions below the regulatory emission limits during real-world operation, and 55%–62% of engine families had average emissions over 5 times the limit (Bernard et al., 2018). These vehicles, now 5–13 years old, largely remain in operation across the EU today.

Diesel tailpipe NO_x emissions contribute significantly to poor air quality in many European cities. On-road diesel vehicles were linked to 35,400 premature deaths in Europe in 2015, accounting for 14% of all premature deaths related to air pollution (Anenberg et al. 2019). The air quality and health impacts of these vehicles extend beyond the EU. Between 2015 and 2020, nearly 5 million used light-duty vehicles were exported, primarily to low- and middle-income countries in Eastern Europe and West Africa (UN Environment Programme, 2020; UN Environment Programme, 2021).

In-use vehicle emissions testing in Europe to address excess NO_x has historically suffered from a lack of enforcement and independent testing (Mock & German, 2015). Compared to the United States, where the U.S. Environmental Protection Agency (EPA) carries out its own investigation, testing in Europe has largely been carried out by manufacturers, or technical companies hired by them, on their own selection of vehicles under narrow, less demanding conditions. Additionally, while similar legal exemptions for calibration changes existed in both the U.S. and the EU, only U.S. authorities have published definitions and guidance on the bounds of these exemptions. Extensive documentation clearly delineating prohibited defeat devices versus exempt calibration changes allowed for effective enforcement in the United States. (Muncrief, German, & Schultz, 2016). Due to a lack of corresponding guidance in Europe, manufacturer claims that exemptions should apply due to risk of engine or aftertreatment damage went largely unchallenged by market surveillance authorities in Europe.

Recent rulings from the Court of Justice of the European Union (CJEU) have changed the landscape for defeat device enforcement in Europe, including for all Euro 5 and Euro 6 vehicles previously type-approved under (EC) No 715/2007 regulation. In case C-693/18 from December 2020, the court clarified that the scope of the definition of defeat devices prohibited under EU law should be interpreted widely. The court stressed that there are extremely limited legal exemptions allowing for the use of auxiliary emissions strategies (AES), which are changes to the emission control strategies that are activated under certain operating conditions. In particular, the court stipulated that protecting engines from aging or clogging cannot be a valid justification for the use of a defeat device; only the need to prevent an immediate risk of damage which creates a specific hazard can justify the presence of a defeat device under the legal exemption.

Three additional rulings in cases C-128/20, C-134/20, and C-145/20 released in July 2022 further clarified that the immediate risk exemption can only be employed in limited circumstances where no other technical solutions are possible. The court also clarified that a defeat device that operates for most of the year under normal driving conditions is not permissible. In particular, the cases considered the legality of the use of a ‘thermal window’ strategy which alters or shuts off emission control systems outside of a 15°C–33°C window. The court concluded that such strategies constitute prohibited defeat devices as they operate at temperatures that are typical within the EU. As highlighted in the manufacturer statements section of this report, numerous manufacturers have explicitly acknowledged the use of equivalent thermal window strategies in a range of vehicle models. There is also substantial evidence of excess emissions under what would be classified as normal driving conditions. Under Articles 51 and 52 of Regulation (EU) 2018/858, EU Member States have the responsibility to investigate cases of potential defeat devices and to require manufacturers to take corrective action if a prohibited defeat device is found. Thus, vehicles employing strategies that should be considered illegal when applying the interpretation set out by the CJEU should be subject to investigation and corrective actions if appropriate.

It is important to identify cases where prohibited defeat devices have been implemented and take proper corrective action to reduce air pollution European cities and to avoid exporting high-emitting vehicles to other countries. Additionally, while updated type-approval testing requirements have helped to reduce the use of defeat devices in newly certified vehicles, further updates to vehicle certification and market surveillance processes can help limit issues of defeat devices and excess NO_x emissions from vehicles in the future.

This report aims to illustrate the extent to which diesel cars in Europe have been using what may now be classified as prohibited defeat devices based on the recent CJEU rulings. There is a large body of evidence showing widespread excess NO_x emissions among diesel vehicles, particularly for Euro 5 and Euro 6 diesel vehicles certified before the Real Driving Emissions (RDE) regulation was introduced (Franco et al., 2014; Ntziachristos et al., 2016). Thus, Euro 5 and pre-RDE Euro 6 diesel vehicles, which represent approximately 53 million vehicles sold in Europe from 2009 to 2019 (Díaz et al., 2020), are the subject of this analysis. This report compiles data from various sources, including official government testing by EU Member States and the UK, testing by independent organizations, and the ICCT remote sensing database. Test types include laboratory, test track, and real-world driving conditions.

The emissions testing data are analyzed against a threshold to identify which vehicle models show evidence of potential defeat devices. For this analysis, we develop recommended thresholds to identify potential defeat devices. Current thresholds recommended by the Joint Research Centre (JRC), the European Commission's science and knowledge service, were examined and modified in cases where evidence supports more stringent thresholds. These thresholds are used to identify when a defeat device is likely present and when a defeat device is almost certainly present.

Additionally, we examine manufacturer comments in official government reports to identify cases where manufacturers explicitly admitted to using strategies that should be considered prohibited defeat devices based on the definition from the CJEU rulings.

Finally, this report discusses responses to excess vehicle emissions to date and proposes recommendations for corrective action. The recommendations are primarily aimed at market surveillance authorities, who have the authority and obligation to ensure that manufacturers take appropriate corrective action when a prohibited defeat device is found. Additionally, we recommend improvements to the type-approval and market surveillance processes, impacting new vehicles and helping reduce excess emissions over their entire lifetime.

DEFINING DEFEAT DEVICES

The concept of a defeat device is defined in Article 3 (10) of Regulation (EC) 715/2007 as the deactivation of emission control systems or alteration leading to reduced effectiveness based on parameters such as temperature, vehicle speed, or transmission gear. The illegal software Volkswagen installed in EA189 diesel engines altered the emission control systems by detecting when the vehicle was undergoing testing based on the position of the steering wheel, vehicle speed, duration of engine operation, and barometric pressure (U.S. Environmental Protection Agency, 2015). While no other manufacturer has been definitively found to use a similar defeat device to date, there is substantial evidence of excess NO_x emissions from vehicles across manufacturers, suggesting that Volkswagen was not the only manufacturer to implement defeat devices.

In order to obtain type-approval allowing vehicles to be put on the market, manufacturers must submit their vehicles to type approval authorities for testing. The type-approval testing conditions for pre-RDE vehicles include a limited ambient temperature range and pre-defined drive cycles that account for a very small portion of real-world driving conditions. Therefore, the emissions performance during testing is often not reflective of performance during on-road operation.

Defeat devices detect when type-approval conditions are not met and modify the emissions control calibration, leading to excess emissions. The use of defeat devices can lower manufacturing costs, reduce development hurdles, and improve vehicle performance such as fuel efficiency during real-world driving (Epstein, 2017). Defeat devices are often calibrated using hysteresis effects where emissions depend on driving history. Figure 1 diagrams a hysteresis effect, where emissions increase outside the type-approval conditions but then stay high, even when type-approval conditions are met again (Bernard et al. 2019). Observations of this pattern are an indication of a defeat device.

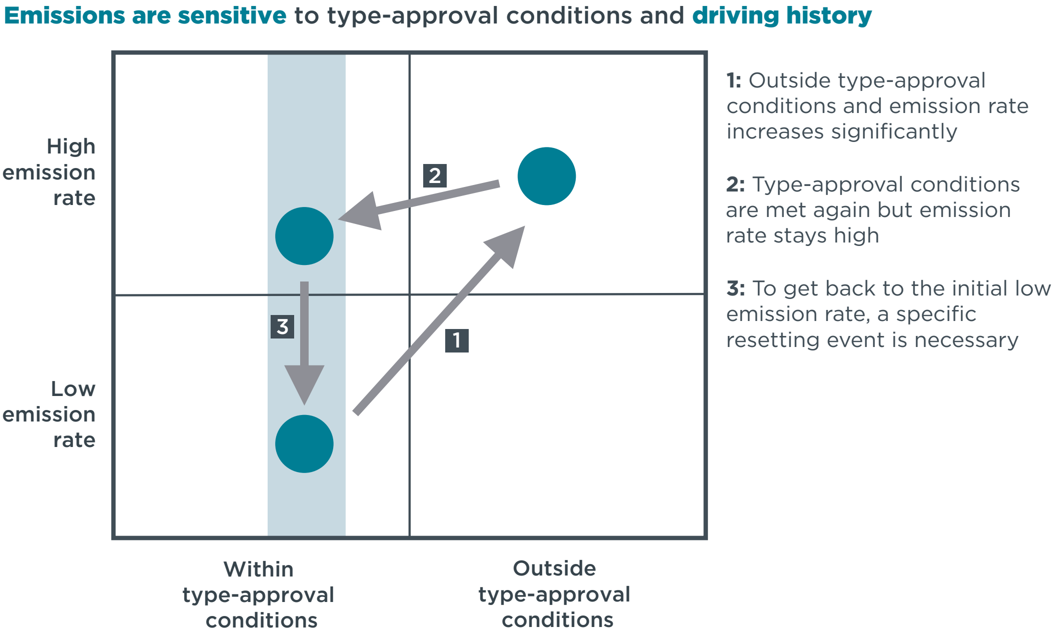


Figure 1. Example of hysteresis effect leading to sustained excess emissions.

One common example of a change in emissions control strategy is the reduction of the exhaust gas recirculation (EGR) rate (Muncrief, German, & Schultz, 2016). The EGR reduces engine-out NO_x emissions and its rate may be decreased once it is detected that the ambient temperature is outside of the bounds of type-approval requirements.

Other parameters potentially monitored by a defeat device include engine speed, engine torque, vehicle speed, timers, altitude, and engine temperature.

Evaluation of the presence of defeat devices can be difficult because these devices are embedded in sophisticated, extensive computer code. Performing a variety of tests, both in a laboratory and on the road, can help screen for vehicles showing suspicious emissions behavior under various conditions. Table 1 lists examples of tests that can provide evidence for identifying potential defeat devices. These tests have been conducted by market surveillance authorities, with the intention that vehicles showing large emission increases compared to their type-approval value will be flagged for further investigation. In practice, many vehicles showed high emissions increases during surveillance testing, yet market surveillance authorities pursued follow-up action for a much smaller number of vehicles.

Table 1. Type of defeat devices that may be indicated by excess emissions in various surveillance test types for Euro 5 and pre-RDE Euro 6 vehicles

Parameter	Type of defeat device	Example of tests to detect possible defeat devices
Ambient temperature	EGR modulation based on temperature window	Test at 10°C ambient temperature
Engine temperature	EGR modulation based on temperature window, Selective Catalytic Reduction (SCR) fails to activate	Hot start tests
Time or distance traveled	EGR modulation based on time or distance window	RDE tests
Engine speed, vehicle speed, or engine torque	EGR modulation based on speed/engine load window	Tests with slightly increased speeds

When interviewed about the excess emissions among Euro 5 and pre-RDE Euro 6 diesel vehicles, many manufacturers cited damage to the engine or emissions control system as justification for changing the emissions control system operation (Ministre de l'Environnement, de l'Energie et de la Mer, 2016; RDW, 2017). Most of these explanations pointed to aging and clogging of the engine or other issues that do not cause immediate, hazardous damage. These justifications do not fall within the narrow legal exemptions clarified in the recent CJEU rulings and therefore the strategies should be considered prohibited defeat devices under the interpretation set out by the CJEU. Additionally, most surveillance tests conducted fall under normal operating conditions, so indications that an AES is activated in these conditions suggests use of a defeat device.

ESTABLISHING EMISSION THRESHOLDS

Emission thresholds are an important part of the process of identifying vehicles with potential defeat devices. Based on the guidance from the European Commission, testing results exceeding the established threshold are categorized as a "suspicious case" and the vehicle typically undergoes a follow-up investigation process (European Commission, 2017). The current thresholds, developed by JRC, are set in the format of emission ratios, which are developed based on acceptable emissions increases given the testing conditions. Updated thresholds were proposed by JRC in 2021 but have not yet been adopted as official recommendations (JRC, 2021b). In this section, we review the current and proposed JRC thresholds, then recommend modified thresholds which are used in this analysis.

JOINT RESEARCH CENTRE GUIDANCE ON EMISSION THRESHOLDS

In JRC's 2017 guidance, thresholds for identifying potential defeat devices are calculated by comparing the ratio of the emissions test result to the type-approval values, which are based on lab test results of the standard New European Driving Cycle (NEDC) or Worldwide Harmonized Light Vehicles Test Procedure (WLTP) for pre-RDE Euro 6 vehicles (Commission Regulation (EU) 2017/1151, 2017).[1] Thresholds are defined for four different testing categories based on the test conditions, with lower thresholds for controlled tests resembling NEDC or WLTP and higher thresholds for more demanding or uncontrolled tests. These categories are:

» **Category 1**: Laboratory testing with similar conditions as official type-approval testing, with only small modifications such as a rolled-down window or activated 4-wheel drive. Emissions are not expected to exceed type-approval values.

» **Category 2**: Laboratory or on-road testing with conditions that differ from official type-approval testing, such as testing in a lower ambient temperature or increasing the speeds in the test cycle. Minor or temporary increases in emissions compared to type-approval values may be expected.

» **Category 3**: On-road testing with uncontrolled conditions that may significantly differ from official type-approval testing. Increases in emissions compared to type-approval values are to be expected. Tests in these categories are typically compared to the emissions limit established by Euro standard regulations instead of the type-approval value. This is based on the expectation that emissions will likely exceed laboratory testing values but should not exceed the emissions limit.

» **Category 4**: Surprise testing, such as roadside vehicle emissions remote sensing. There is no official market surveillance methodology that describes how to use the data, but third parties have shown that remote sensing can provide useful information on emissions during on-road operations when vehicles cannot detect that testing is occurring.

The JRC's proposed category definitions and the corresponding emission thresholds would impact market surveillance of RDE-compliant vehicles (JRC, 2021b). Under current guidance, the emission ratios (ERs) are calculated using official type-approval test values as a baseline. In the JRC's proposed updated thresholds, the ratio is calculated based on the Euro standard emissions limit instead of the official type-approval test values. Type-approval values are always lower than the emissions limit, so this change would reduce the stringency of the regulation, as illustrated in Figure 2.

1 In some cases, the ratio to emissions limits is used when type-approval values are not available. In this report, emission ratios (ERs) refer to the ratio to type-approval values.

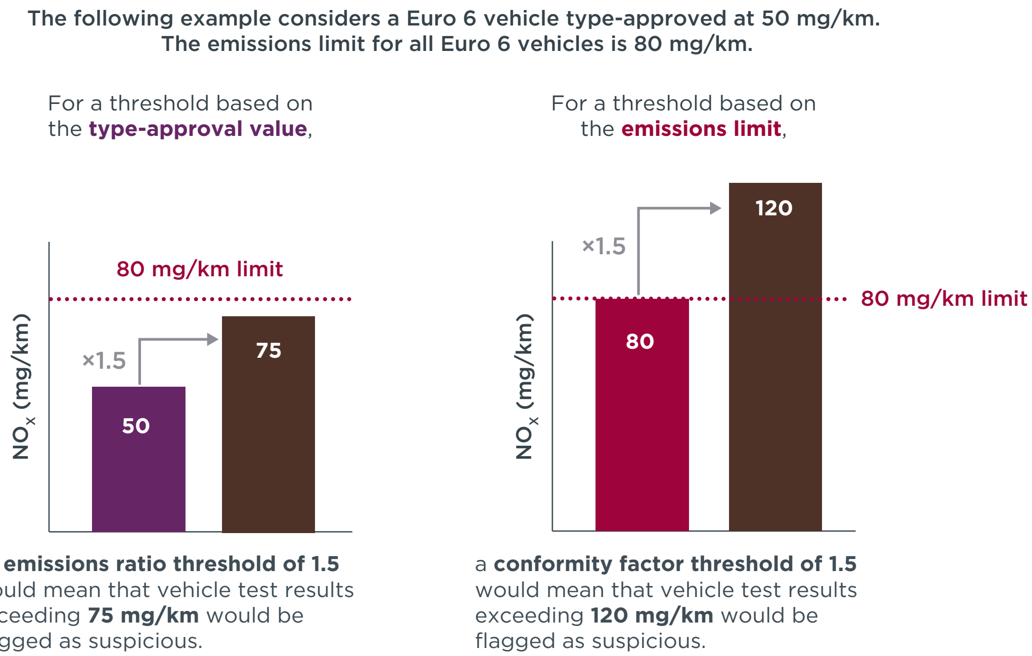


Figure 2. Comparison of thresholds determined by ratio to type-approval value versus emissions limit

Another component of the 2021 JRC proposal is the definition of four categories of emission exceedances: low priority, medium priority, high priority, and fail. Emission thresholds are used for preliminary screening tests and all indications of possible defeat devices should be investigated further. Categorizing vehicles as low and medium priority implies that not all vehicles showing suspicious emissions will be investigated.

Finally, in the JRC proposal, several categories of testing use a relative analysis method. This method compares emission testing results to other vehicles of the same fuel type, emissions standard, and other criteria, and only outliers are flagged. This method may result in false passes; as demonstrated in this analysis, some vehicle groups, such as Euro 5 diesels and Euro 6 diesels, have excess emissions across almost all vehicle models and manufacturers. Vehicles should be evaluated against a common threshold to identify all vehicles that may be equipped with defeat devices, not just the worst offenders.

The development of the ICCT recommended thresholds relies on the framework established in the 2017 guidance and does not adopt the three main changes proposed by JRC in 2021. Emission ratios are calculated against the type-approval values, only two thresholds are defined, and both should result in follow-up investigation. All vehicles are analyzed against these thresholds, as opposed to using the relative analysis method.

ICCT RECOMMENDED EMISSION THRESHOLDS

This section provides an overview of the ICCT recommended thresholds, which are based on the expected physical responses of the engine and emissions control system and their impact on potential emission increases. We define two categories: one threshold for high emissions indicating the likely application of a defeat device and warranting follow-up testing (suspicious threshold), and one threshold for extreme emissions that are so high that a defeat device is almost certainly present (extreme threshold). The complete methodology for developing the thresholds is in Appendix A.

The ICCT suspicious thresholds for most test types in this analysis are developed using the ratio to the type-approval test values, not the emissions limit.[2] Only results from testing in uncontrolled conditions (Categories 3 and 4) are evaluated against the ratio to the emissions limit, referred to as conformity factors (CFs) in this analysis.

Figure 3 shows the ICCT suspicious thresholds for Category 1 tests, which remains the same as the current JRC threshold from the 2017 guidance. The proposed JRC thresholds, which are based on the emissions limit instead of the type-approval value, are significantly higher than both the current JRC threshold and the ICCT suspicious threshold, based on the case of a vehicle with a type-approved value of 50 mg/km for NO_x emissions. The ICCT extreme threshold is the same as JRC's proposed fail threshold.

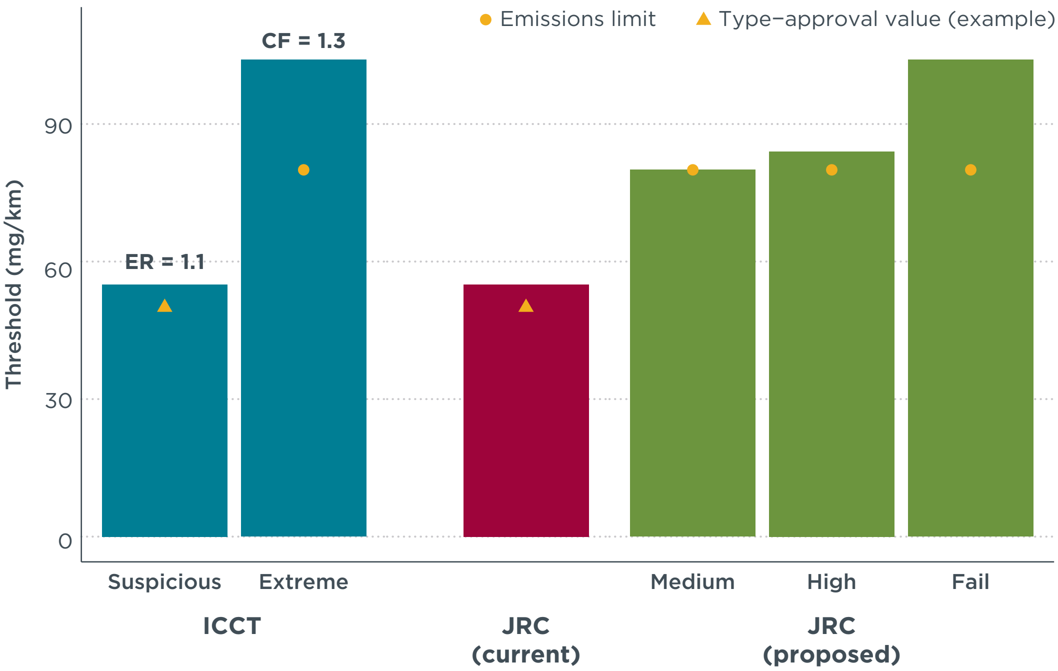


Figure 3. ICCT recommended thresholds compared to existing and proposed thresholds for Category 1 tests, using an example of a Euro 6 vehicle type-approved at 50 mg NO_x/km.

For most tests under Category 2, the ICCT suspicious thresholds remain the same as the current JRC thresholds. However, in select cases, the current JRC threshold was found to be too lenient for select test types for which lower emissions are expected. To define different thresholds, Category 2 is split into Categories 2a, 2b, and 2c (Figure 4). Category 2a remains similar to JRC's current and proposed Category 2, with test conditions modified such that minor or temporary emission increases may be expected. Category 2b test conditions should not change the physical response of the engine and emission control system, such as revising the order of the test phases or reducing the engine load. Finally, Category 2c tests are hot start tests, which are expected to result in lower emissions due to the EGR and aftertreatment systems being warm and fully functional from the start of the test (German, 2016). The full definitions of each category are in Appendix B and the list of specific tests of each category are in Appendix C.

2 Emissions ratios to the type-approval values are preferred, but the suspicious thresholds for Category 1 and Categories 2a, 2b, and 2c tests are also developed for the ratio to the emissions limit. This threshold is used in the analysis of reports where vehicles' official type-approval value were not provided.

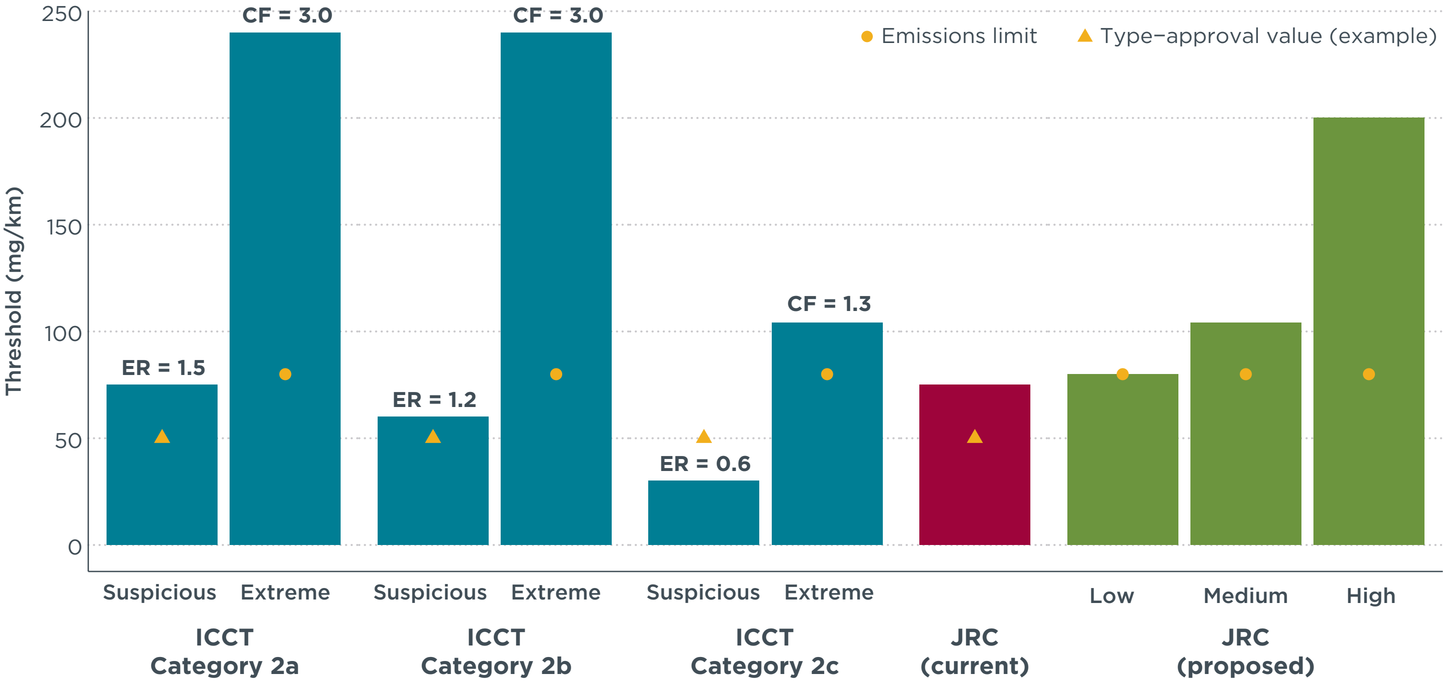


Figure 4. ICCT recommended thresholds compared to existing and proposed thresholds for Category 2 tests, using an example of a Euro 6 vehicle type-approved at 50 mg NO_x/km.

ICCT recommended thresholds for Categories 3 and 4 are developed based on a combination of remote sensing data and data from an ICCT database of Member State on-road tests. Petrol vehicle on-road emissions data from both sources are used to develop the ICCT thresholds for diesel vehicles, as they provide a reference for expected average emission increases for a fleet with high rates of compliance. Figure 5 shows the suspicious and extreme thresholds for Category 3 tests. The current JRC thresholds are defined as a range from 2.0 to 5.0 and in application have been applied to the minimum and maximum based on the moving average window method, which is not used for the analysis (JRC, 2017). The recommended thresholds for Category 4, which are not included in JRC's current guidance, are the same as the recommended Category 3 thresholds.

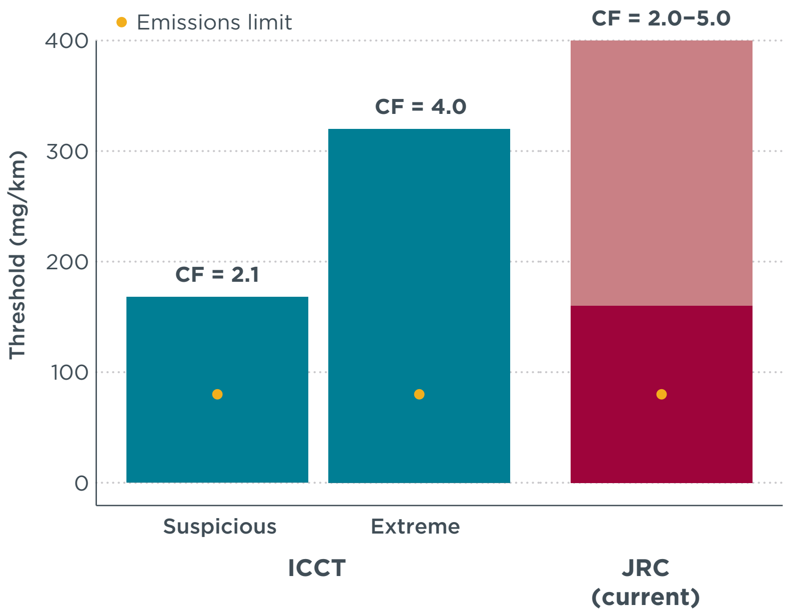


Figure 5. ICCT recommended thresholds for Categories 3 and 4 compared to the existing Category 3 threshold. The 2021 proposed JRC threshold is based on a relative analysis and therefore is not shown as it is defined based on results from other vehicles.

DATA SUMMARY

OFFICIAL GOVERNMENT TESTING

This report analyzes Euro 5 and pre-RDE Euro 6 diesel vehicle testing results from official government reports released to the public from EU member states, the UK, and JRC. (Table 2). Most of the vehicle tests were performed in 2016 and 2017 as part of initial investigations of excess NO_x emissions in Euro 5 and pre-RDE Euro 6 diesel vehicles. Some reports focused on follow-up testing for select vehicles showing the highest emissions.

Table 2. Summary of official government reports included in analysis

Report	Number of vehicles tested	Test categories					Citation
		1	2a	2b	2c	3	
Belgium	38		✓				Ministre wallon de l'Environnement. (2016)
France	86	✓	✓				Ministre de l'Environnement, de l'Energie et de la Mer (2016)
France	10	✓	✓				IFPEN (2017)
Germany	53		✓		✓	✓	Bundesministerium für Verkehr und digitale Infrastruktur (2016)
Italy	17		✓	✓	✓		Ministero delle infrastrutture e die trasporti (2016)
Joint Research Centre	3	✓	✓		✓	✓	Joint Research Centre (2016)
Joint Research Centre	6	✓	✓	✓	✓	✓	Martini et al. (2018)
Joint Research Centre	2	✓					Clairotte et al. (2020)
Netherlands	30		✓			✓	RDW (2016)
Netherlands	16		✓	✓	✓	✓	RDW (2017)
United Kingdom	37		✓		✓	✓	Department for Transport (2016)
United Kingdom	10	✓	✓		✓	✓	Department for Transport (2018)
United Kingdom	13	✓	✓		✓	✓	Department for Transport (2019)

In many cases, individual vehicles were subjected to multiple tests and some vehicle models were tested by multiple jurisdictions. Table 3 summarizes the number of individual vehicles tested, total number of tests, and unique vehicle models compiled from official government reports. Unique vehicle models are defined by the brand, name, engine displacement, and emission standard (ex. Ford Focus 1.6L Euro 5), plus engine power when specified (ex. Renault Captur 110ch 1.5L Euro 6). Three vehicles were tested after recalls and are classified as different vehicle models from the pre-recall vehicles.

Table 3. Combined total number of emission tests, number of vehicles tested, and number of vehicle models across all official government reports

Vehicle category	Number of emission tests	Number of vehicles tested	Number of unique vehicle models
Euro 5	824	186	124
Euro 6	735	135	95

INDEPENDENT REAL-WORLD TESTING

Following Dieselgate, a number of independent organizations measured vehicle emissions from a variety of manufacturers and publicly released the results. These emissions tests used portable emissions measurement systems (PEMS), which directly measure the vehicles' tailpipe exhaust. These tests fall under Category 3 of on-road testing and only differ in that the tests are not mandated by official government authorities.

This report analyzes average emissions data by vehicle from four different independent bodies— Netherlands Organisation for Applied Scientific Research (TNO), Deutsche Umwelthilfe (DUH), the Zweites Deutsches Fernsehen (ZDF) German TV channel, and the German Auto Motor Sport—evaluating the results against the recommended thresholds (Baldino et al., 2017; Auto Motor und Sport, 2017). In total, five Euro 5 and 104 Euro 6 vehicles were tested by these independent organizations.

REMOTE SENSING

Roadside vehicle emissions remote sensing is a measurement technique used to unobtrusively detect the emissions of in-use vehicles. Limited data is collected from each vehicle, as only one measurement is taken for each vehicle that drives by the remote sensing equipment. However, emissions from thousands of vehicles can be measured in a single day and the aggregated results provide information on the exhaust emissions over a range of operating conditions and over time. Remote sensing testing is part of Category 4, as defined by JRC.

This report analyzes data from ICCT's remote sensing database, which contains measurements for many of the vehicles tested by Member States. The initial database was built upon the CONOX remote sensing database and data from individual remote sensing campaigns performed in France, Spain, Sweden, Switzerland, and the United Kingdom between 2011 and 2017 (Bernard et al., 2018). The CONOX database of more than 700,000 measurements was updated with additional measurements from TRUE remote sensing campaigns in London and Paris. This includes 100,000 measurements in London in the winter of 2017/2018 and 180,000 measurements at three locations in Paris in the summer of 2018 (Bernard 2019). This set of almost 1 million measurements is grouped and analyzed by engine family for this analysis.[3] To limit the effect of the deterioration of emission control systems due to aging, this analysis only uses remote sensing measurements from vehicles not older than 5 years at the time of measurement. Average values per engine family are reported for those with at least 30 measurements.[4] In total, 55 Euro 5 and 39 pre-RDE Euro 6 engine families meet these requirements and are included in the analysis.

MANUFACTURER COMMENTS FROM MARKET SURVEILLANCE REPORTS

For five market surveillance reports, the authorities interviewed manufacturers for explanations on vehicles showing excess emissions.[5] In the five reports, 41 of the 66 Euro 5 and 40 of the 79 pre-RDE Euro 6 vehicle models tested were flagged by authorities as requiring follow up with manufacturers. We examine these manufacturer statements in the context of the recent CJEU rulings.

3 Engine families consist of vehicles sharing the same manufacturer group, emission standard, fuel type, and engine displacement. This method increases fleetwide coverage by grouping similar vehicles while continuing to separate vehicles by factors that can have a significant impact on emissions (Bernard et al., 2018).

4 This minimum of 30 measurements is based on an ICCT analysis which found that remote sensing estimates with at least 30 samples agree well with actual NO_x emissions from vehicles. (Bernard, Dornoff, & Carslaw, 2022)

5 These reports include the following: Bundesministerium für Verkehr und digitale Infrastruktur (2016), Department for Transport (2018), Department for Transport (2019), Ministre de l'Environnement, de l'Energie et de la Mer (2016), RDW (2017).

RESULTS

OFFICIAL GOVERNMENT EMISSIONS TESTING RESULTS

Across the 13 reports from EU Member States and the UK shown in Table 2, 1,559 tests were conducted on Euro 5 and pre-RDE Euro 6 diesel vehicles. A majority of tests showed NO_x emissions at a level indicating the likely application of a defeat device. Figure 6 shows the percentage of tests exceeding the ICCT suspicious and extreme thresholds by category. This section reviews the excess emissions across manufacturers, vehicle models, and test types.

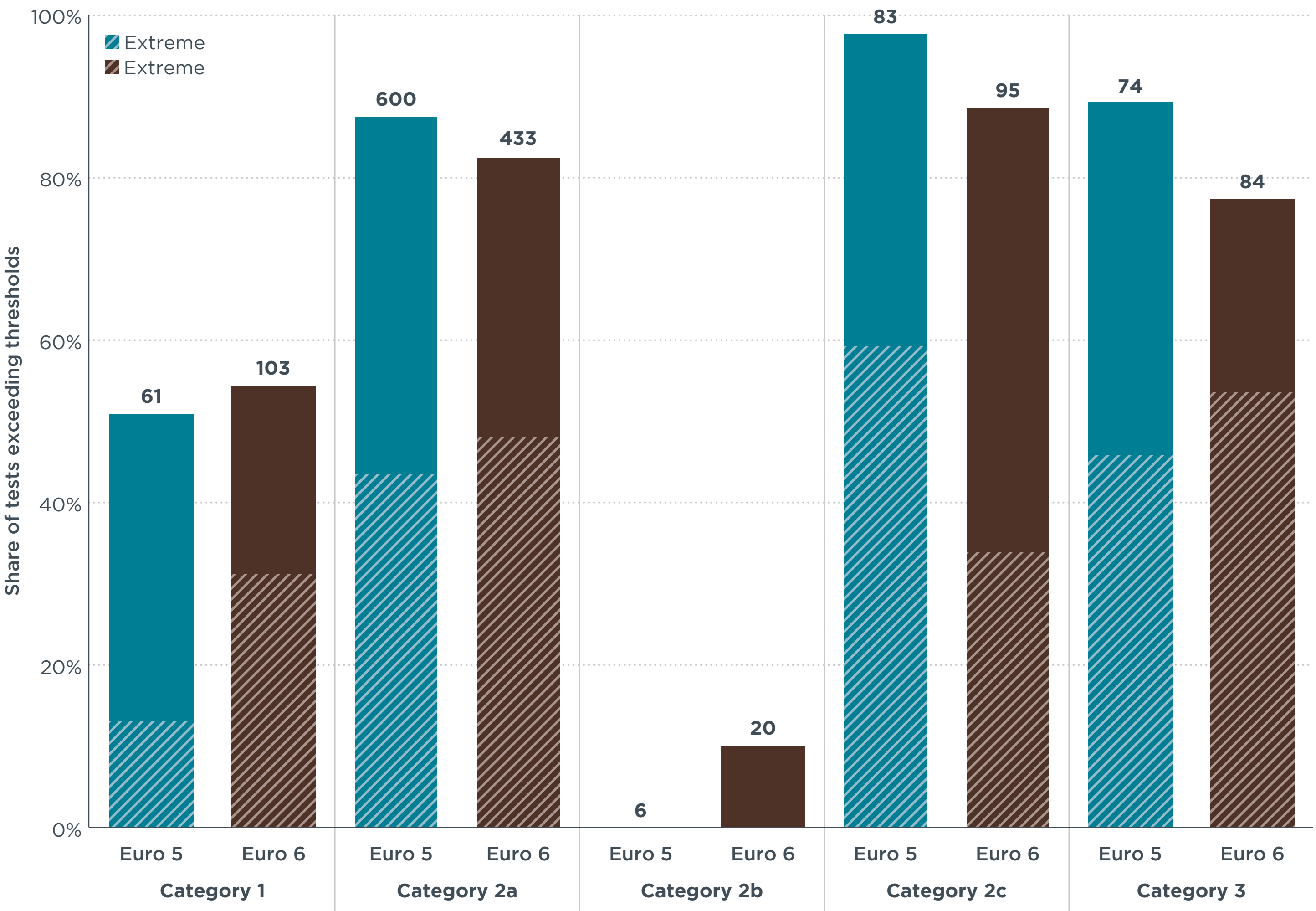


Figure 6. Summary of share of official government tests exceeding the ICCT suspicious thresholds and extreme thresholds by Euro standard and test category. Numbers above each bar indicate the total number of tests.

Most tests are classified as Category 2a tests, over 80% of which showed emissions over the ICCT suspicious threshold indicating the likely application of a defeat device. The share of tests exceeding the suspicious threshold were even higher for Category 2c, in which 98% of the tests on Euro 5 vehicles exceed the suspicious threshold.

Additionally, a large number of tests exceeded the extreme threshold, with emissions so high that a defeat device is almost certainly present. Aside from Category 2b, which covers a small number of tests, the share of tests exceeding the extreme threshold in each category ranged between 13% and 59%. In total, 151 of the 219 vehicle models tested had at least one test in any category showing emissions over the extreme threshold.

Results are presented below by category, and each figure shows results for vehicle models with tests exceeding the ICCT suspicious threshold, representing 81% of total tests. A more detailed table by vehicle model is presented in the supplementary material published with this report.[6]

CATEGORY 1

Category 1 tests involve very minor modifications to official type-approval lab testing such that notable increases in emissions raise high suspicion of a defeat device. Approximately half of the vehicle models tested showed suspicious emissions in at least one test (Figure 7). In addition, 14% of Euro 5 and 36% of pre-RDE Euro 6 models exceeded the extreme threshold in at least one test. Unlike other categories, the pre-RDE Euro 6 vehicle models had consistently higher ERs compared to Euro 5 models.

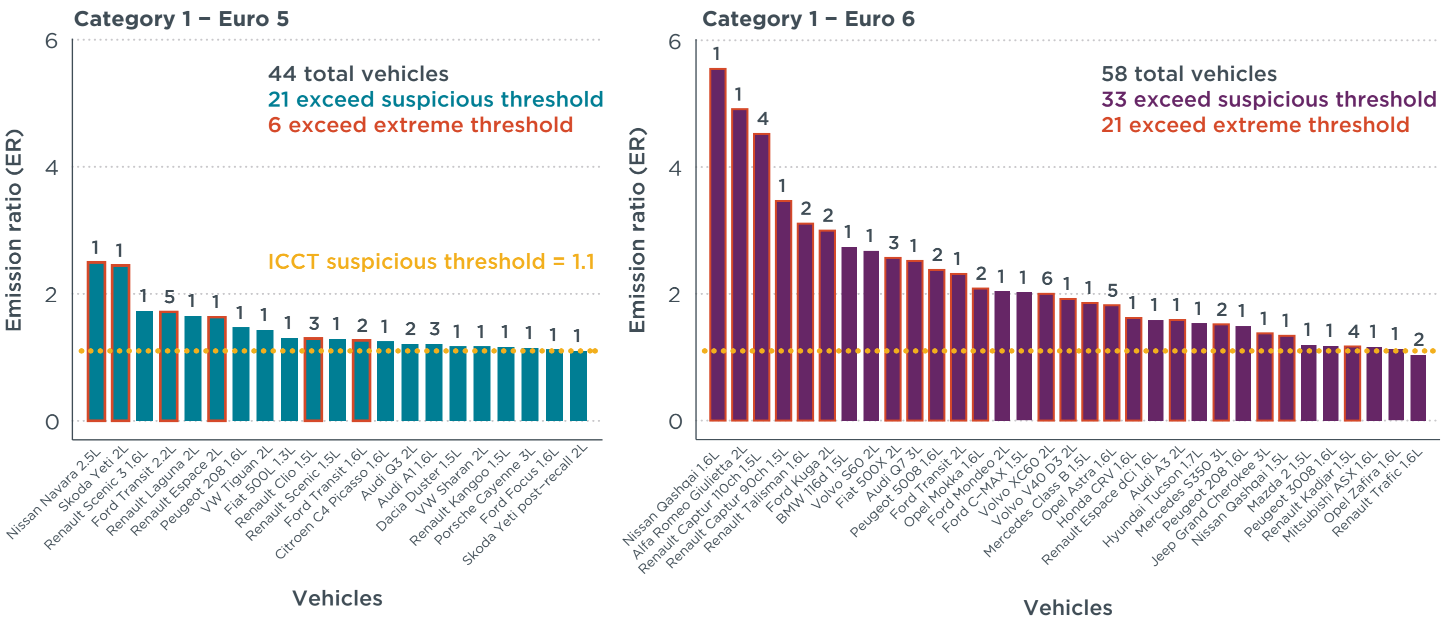
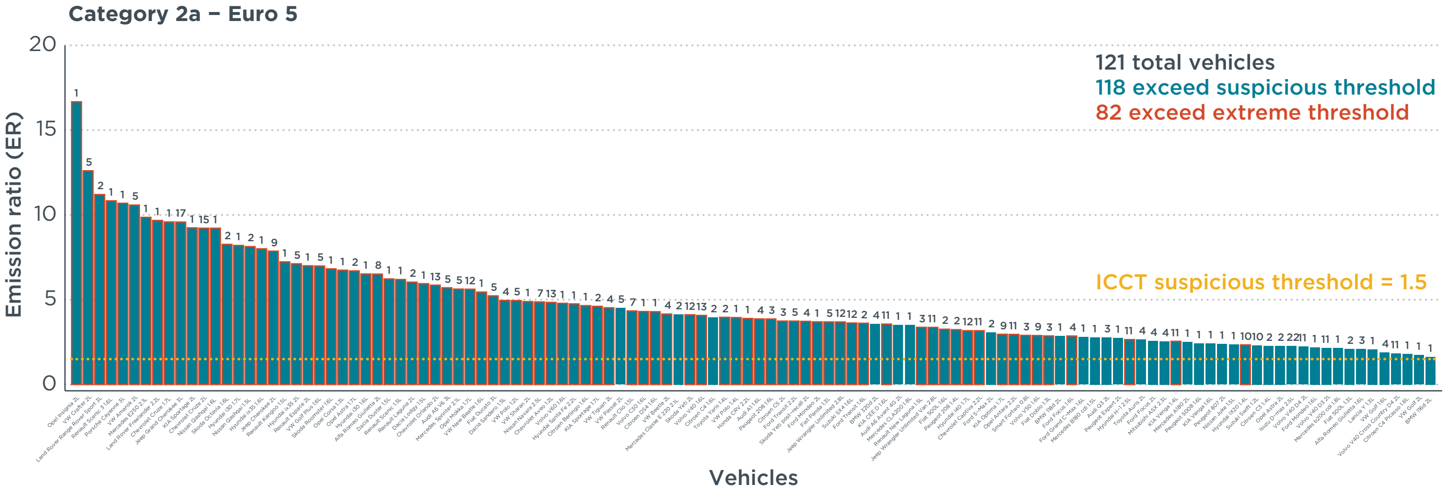


Figure 7. Average NO_x emission ratios for Category 1 tests by diesel Euro 5 and 6 vehicle model, showing only those with tests exceeding the suspicious threshold. The count above each bar shows the number of tests performed and the red outline indicates that at least one test for the given vehicle model exceeds the extreme threshold (CF = 1.3).

CATEGORY 2A

Category 2a contained the largest number of tests and vehicle models tested. Most of the tests with the highest ERs were some variation of the NEDC test, for example with 10% higher speeds and on-road or track tests measured with PEMS. Vehicles showed some of the highest ERs in Category 2a tests (Figure 8). Out of the 121 Euro 5 vehicle models, 97% exceeded the suspicious threshold and 67% exceeded the extreme threshold in at least one test. Of the 91 pre-RDE Euro 6 models, 93% exceeded the suspicious threshold and 65% exceeded the extreme threshold in at least one test. Several vehicle models had extremely high emissions: six Euro 5 vehicles and 23 pre-RDE Euro 6 vehicles showed average ERs above 10. Many of the vehicle models showing extreme emissions had consistently high emissions over multiple tests.

6 Detailed information by vehicle model can be found at https://theicct.org/wp-content/uploads/2022/12/NOx_assess_supplementary_table.xlsx.



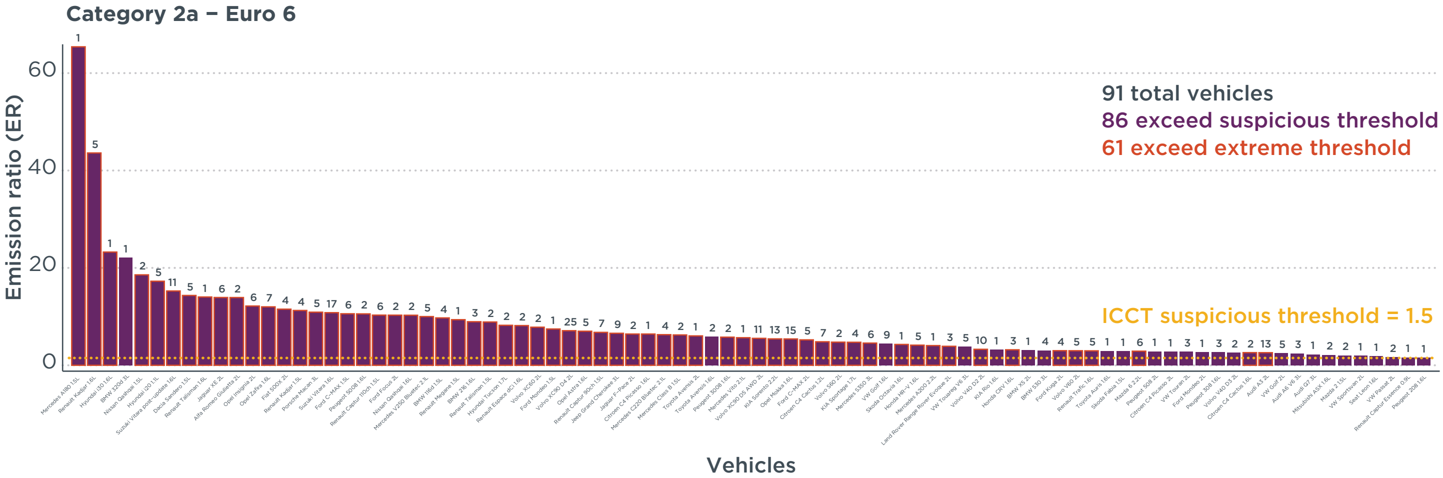


Figure 8. Average NO_x emission ratios for Category 2a tests by diesel Euro 5 and 6 vehicle model, showing only those with tests exceeding the suspicious threshold. The count above each bar shows the number of tests performed and the red outline indicates that at least one test for the given vehicle model exceeds the extreme threshold (CF = 3.0).

CATEGORY 2B

Category 2b included by far the fewest number of tests, with a total of only 26 tests on 18 vehicles. Most of these were NEDC tests performed without full preconditioning or at a slightly higher ambient temperature. Figure 9 shows the two Euro 6 vehicle models with tests exceeding the ICCT suspicious threshold, accounting for 17% of tested vehicle models. No Euro 5 vehicles showed tests exceeding the suspicious threshold in Category 2b.

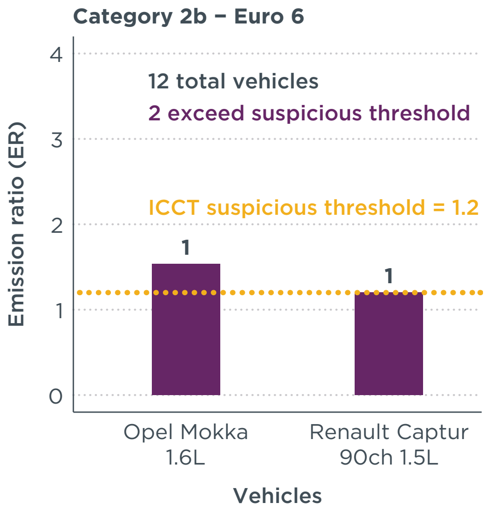


Figure 9. Average NO_x emission ratios for Category 2b tests by diesel Euro 5 and 6 vehicle model, showing only those with tests exceeding the suspicious threshold. The count above each bar shows the number of tests performed.

CATEGORY 2C

Category 2c consists only of hot-start tests. Despite the low emissions expected from a hot start test, numerous vehicles showed high emissions, with eight vehicles averaging around or above an ER of 5.0 (Figure 10). Of Euro 5 models tested, 98% exceeded the suspicious threshold and 49% exceeded the extreme threshold in at least one test. For pre-RDE Euro 6 models, 90% exceeded the suspicious threshold and 40% of exceeded the extreme threshold in at least one test.

The ICCT suspicious threshold in this category of 0.6 is notably lower than the current JRC threshold of 1.5. However, 67% of Euro 5 and 57% of Euro 6 models have tests which exceeded even the less stringent JRC threshold.

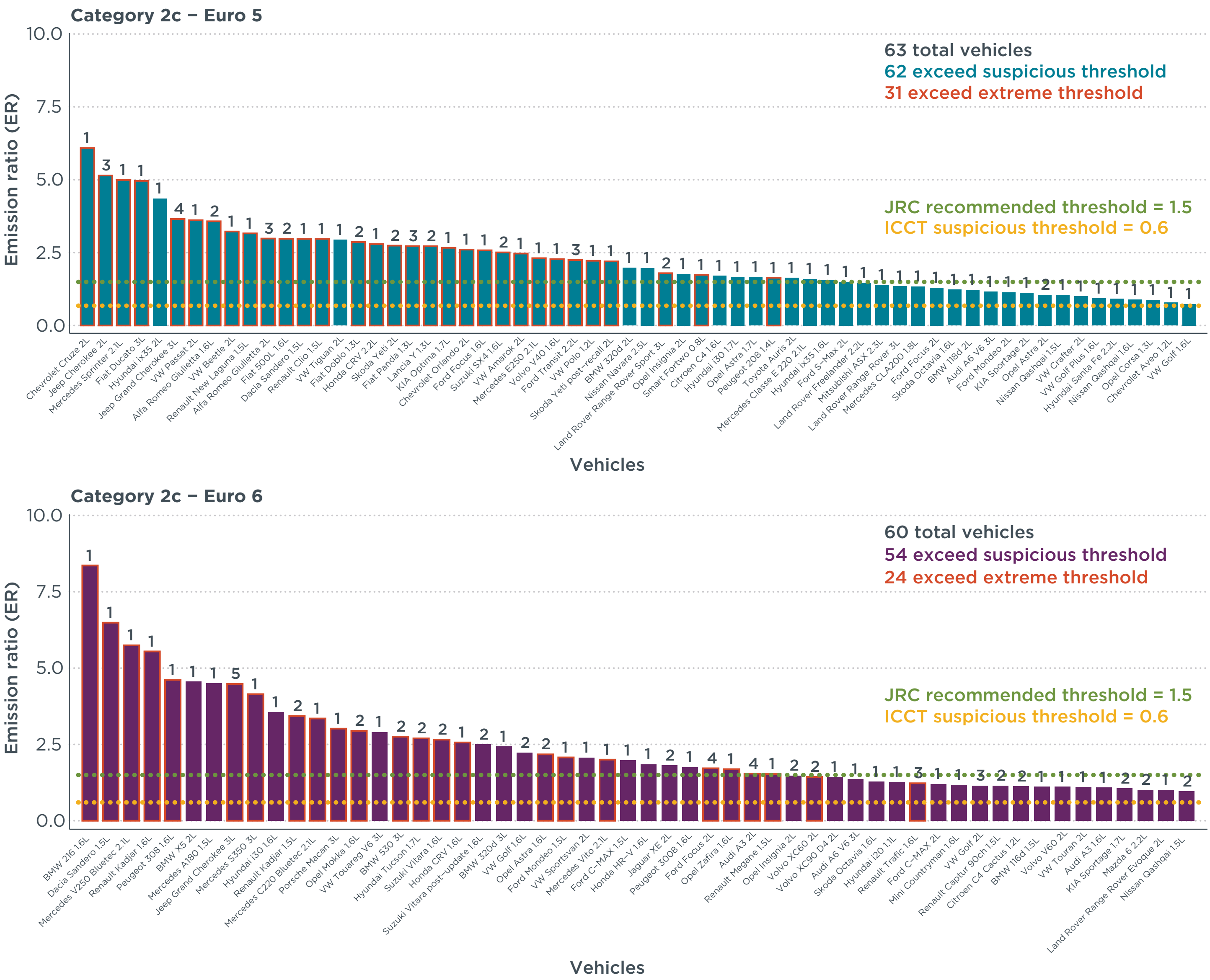
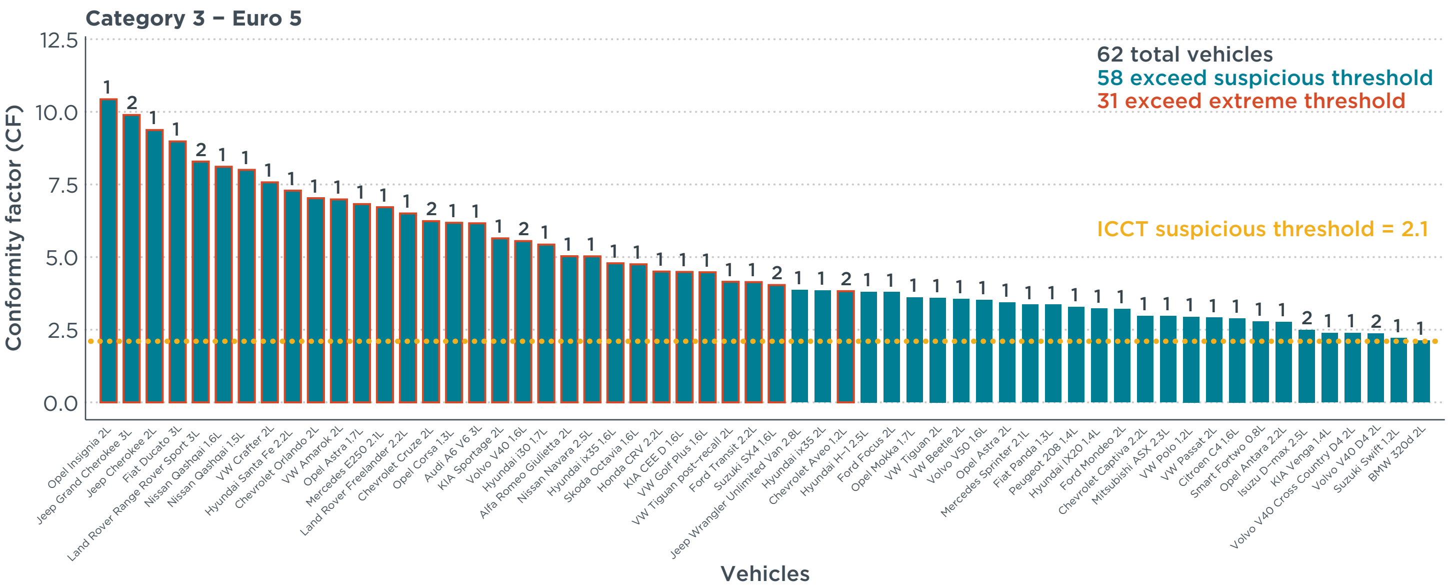


Figure 10. Average NO_x emission ratios for Category 2c tests by diesel Euro 5 and 6 vehicle model, showing only those with tests exceeding the suspicious threshold. The count above each bar shows the number of tests performed and the red outline indicates that at least one test for the given vehicle model exceeds the extreme threshold (CF = 3.0).

CATEGORY 3

The Category 3 tests considered in this section are all RDE and other on-road tests. Figure 11 shows vehicle model average CFs, or ratio to the emissions limit, with numerous vehicles emitting more than ten times the emissions limit. Of the tested Euro 5 vehicle models, 94% exceeded the suspicious threshold and 50% exceeded the extreme threshold in at least one test. Of pre-RDE Euro 6 models tested, 85% exceeded the suspicious threshold and 56% exceeded the extreme threshold in at least one test.



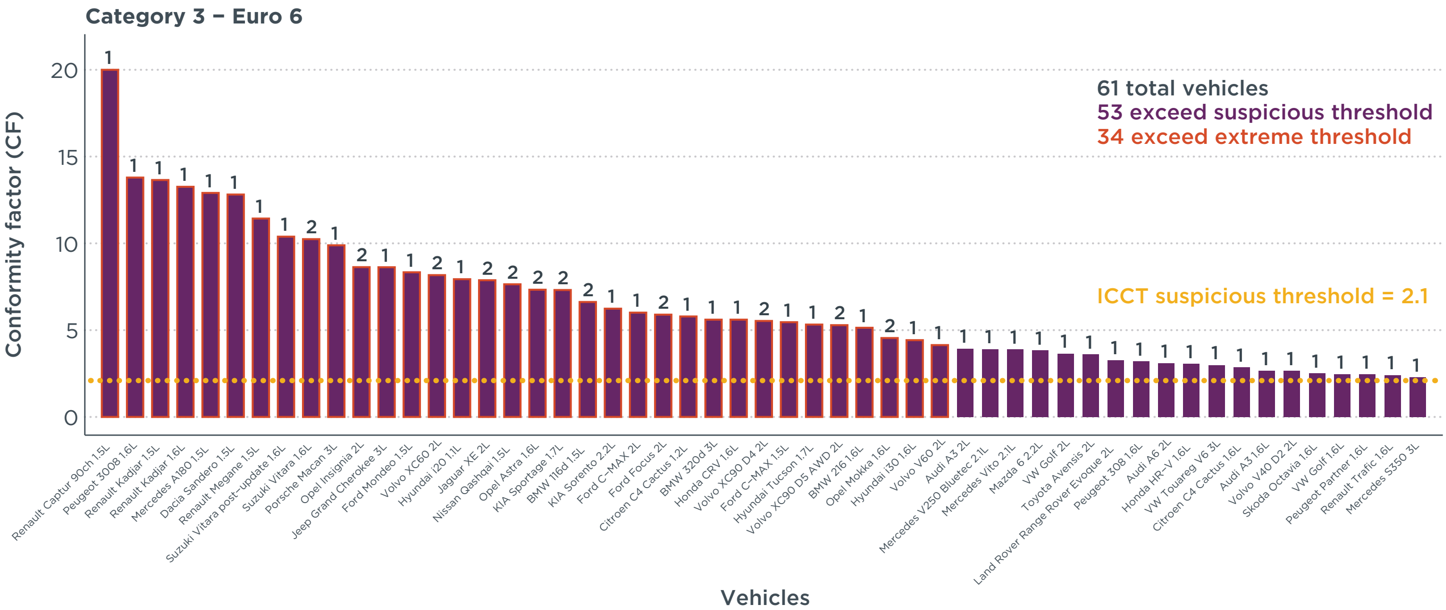


Figure 11. Average NO_x conformity factors of official government Category 3 tests by diesel Euro 5 and 6 vehicle model, showing only those with tests exceeding the suspicious threshold. The count above each bar shows the number of tests performed and the red outline indicates that at least one test for the given vehicle exceeds the extreme threshold (CF = 4.0).

ON-ROAD TESTING BY INDEPENDENT ORGANIZATIONS

This section shows the results of Category 3 on-road tests conducted by independent organizations using PEMS. The results are evaluated by vehicle model. All five of the Euro 5 vehicles tested exceeded the suspicious threshold and two vehicle model averages exceeded the extreme threshold (Figure 12). Out of the 104 Euro 6 vehicles tested, 80% exceeded the suspicious threshold, 56% exceeded the extreme threshold (Figure 13).

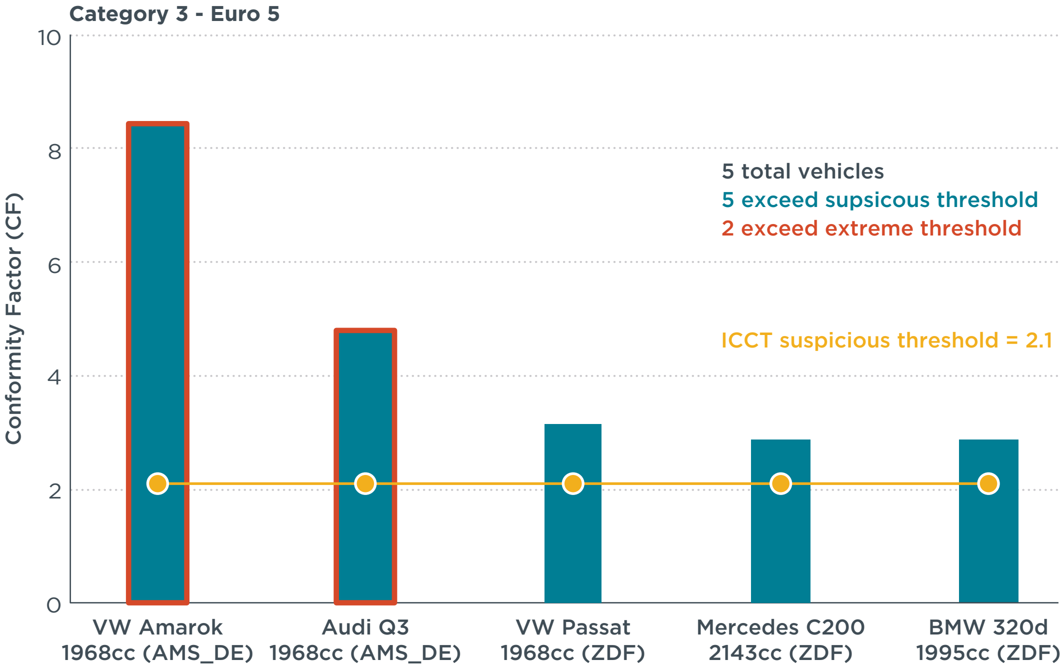


Figure 12. Average NO_x conformity factors for independent Category 3 tests by Euro 5 diesel vehicle model, showing only those with averages exceeding the suspicious threshold. The test source is indicated in parenthesis. The red outline indicates that the vehicle model's average emissions exceed the extreme threshold (CF = 4.0).

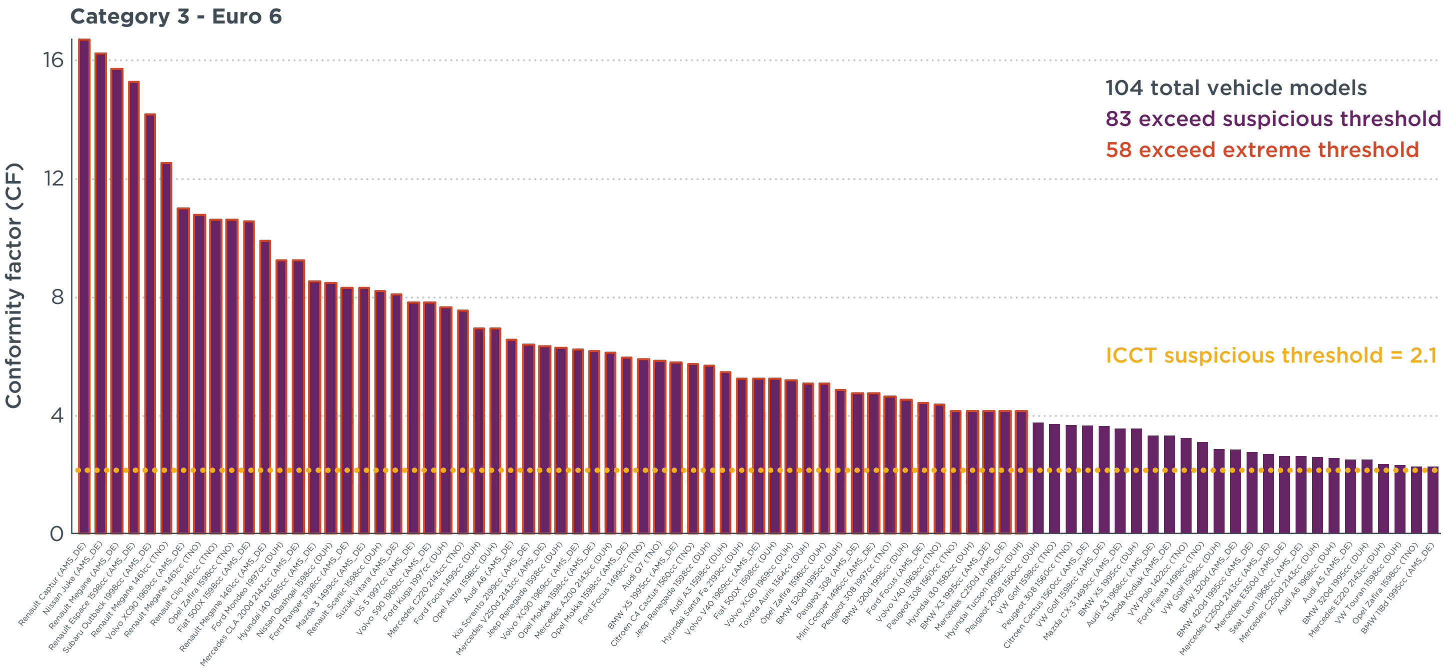


Figure 13. Average NO_x conformity factors for independent Category 3 tests by Euro 6 diesel vehicle model, showing only those with averages exceeding the suspicious threshold. The test source is indicated in parenthesis. The red outline indicates that the vehicle model's average emissions exceed the extreme threshold (CF = 4.0).

From all vehicles showing suspicious emissions in testing by independent organizations, 40 unique Euro 6 vehicle models were not tested in any official government report. This suggests that future market surveillance activities should extend beyond the initial set of vehicle models tested by governments, as other vehicle models also show evidence of possible defeat devices.

REMOTE SENSING RESULTS BY ENGINE FAMILY

The remote sensing results are aggregated by engine family instead of vehicle model due to the number of measurements in the database. On average, there were 465 measurements for each Euro 5 engine family and 502 measurements for each Euro 6 engine family.

Results show that nearly all engine families show suspicious emissions (Figure 14 and Figure 15). All 55 Euro 5 engine families exceeded the suspicious threshold of 2.1 and over 74% of the families exceeded the extreme threshold of 4.0 times the emissions limit. For Euro 6 engine families, 38 out of 39, or approximately 97%, exceeded the suspicious threshold and 72% exceeded the extreme threshold.

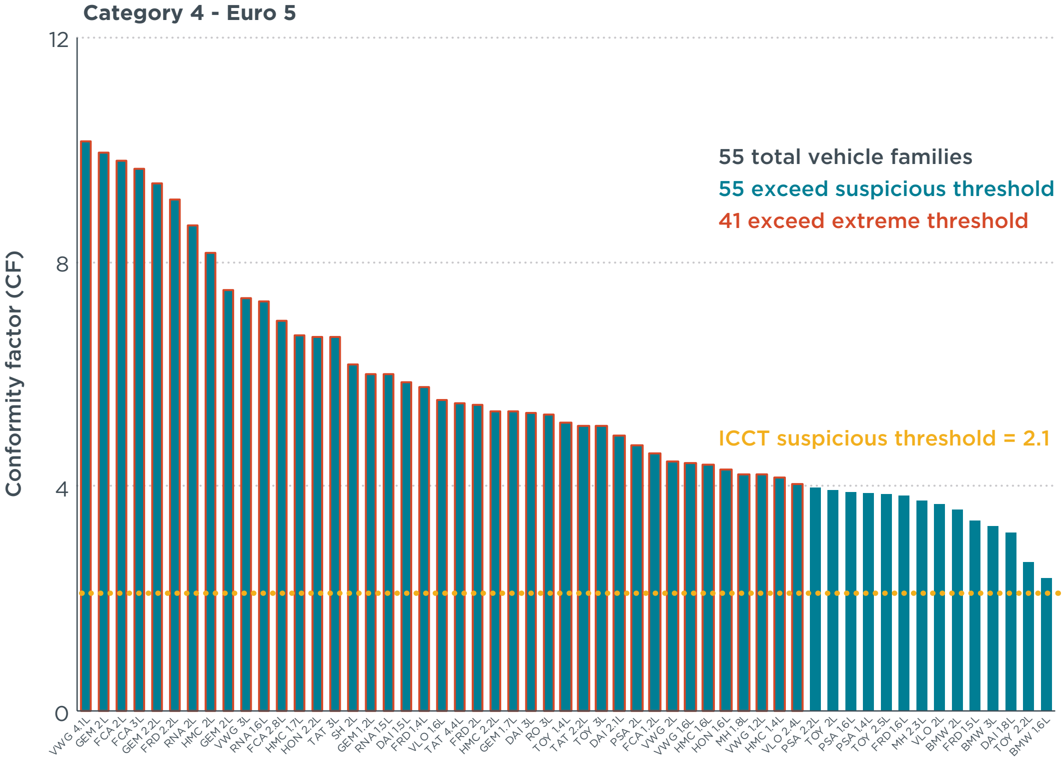


Figure 14. Average NO_x conformity factors from Category 4 remote sensing by Euro 5 diesel cars, grouped by vehicle engine family. The red outline indicates that the engine family's average emissions exceed the extreme threshold (CF = 4.0).

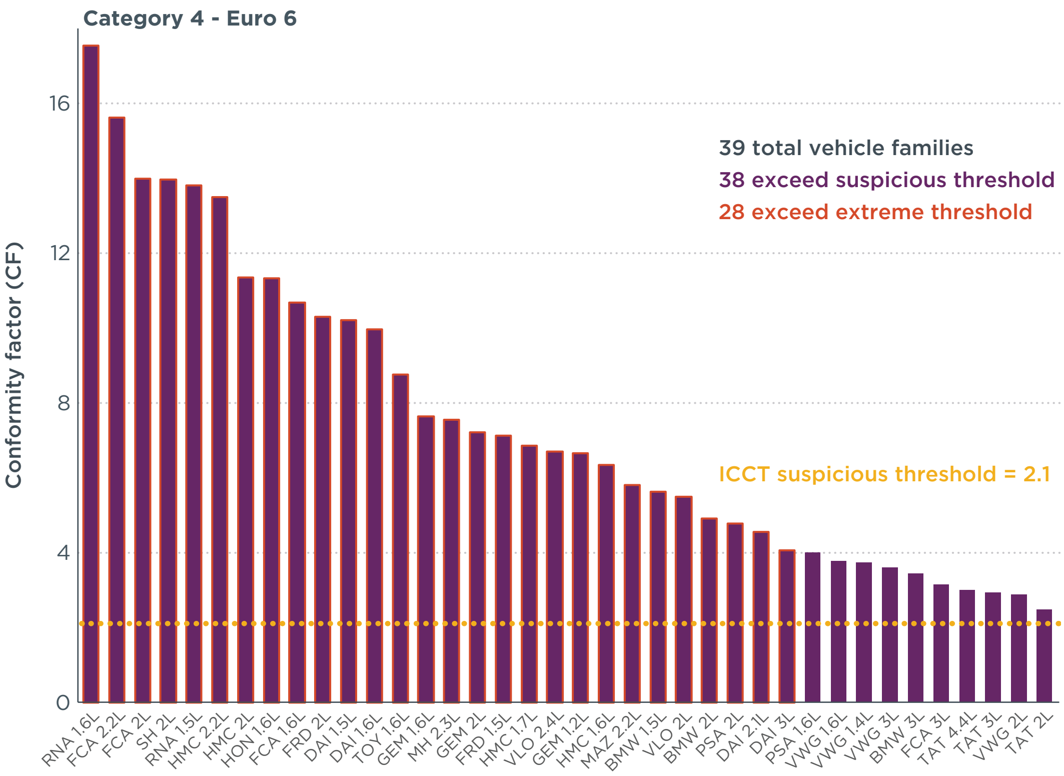


Figure 15. Average NO_x conformity factors from Category 4 remote sensing by Euro 6 diesel cars, grouped by vehicle engine family, showing only those with averages exceeding the suspicious thresholds. The red outline indicates that the engine family's average emissions exceed the extreme threshold (CF = 4.0).

In general, the Member State real-world surveillance test results and the average remote sensing measurements are relatively similar. A specific example of such results, illustrated using the 1.6L engine family including Nissan Qashqai and Renault Talisman, is discussed in Appendix D. This suggests that remote sensing is a good source of data to screen for vehicles that may be equipped with defeat devices. Out of the 94 engine families, 16 Euro 5 and 13 pre-RDE Euro 6 families were not tested in any official government reports included in this analysis. Thus, it is important for authorities to extend future screening to include not just vehicles they have already tested, but also to vehicles showing high emissions based on remote sensing data and other independent data sources.

MANUFACTURER STATEMENTS IN OFFICIAL GOVERNMENT MARKET SURVEILLANCE REPORTS

In addition to conducting surveillance testing, market surveillance authorities also questioned manufacturers about the causes of high emissions found during the testing. The interviews were conducted in 2016 and 2017, prior to the CJEU defeat device rulings from December 2020 and July 2022. This section evaluates the manufacturer explanations in light of the CJEU rulings.

Figure 16 shows a summary of the applied calibration strategies that would be classified as prohibited defeat devices under the interpretation established in the CJEU rulings. Many manufacturers explained their strategies as for the prevention of engine clogging and aging of the engine, such as the examples show in in Table 4. Most did not point to sudden or exceptional damage, which cases C-693/18, C-128/20, C-134/20, and C-145/20 specify is the only circumstance under which an AES is permissible. Results show, by manufacturer, the number of vehicle models for which the calibration strategy was used as an explanation for high emissions.

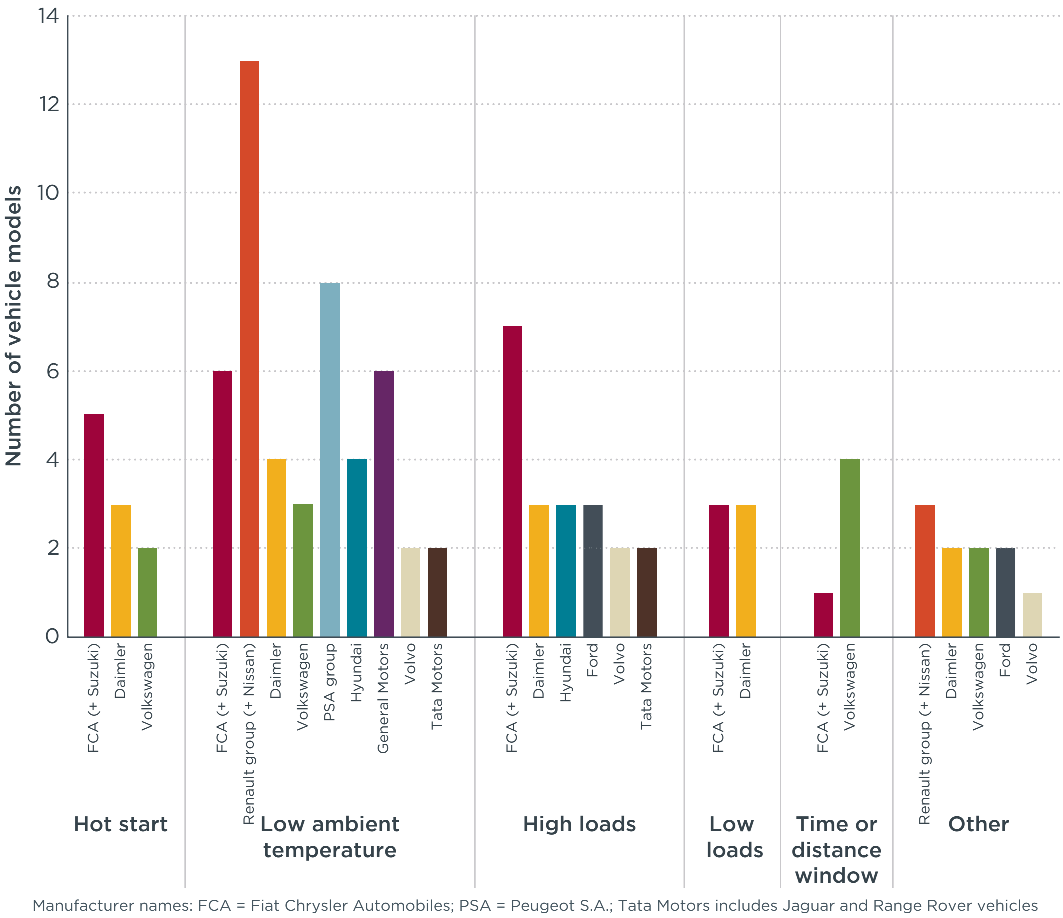


Figure 16. Summary of manufacturer statements indicating use of a defeat device by vehicle operating condition. The "other" category includes variation in the pre-loading of NO_x on the lean NO_x trap (LNT), change in ambient pressure, and other engine parameters. Manufacturers are listed according to their names at the time of testing. Daimler is now Mercedes-Benz Group; FCA and PSA group have merged to form Stellanis.

Altering the emission control system in low ambient temperatures was the most common strategy deployed and was used as an explanation for 48 vehicle models across almost all interviewed manufacturers. A temperature window strategy, which deactivated the EGR in ambient temperatures outside of 15°C –33°C, was the subject of cases C-128/20, C-134/20, and C-145/20, and the court concluded in each case that the strategy is a prohibited defeat device.

The three cases in 2022 offered additional clarification on other strategies, outlining that any AES that operates for most of the year under normal traffic conditions is not permissible. Tests with higher loads, most of which are modest 10% increases in speed from the relatively low-load NEDC test, would likely fall under the classification of normal traffic conditions. Manufacturers cited higher loads as an explanation for calibration changes for 16 vehicle models. Additionally, manufacturers indicated that 10 vehicle models use modified calibrations under hot start tests, likely also considered normal conditions.

One trend noted in four Euro 6 vehicles was that variation in the pre-loading of NO_x on the lean NO_x trap (LNT) resulted in high emissions. In a properly functioning LNT, if the NO_x loading is full at the beginning of the test, this should trigger an immediate purge of the stored NO_x. The absence of LNT purges after altered pre-conditioning can be considered an indication of a defeat device. Although the CJEU did not specifically rule on this issue, changing LNT purge operation based on pre-conditioning test conditions is likely not an exempt strategy as there is no immediate risk of damage.

In a limited number of cases, manufacturers pointed to testing equipment error or a regeneration event as the reason for excess emissions. Some of these claims were followed up with additional testing that confirmed the error, some were flagged for follow-up testing, and some claims were accepted by market surveillance authorities despite a lack of conclusive evidence (Ministre de l'Environnement, de l'Energie et de la Mer, 2016). For the vast majority of tests, the manufacturer confirmed the results and provided explanations such as the examples listed in Table 4. Full results by vehicle model are presented in supplementary material published with this paper.[7]

Table 4. Example explanations from manufacturers from surveillance interviews for each type of defeat device by vehicle operating condition

Operating condition	Manufacturer	Example explanation from report	Source
Hot start	FCA	"Modulation of the EGR rate on hot engine running cycles, in particular at low average speed, to protect the engine and after-treatment against the risk of clogging." (translated)	Ministre de l'Environnement, de l'Energie et de la Mer (2016)
Low ambient temperature	General Motors	"Opel and Chevrolet said that they make limited use of exhaust gas recirculation. The EGR system is switched off at particular temperatures within the temperature range of 0 °C to 30 °C (depending on the engine type at 14°C or 18°C). The reason for this switch-off is the quality of the parts that were used and the influence of the temperature on the emission control system."	RDW (2017)
High loads	Ford	"This increase in engine load ... takes the engine out of the optimal operating zones of the EGR. The limits of use of the EGR are justified by the need to protect the engine and components." (translated)	Ministre de l'Environnement, de l'Energie et de la Mer (2016)
Low loads	Volkswagen	"Due to the low engine load in the 'low load cycle' NEDC, the exhaust gas temperatures necessary for the SCR catalytic converter would only be reached later." (translated)	Bundesministerium für Verkehr und digitale Infrastruktur (2016)
Time or distance window	FCA (Suzuki vehicle)	"FCA was unable to explain the finding that the duration for which the engine is switched on affects the operation of the EGR system. FCA contradicted this and said that there is a time-related switch in the vehicle."	RDW (2017)
Other	Volvo	"The LNT was saturated with NO_x at the start of the test but the preconditioning had not been adequate to achieve optimum deNO_x of the LNT." and "[Volvo] also thought that pre-conditioning prior to the tests should have dealt with the deNO_x issue. The following were also noted as factors that could have affected the results: the lack of stop-start; air-conditioner being active; alternator smart charge and driver behaviour."[a]	Department for Transport (2019)

[a] LNT technology works as a buffer for NO_x, which needs to be purged during rich exhaust operation events at the expense of fuel economy. Volvo's statement mentions that the initial preconditioning had not been adequate and led the vehicle to start the official test without any NO_x storage capacity left, suggesting the purge of the LNT was not triggered properly. However, the vehicle met the NO_x limit when re-tested in the situation when "[t]he preconditioning was carried out in Dyno Mode (activated by a Volvo engineer) to ensure the battery would not overcharge, activate stop-start and deactivate non-essential activities such as the air conditioning."

At their time of publication, the official government reports did not conclusively identify any vehicles employing defeat devices. However, in several cases, vehicle models were identified by market surveillance authorities as having highly suspicious explanations that seem to indicate the use of a defeat device, even by the less stringent thresholds and the more limited definition of a defeat device at the time. Multiple reports identified vehicles with suspicious test results and manufacturer explanations and identified the need for follow-up studies and reports. However, as of 2022, three to six years after the initial reports were published, there are still several issues that have not been resolved in any publicly released follow-up report. Test results for vehicles flagged for follow-up investigation based on manufacturer claims of testing equipment error or regeneration have also not been released by authorities.

7 Detailed information by vehicle model can be found at https://theicct.org/wp-content/uploads/2022/12/NOx_assess_supplementary_table.xlsx.

Some vehicles were recalled following the release of the official government reports; however, there has been relatively little disclosure regarding the specifics of the fixes and the effectiveness of the updates (Bernard and Baldino, 2017). Nearly all fixes were software-only, and limited testing results on vehicles after updates show that fixes were not effective in reducing emissions to the regulatory limit (German, 2017). The following information on recalls were provided in the official government reports:

» **Fiat Chrysler Automobiles** deployed new calibrations in select Jeep and Fiat Euro 6 vehicle models starting in 2016. Voluntary software updates were offered to customers of existing vehicles. One update to Euro 5 vehicles was stated to only bring down emissions to six times the emissions limit, the largest possible reduction without large hardware modifications according to FCA. Additionally, a software update was issued for one Suzuki Euro 6 model with an FCA engine; however, excess emissions remained to be an issue (Department for Transport, 2018; Department for Transport, 2019; Ministre de l'Environnement, de l'Energie et de la Mer, 2016; RDW, 2017)

» **Renault Group** issued a software update to correct a calibration bug in 2015. Testing of this first update showed excess emissions. A second update was issued; however, this update was not made available to older vehicles and no test results were released after this update (Department for Transport, 2019; Ministre de l'Environnement, de l'Energie et de la Mer, 2016)

» **Mercedes-Benz Group (formerly Daimler)** contested the finding of illegal emission strategies but offered a voluntary recall in 2018. No test results were released after this update. (Department for Transport, 2019)

» **Opel (under General Motors)** issued a calibration update. No test results from official government authorities were released after this update. (Ministre de l'Environnement, de l'Energie et de la Mer, 2016)

» **Volvo** stated to UK authorities that they would be offering a software update, but no additional details were given. (Department for Transport, 2019)

Overall, enforcement activities have been insufficient in addressing the widespread issue of excess emissions. The number of vehicles affected by recalls and software updates is small compared to the large number of vehicles showing excess NO_x across several sources. Additionally, three to seven years after manufacturers stated that recalls were planned or in progress, follow-up testing data is still not available for many vehicles.

CONCLUSION

This report compiled evidence from various government authorities and independent bodies on instances of high NO_x emissions from diesel cars in Europe. The large collection of data was analyzed against emission thresholds to determine how widespread the applications of defeat devices may be. Key findings include:

"Suspicious" levels of NO_x emissions were found in 77%–100% of tests and vehicle averages, indicating the likely use of a prohibited defeat device. The largest group of data was testing by official government authorities under controlled settings. Exceedance of the suspicious emissions threshold was seen in 85% of tests on Euro 5 vehicles and 77% of tests on pre-RDE Euro 6 vehicles. Similar rates were observed for government tests conducted under real-world conditions and real-world tests from independent organizations. Remote sensing measurements showed up to 100% engine family averages exceed the suspicious threshold.

"Extreme" levels of NO_x emissions were found in 40%–75% of tests and vehicle averages, indicating that a prohibited defeat device is almost certainly present. Approximately 42% of tests by official government authorities under controlled settings exceeded the extreme threshold. Results from government and independent real-world testing showed similar or higher rates of extreme emissions. Remote sensing measurements showed approximately 75% engine family averages exceed the suspicious threshold.

Over 200 unique vehicle models were found to have high NO_x emissions above the 'suspicious' threshold. Of unique vehicle models tested by official government authorities, 95% showed suspicious emissions in at least one test, and nearly 70% of vehicle models showed extreme emissions in at least one test. These results are supported by independent testing and remote sensing data.

Strategies used in 66 unique vehicle models, as described by manufacturers during market surveillance interviews, should now be considered prohibited defeat devices according to the latest CJEU rulings. These rulings identify the extremely limited circumstances in which the use of such defeat devices can be legally justified. Nearly 50 unique vehicle models alter emission control systems in low ambient temperatures, a strategy that was specifically ruled on in case C-128/20.

Evidence over multiple sources show high NO_x emissions from Euro 5 and 6 diesel vehicles across manufacturers. The comparatively limited corrective action to date highlights the need for additional market surveillance activities to address defeat devices and systemic changes to ensure comprehensive enforcement. The latest CJEU rulings have importantly removed a barrier to enforcement by defining what constitutes prohibited defeat devices, outlining the limited conditions under which emission control system calibration changes are permitted. In addition, the rulings present an opportunity to improve market surveillance and vehicle certification processes.

Several changes are recommended to clarify the definition of defeat devices and improve the methods for identifying potential defeat devices. The following steps are recommended for the European Commission and the Department for Transport in the UK:

» **Revise recommended thresholds:** This report provides evidence that the current and proposed JRC thresholds are not stringent enough to identify vehicles with potential defeat devices. It is recommended that the thresholds for detecting suspicious vehicles be revised.

» **Define defeat devices:** Identify categories of emission control strategies that constitute defeat devices according to the CJEU rulings to ensure that consistent definitions are used across all Member States, manufacturers, and vehicles.

Beyond identifying suspicious vehicles, authorities should ensure that manufacturers sufficiently follow through with fixes. The following steps are recommended for EU Member State and UK market surveillance authorities:

» **Require manufacturers to take corrective measures if a prohibited defeat device is present:** Corrective action should be required for vehicles with multiple test results showing extremely high emissions that can only be explained by the use of a prohibited defeat device or for vehicles with manufacturer statements indicating use of a strategy that can now be classified as a prohibited defeat device.

» **Conduct additional market surveillance if a prohibited defeat device is suspected:** A thorough investigation should be conducted for vehicles where a prohibited defeat device is likely present based on results from past government testing, independent testing, and remote sensing. The investigations should be extended to vehicle families sharing the same powertrain, and manufacturers should provide a list of other models potentially affected.

» **Evaluate emissions after recalls and fixes:** After a manufacturer recalls a vehicle, authorities should ensure that the updated vehicle emits less than the emissions limit. It is important that this testing includes real-world driving conditions and extends through the vehicle's entire useful life.

» **Increase transparency:** After identifying vehicles with excess emissions, data from additional market surveillance testing and emission evaluations after recalls should be released by authorities in a timely manner. This piece of enforcement is essential, as it helps ensure the fixes effectively reduce emissions. Additionally, information should be provided to consumers regarding how the updates impact emissions, fuel economy, and vehicle durability.

Finally, while the introduction of RDE testing requirements with Euro 6d-TEMP vehicles has helped to lower real-world emissions of new diesel vehicles, there is still evidence of high real-world emissions in RDE-certified vehicles under certain conditions. The following changes are recommended to bring in-use emissions in line with emission standard limits during the realistic useful life of the vehicles and to allow scrutiny of manufacturers' use of AES and associated enforcement:

» **Extend the scope of RDE testing:** While this report focuses on Euro 5 and pre-RDE Euro 6 diesel vehicles, there are important implications for the vehicle certification process. The RDE requirements were introduced starting with Euro 6d-TEMP vehicles to address excess real-world emissions. Vehicles type-approved under those new regulatory requirements were found to emit significantly less than Euro 6 vehicles but fall short of delivering low emissions under normal real-world driving conditions. For example, emissions during dynamic driving style or hilly roads, which go beyond the boundaries defining a compliant RDE trip, were shown to have emissions multiple times higher than the applicable limit (Transport & Environment 2018). The Euro 7 regulation should aim to significantly enlarge the scope of permissible on-road testing conditions.

» **Increase AES transparency:** The Euro 6e regulation introduced the requirement that vehicles report the use of an AES during driving through the on-board diagnostic connection (European Commission 2022). However, further details should be recorded on the lifetime runtime of each individual AES. Additionally, testing of AES activation should include conditions outside of the RDE requirements. These steps would help determine the frequency of activation during real-world usage to better support the assessment of allowable uses of the AES.

» **Perform testing beyond the current in-service conformity requirements:** The Euro 6 regulation allows the verification of in-use emissions of vehicles up to 5 years of age or 100,000 km (whichever comes first), which is far less than their typical lifetime. Euro 7 regulation should extend the definition of the useful life of vehicles. Additionally, testing for defeat device should be carried out beyond the scope of the in-service conformity requirements to verify that further emissions control deterioration is not the result of deliberate changes in the control strategy.

» **Extend the definition of vehicles suitable for testing**: Vehicles that can currently be selected for in-service conformity testing must follow a list of criteria which, in practice, significantly restrict the scope of selectable vehicles. Criteria to exclude a vehicle for testing should be limited, and on-board malfunctions information should primarily be used instead.

These actions would help reduce excess NO_x by targeting diesel vehicles with prohibited defeat devices in operation today, closing gaps in enforcement practices, and widening testing requirements for future vehicle certification.

REFERENCES

Anenberg, S., Miller, J., Henze, D., and Minjares, R. (2019). *A Global Snapshot of the Air Pollution-Related Health Impacts of Transportation Sector Emissions in 2010 and 2015.* International Council on Clean Transportation. https://theicct.org/publication/a-global-snapshot-of-the-air-pollution-related-health-impacts-of-transportation-sector-emissions-in-2010-and-2015/.

Balawender, K., Jaworski, A., and Kuszewski, H. (2016). An Assessment of Consistence of Exhaust Gas Emission Test Results Obtained under Controlled NEDC Conditions, IOP Conf. Ser.: Mater. Sci. Eng. 148 (012059). https://doi.org/10.1088/1757-899X/148/1/012059.

Baldino, C., Tietge, U., Muncrief, R., Bernard, Y., and Mock, P. (2017). *Road Tested: Comparative Overview of Real-World versus Type-Approval NOX and CO2 Emissions from Diesel Cars in Europe*. International Council on Clean Transportation. https://theicct.org/publication/road-tested-comparative-overview-of-real-world-versus-type-approval-nox-and-co2-emissions-from-diesel-cars-in-europe/.

Bernard, Y. (2019, September 10). Real-World Emissions from Remote Sensing: An Update of the TRUE Rating. *The Real Urban Emissions Initiative* (blog). https://www.trueinitiative.org/blog/2019/september/real-world-emissions-from-remote-sensing-an-update-of-the-true-rating.

Bernard, Y., and Baldino, C. (2017, August 30). "Will the Future RDE Regulation Be Enough to Restore Trust in Diesel Technology?" *ICCT staff blog*. https://theicct.org/will-the-future-rde-regulation-be-enough-to-restore-trust-in-diesel-technology/.

Bernard, Y., Dornoff, J., and Carslaw, D.C. (2022). Can Accurate Distance-Specific Emissions of Nitrogen Oxide Emissions from Cars Be Determined Using Remote Sensing without Measuring Exhaust Flowrate? *Science of The Total Environment* 816 (April): 151500. https://doi.org/10.1016/j.scitotenv.2021.151500.

Bernard, Y., German, J., Kentroti, A., and Muncrief, R. (2019). *Catching Defeat Devices: How Systematic Vehicle Testing Can Determine the Presence of Suspicious Emissions Control Strategies*. International Council on Clean Transportation. https://theicct.org/publication/catching-defeat-devices-how-systematic-vehicle-testing-can-determine-the-presence-of-suspicious-emissions-control-strategies/.

Bernard, Y., Tietge, U., German, J., and Muncrief, R. (2018). *Determination of Real-World Emissions from Passenger Vehicles Using Remote Sensing Data*. International Council on Clean Transportation. https://theicct.org/publication/determination-of-real-world-emissions-from-passenger-vehicles-using-remote-sensing-data/.

Bundesministerium für Verkehr und digitale Infrastruktur. 2016. Bericht Der Untersuchungskommission „Volkswagen" [Report of the investigative commission "Volkswagen"]. https://www.autoevolution.com/pdf/news_attachements/630000-diesel-cars-of-german-origin-to-be-recalled-in-europe-more-to-follow-106820.pdf.

Clairotte, M., Valverde, V., Bonnel, P., Giechaskiel, P., Carriero, M., Otura,, M. Fontaras, G, ... Cotogno, G. (2020). *Joint Research Centre 2019 Light-Duty Vehicles Emissions Testing, Contribution to the EU Market Surveillance: Testing Protocols and Vehicle Emissions Performance*. Joint Research Centre. https://op.europa.eu/publication/manifestation_identifier/PUB_KJNA30482ENN.

CLCV and Others (Defeat device on diesel engines). C-693/18. 17 December 2020. The Court of Justice of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62018CA0693.

Commission Regulation (EU) 2017/1151. 2017 Official Journal of the European Union. COM, GROW. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32017R1151

Department for Transport. (2016). *Vehicle Emissions Testing Programme*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/548148/vehicle-emissions-testing-programme-web.pdf.

Department for Transport. (2018). *Vehicle Market Surveillance Unit: Results of the 2017 Programme*. https://www.gov.uk/government/publications/vehicle-market-surveillance-unit-programme-results-2017.

Department for Transport. (2019). *Vehicle Market Surveillance Unit: Results of the 2018 Vehicle Emissions Testing Programme*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/926212/vehicle-market-surveillance-unit-programme-results-2018.pdf.

Díaz, S., Mock, P., Bernard, Y., Bieker, G., Pniewska, I., Ragon, P.L., Rodríguez, F., Tietge, U., and Wappelhorst, S. (2020). *European Vehicle Market Statistics 2020/21*. International Council on Clean Transportation. https://theicct.org/publication/european-vehicle-market-statistics-2020-21/.

DS v Porsche Inter Auto GmbH & Co KG and Volkswagen AG. C-145/20. 14 July 2022. The Court of Justice of the European Union. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:62020CJ0145.

Epstein, R. (2017, September 27). The Role of Defeat Devices in Environmental Protection: Beyond the VW Scandal. *Forbes*. https://www.forbes.com/sites/richardepstein/2017/09/27/the-role-of-defeat-devices-in-environmental-protection-beyond-the-vw-scandal/?sh=4a7dd58b52c1.

European Commission. (2017). Guidance on the Evaluation of Auxiliary Emission Strategies and the Presence of Defeat Devices with Regard to the Application of Regulation (EC) No 715/2007. https://www.europarl.europa.eu/meetdocs/2014_2019/plmrep/COMMITTEES/EMIS/DV/2017/02-09/C_2017_352_EN.pdf.

European Commission. (2022). Draft Commission Regulation Amending Commission Regulation (EU) 2017/1151 as Regards the Emission Type Approval Procedures for Light Passenger and Commercial Vehicles. https://ec.europa.eu/info/law/better-regulation/.

Franco, V., Posada, F., German, J., & Mock, P. (2014). *Real-world exhaust emissions from modern diesel cars*. International Council on Clean Transportation. https://theicct.org/publication/real-world-exhaust-emissions-from-modern-diesel-cars/.

German, J. (2016, May 12). The Emissions Test Defeat Device Problem in Europe Is Not about VW. *ICCT staff blog*. https://theicct.org/the-emissions-test-defeat-device-problem-in-europe-is-not-about-vw/.

German, J. (2017). *VW Defeat Devices: A Comparison of U.S. and EU Required Fixes*. International Council on Clean Transportation. https://theicct.org/publication/vw-defeat-devices-a-comparison-of-u-s-and-eu-required-fixes/.

GSMB Invest GmbH & Co. KG v Auto Krainer GesmbH. C-128/20. 14 July 2022. The Court of Justice of the European Union. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:62020CJ0128.

IFPEN. (2017). *Contrôle Des Émissions de Polluants Atmosphériques et de CO2 : Analyses Complémentaires Menées Par IFPEN* [Control of Atmospheric Pollutants and CO2 Emissions: Additional Analyzes Conducted by IFPEN]. https://www.ecologie.gouv.fr/sites/default/files/Rapport%20final%20-%20Mission%20d'expertise%20IFPEN.pdf.

IR v Volkswagen AG. C-134/20. 14 July 2022. The Court of Justice of the European Union. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:62020CJ0134.

Jimenez-Palacios, J. L. (1999). Understanding and Quantifying Motor Vehicle Emissions with Vehicle Specific Power and TILDAS Remote Sensing [Thesis (Ph.D.), Massachusetts Institute of Technology, Dept. of Mechanical Engineering]. http://dspace.mit.edu/handle/1721.1/44505.

Joint Research Centre. (2015). *RDE—Preliminary Uncertainty Assessment*.

Joint Research Centre. (2016). Explanatory note, Interim Report for Administrative Arrangement DG-GROW/JRC. https://www.asktheeu.org/en/request/5554/response/17549/attach/5/Explanatory%20note%20final.pdf?cookie_passthrough=1.

Joint Research Centre. (2017). Q&A on RDE. https://wiki.unece.org/download/attachments/65503466/Q%26A%20RDE%20vs2b.pdf?api=v2.

Joint Research Centre. (2021a). *Real Driving Emissions (RDE): 2020 Assessment of Portable Emissions Measurement Systems (PEMS) Measurement Uncertainty*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/440720.

Joint Research Centre. (2021b). Guidance on Defeat Devices and Reporting on Not Approved Auxiliary Emission Strategies.

Luján, J.M., Climent, H., Dolz, V., Moratal, A., Borges-Alejo, J., and Soukeur, Z. 2016. Potential of Exhaust Heat Recovery for Intake Charge Heating in a Diesel Engine Transient Operation at Cold Conditions. *Applied Thermal Engineering* 105 (July): 501–8. https://doi.org/10.1016/j.applthermaleng.2016.03.028.

Martini, G., Fontaras, G., Clairotte, M., Otura, M., Krasenbrink, A., Bonnel, P., Pavlovic, J., et al. (2018). *Joint Research Centre 2017 Light-Duty Vehicles Emissions Testing Contribution to the EU Market Surveillance: Testing Protocols and Vehicle Emissions Performance*. https://publications.jrc.ec.europa.eu/repository/handle/JRC111909.

Ministero delle infrastrutture e dei trasporti. (2016). *Programma Di Prove per La Valutazione Del Comportamento Emissioni Delle Auto Diesel Euro 5 Commerciate in Italia Con Prove Di Laboratorio e in Pista* [Test Program for Evaluating the Emissions Behavior of Euro 5 Diesel Cars Marketed in Italy With Laboratory and Track Tests]. https://www.mit.gov.it/nfsmitgov/files/media/pubblicazioni/2017-03/Report%20Istituto%20Motori%20CNR_per%20MIT_finale.pdf.

Ministre de l'Environnement, de l'Energie et de la Mer. (2016). *Rapport Final de La Commission Indépendante Mise En Place Par La Ministre Ségolène Royal Après La Révélation de l'affaire Volkswagen* [Final Report of the Independent Commission Set up by Minister Ségolène Royal After the Revelation of the Volkswagen Affair]. https://s3-prod-europe.autonews.com/s3fs-public/CA106722825.PDF.

Ministre wallon de l'Environnement. (2016). *Résultats de l'évaluation des rejets atmosphériques par les véhicules légers diesel* [Results of the Assessment of Emissions from Light-Duty Diesel Vehicles]. https://www.issep.be/wp-content/uploads/RapportVWFINAL-juin16.pdf

Mock, P., and German, J. (2015). *The Future of Vehicle Emissions Testing and Compliance*. International Council on Clean Transportation. https://theicct.org/publication/the-future-of-vehicle-emissions-testing-and-compliance/.

Muncrief, R., German, J., and Schultz, J. (2016). *Defeat Devices under the U.S. and EU Passenger Vehicle Emissions Testing Regulations*. International Council on Clean Transportation. https://theicct.org/publication/defeat-devices-under-the-u-s-and-eu-passenger-vehicle-emissions-testing-regulations/.

Ntziachristos, L., Papadimitriou, G., Ligterink, N., & Hausberger, S. (2016). Implications of diesel emissions control failures to emission factors and road transport NO_x evolution.

Atmospheric Environment, 141, 542–551. https://doi.org/10.1016/j.atmosenv.2016.07.036.

RDW. (2016). *RDW Emission Test Programme - Results of Indicative Tests for the Presence of an Unauthorised Defeat Device*.

RDW. (2017). *RDW Emission Test Programme-Results of the Follow-up Investigation into the Presence of Unauthorised Defeat Devices*.

Stegmaier, G. (2017, January 2). NOx-Tests Im Straßenverkehr Unter Realbedingungen [NOx tests in road traffic under real conditions]. *Auto Motor und Sport*. https://www.auto-motor-und-sport.de/test/nox-abgastests-realbetrieb-strassenverkehr-neuwagen-testverfahren/.

Transport & Environment. (2018). *Cars with Engines: Can They Ever Be Clean?* Transport & Environment. https://www.transportenvironment.org/wp-content/uploads/2021/07/2018_09_TE_Dieselgate_report_final.pdf.

UN Environment Programme. (2020). *Used Vehicles and the Environment*. https://wedocs.unep.org/handle/20.500.11822/34175.

UN Environment Programme. (2021). *Used Vehicle and the Environment - Progress and Updates 2021*. http://www.unep.org/resources/report/used-vehicles-and-environment-progress-and-updates-2021.

U.S. Environmental Protection Agency. (2015). Notice of Violation. Office of Enforcement and Compliance Assurance. https://www.epa.gov/sites/default/files/2015-10/documents/vw-nov-caa-09-18-15.pdf.

U.S. Environmental Protection Agency. (2016). Freedom of Information Act request EPA-HQ-2016-006283, FTP emission data by bag for 2009-2015 light-duty diesel vehicles [database]. https://foiaonline.gov/foiaonline/action/public/submissionDetails?trackingNumber=EPA-HQ-2016-006283&type=Request.

APPENDIX A

This appendix outlines the methodology used to determine the ICCT recommended high and extreme emissions thresholds indicating if vehicles likely use a prohibited defeat device or that a prohibited defeat device is almost certainly present. Current JRC recommended thresholds are used except in categories for which evidence supports a more stringent threshold. The thresholds are summarized below in Table A1.

Table A1. Summary of ICCT recommended NO_x emission thresholds by category for Euro 5 and pre-Euro 6d-TEMP vehicles

Category	Test type	Recommended suspicious emissions threshold		Extreme threshold
		ER (preferred)	CF	CF
1	Modifications that should not change the response of the emission control system, e.g. rolled down window, plugging into OBD	1.1	0.9	1.3
2a	Modified test conditions that can cause minor or temporary emission increases, e.g. colder temperatures, minor increases in speed	1.5	1.2	3.0
2b	Test changes that should not change the physical response of the engine and emission control system, e.g. revised test phases, lower speeds	1.2	1.0	3.0
2c	Hot start tests	0.6	0.5	1.3
3	RDE & real-world surveillance tests	N/A	2.1	4.0
4	Remote sensing measurements	N/A	2.1	4.0

For Categories 1–2c, it is preferred to use the ER against the type-approval values as this more accurately reflects changes to the emission performance under different testing conditions. However, the type-approval value is not available for all vehicles, accounting for roughly 25% of the test in this analysis. Therefore, a conformity factor (CF) threshold, or threshold based on the ratio to the emissions limit, is defined for Categories 1–2c for tests on vehicles with missing type-approval values. The CF threshold for each category is determined by multiplying the ER threshold by 0.78, which is the average ratio of the type-approval value to the emissions limit for Euro 5 vehicles analyzed in this report.[8]

CATEGORY 1

Category 1 testing condition modifications should not change the physical response of the engine and emission control system and, thus, should not affect vehicle emissions. Some examples include testing vehicles with an open door or briefly engaging reverse gear during a vehicle stop. The complete list of tests by category is presented in Appendix C.

Any emission increase with a Category 1 test should raise suspicion of the presence of a prohibited defeat device. JRC estimates a 3% level of uncertainty for lab testing, and a Euro 4 petrol vehicle under the NEDC cycle showed an 11% coefficient of variation (Balawender, Jaworski, and Kuszewski, 2016; JRC, 2015). Therefore, an emission allowance of 10% is selected to account for test-to-test emission variability, setting the suspicious threshold at an ER of 1.1 when compared to type-approval values.

When type-approval values are not available, a CF threshold of 0.9 should be used, calculated based on the Euro 5 average ratio of type-approval values to the emissions limit (0.78 x 1.1 = 0.9, rounded up). In other words, a test result too close to the regulatory limit can also be suspicious because manufacturers typically use built-in margin, in particular to account for future emission deterioration.

8 The average ratio of type-approval values to the emissions limit is 0.61 for Euro 6 vehicles in this analysis. The 0.78 figure is used as it is the more conservative of the two.

The extreme threshold is designed to account for not only test-to-test variability but also deterioration and manufacturer risk avoidance. JRC's 2021 proposed "fail" threshold of a CF > 1.3 is used. On average, this represents a large 67% increase from type-approval values for Euro 5 vehicles and a 130% increase for Euro 6 vehicles. Therefore, a threshold of 1.3 can be used to identify vehicles with prohibited defeat devices with near certainty.

CATEGORY 2

Category 2 testing is conducted under conditions that are different from the legislative cycle but with testing conditions that are still controlled. It is recommended in this analysis to evaluate this group of tests differently depending on the type of test, distinguished by labels of Category 2a, 2b, and 2c.

CATEGORY 2A

Category 2a tests are defined as tests with conditions modified such that minor or temporary emission increases may be expected. JRC's current Category 2 ER threshold is 1.5 compared to type-approval values.

JRC's current recommended Category 2 ER of 1.5 is adopted as the ICCT suspicious threshold for Category 2a, as evidence supports that emissions increases should be less than 50%. One common Category 2a test condition is slightly increased vehicle speed. The maximum speed increase is 10%, and load increase are, at worse, proportional to the square of the speed increases (Jimenez-Palacios, 1999). Thus, emission increases in Category 2a tests with increased speed should result in a maximum of a 20% increase in load and emissions.

The other most common change in this category is a reduction in ambient temperature. Lower temperatures delay the catalyst and EGR operation; however, this additional warm up time accounts for a small fraction of the total test time. Testing at an ambient temperature of -7°C, which is lower than the minimum of 3°C in this category, showed that the EGR began operating after 100 seconds, which is less than 10% of the total NEDC time (Luján et al., 2016).Finally, some tests in this group include on-road or track testing measured by PEMS, which has an approximate measurement uncertainty of 23% for NO_x (JRC 2021a). Therefore, the suspicious threshold ER of 1.5 is appropriate.

The corresponding CF is 1.2 is calculated using the same logic as for the Category 1 CF.

The extreme threshold is set at a CF of 3.0. This is determined by doubling the suspicious CF threshold and rounding up, greatly reducing any chance that the high emissions can be attributed to factors outside of a prohibited defeat device. In support, the JRC 2021 proposed thresholds include a "high priority" threshold of 2.5, suggesting that an extreme threshold of 3.0 is reasonable.

CATEGORY 2B

Category 2b test conditions are modified slightly and may cause minor changes in engine and emission control system behavior but should not result in emission increases. In some cases, such as a reduction in speed, an emissions decrease may even be expected. Therefore, Category 2b should have a lower threshold compared to Category 2a but higher than Category 1 as the changes are more significant.

A suspicious ER threshold of 1.2 is recommended based on doubling the Category 1 allowance to account for other factors beyond test-to-test variability. This is supported by Category 2b test results from petrol vehicles, which show that emissions remain the same or decrease (JRC, 2018). The CF threshold is 1.0 when using emission limits as the baseline.

The extreme threshold is a CF of 3.0, as explained under Category 2a.

CATEGORY 2C

Category 2c tests are hot start tests, which are expected to result in lower emissions. This is due to the fact that in-cylinder (e.g. EGR) and aftertreatment emission control systems are more effective with a warm up engine.

Data from the U.S. EPA provides evidence for reduced emissions after hot starts. In the United States, 30 diesel light-duty vehicles were tested from both a cold start and a hot engine restart using the same drive cycle (FOIA online, 2016). On average, hot start NO_x emissions were only 12% of cold start emissions, and the highest ratio of hot start to cold start NO_x emissions was 58%. In contrast, vehicles tested in Europe exceeded the type-approval values: the average hot start emissions for 19 Euro 6 cars tested in the UK was 80 mg/km and the average for 30 Euro 6 cars tested in Germany was 110 mg/km. Thus, for hot start tests, the ER for hot start tests should be no more than 0.6, rounded up from the maximum of the 30 US diesel vehicles. The corresponding CF threshold is 0.5.

The Category 2c extreme threshold is set at a CF of 1.3, the same as the Category 1 CF. Hot start tests should not change the operation of the engine or emission control system and emissions should always be lower.

CATEGORY 3 AND CATEGORY 4

Category 3 tests are conducted on the road under conditions that are uncontrolled to a large extent. This category includes tests that are compliant with RDE requirements as well as those that are slightly outside of the RDE boundary conditions or measured using Smart Emission Measuring System (SEMS) instead of the RDE-compliant PEMS. Category 4 tests are conducted during real-world operation by remote sensing.

Although the two categories have differing conditions and measurement methods, the thresholds are evaluated together, as evidence shows that the emission results line up relatively well. As shown below in Table B-2, the percent of vehicles exceeding different CFs is similar enough between official government testing Category 3 testing and remote sensing to justify using the same thresholds for both categories. This choice is also partially due to limited data, as emissions from diesel cars nearly all show high real-world emissions and therefore is not a good source for determining an appropriate cutoff for suspicious vehicles.

Table A2. Comparison of official government Category 3 real-world testing with remote sensing data on Euro 5 and pre-RDE Euro 6 diesel vehicles.

	Euro 5		Euro 6	
	Official government (Cat. 3)	Remote sensing (Cat. 4)	Official government (Cat. 3)	Remote sensing (Cat. 4)
CF < 1	0%	0%	0%	3%
CF < 2	2%	0%	3%	12%
CF < 5	62%	46%	39%	51%

Instead, petrol vehicle emissions data are used as a surrogate in determining the thresholds. Emissions from diesel vehicles with correctly dimensioned emission control systems should not significantly differ from petrol emissions under RDE conditions. While there have been some reports of potential prohibited defeat devices in petrol vehicles, these cases are likely a small minority. One source on Euro 6 petrol vehicles is the ICCT PEMS database, which compiles RDE tests from different sources, primarily from manufacturer reported results. The ICCT PEMS database shows that 94% of Euro

6 petrol vehicles are within a CF of 2.1. Euro 5 and 6 petrol vehicle remote sensing data show that 89% of Euro 5 petrol engine families and 95% of Euro 6 petrol engine families are within a CF of 2.1. Both sources show that a large majority (89%–95%) of petrol vehicles with CF < 2.1, meaning that vehicles exceeding this have a high likelihood of employing a prohibited defeat device. Therefore, the suspicious threshold is set at a CF of 2.1 for Categories 3 and 4.

The extreme threshold is set at a CF of 4.0, also based on petrol data from the ICCT PEMS database and remote sensing data. Over 99% of the Euro 6 petrol vehicle from the ICCT PEMS database have a CF < 4.0 and almost 99% of both Euro 5 and Euro 6 petrol family averages from remote sensing data have a CF < 4.0.

APPENDIX B

This appendix defines the different categories used in this analysis to group testing conditions. These are generally grouped similarly to JRC's recommended categories. The major difference is for Category 2, which in this analysis is split into Category 2a, 2b, and 2c to account for differences within controlled testing.

CATEGORY 1

This category follows JRC's recommended definition of controlled laboratory testing with minimal changes to NEDC or WLTP (European Commission, 2017).

CATEGORY 2A

Potential changes to the testing include lower ambient temperature, altered preconditioning, altered shift patterns, slight increases to vehicle speed, increasing the engine load by turning on the AC or lights, and performing the type-approval test cycle on a test track instead of in a laboratory. Each of these changes and the expected engine and emission control system responses are outlined below:

» Testing at colder ambient test temperatures can modestly extend the cold start interval and delay proper operation of EGR and aftertreatment. However, once the engine and emissions control system reach normal operating temperature, ambient temperature should not impact their physical responses.

» Elimination or alteration of vehicle preconditioning before the official test could affect operation immediately after the start of the test. However, if there are no hysteresis effects embedded, the engine and emission control system should quickly return to normal operation.

» Changing shift patterns (manual transmission) can change the torque versus engine speed and have minor impacts on how the engine operates. However, this should have no impact on operation of the emissions control system and overall average engine loads do not significantly change. Thus, emission impacts should be minimal.

» Modest increases to the test cycle vehicle speeds cause an increase in engine speeds and loads. Examples include increasing NEDC speeds by 10% and testing on the WLTP instead of the NEDC. Engine out emissions are roughly proportional to engine load, so increases in engine speeds and load will have proportional increases in engine out emissions. Since tests in this category only slightly increase speed, there should be only modest increases in emissions.

» Increasing the engine load by turning on the air conditioning or lights has a similar impact as increasing the vehicle speed. Overall emission changes should be proportional to the load changes, which are relatively small for tests in this category.

» Testing a vehicle on a track instead of in a laboratory can increase the engine load but could also decrease the load. The response depends on how the real-world tire rolling resistance and aerodynamic load compare with the coefficients submitted by the manufacturer for dynamometer testing. Thus, this should have little or no impact on emissions.

Extremely low ambient temperatures (below 3°C), [9] very high engine loads, and very low speed cycles with a cold start are avoided for Category 2a tests.

9 Under the first RDE legislation, if temperatures drop below 3°C, this is considered 'extended' conditions and the emissions results for the test are divided by a factor of 1.6 (UK 2018 report). Tests below 3°C are not included in this analysis.

CATEGORY 2B

Examples include repetition of selected phases of the test cycle, testing with reduced engine loads (e.g. minor reductions to the test cycle vehicle speeds),[10] and testing at higher ambient temperatures with normal vehicle loads.[11]

CATEGORY 2C

The physical response of the engine and emissions control system after they warm up should not differ from cold starts. However, emissions should be lower on the hot start test for diesel vehicles because the EGR and aftertreatment are fully warm when the test starts (German, 2016). During a hot start the catalyst can be effective from the first second of the test, while for cold starts there is a delay until the catalyst heat up. Similarly, the full EGR can be used with a warm engine, while during cold starts the EGR has a limited ability to significantly lower diesel engine-out NO_x due to limited exhaust pressure upstream of the turbocharger and combustion instability due to cold cylinders.

Manufacturers have claimed that NO_x formation is higher after hot starts, but NO_x formation is dominated by peak combustion temperature, which is only minorly impacted by the engine block temperature.

CATEGORY 3 AND CATEGORY 4

Category 3 tests are conducted on the road under conditions that are uncontrolled to a large extent. This category includes tests that are compliant with RDE requirements as well as those that are slightly outside of the RDE boundary conditions or measured using Smart Emission Measuring System (SEMS) instead of the RDE-compliant PEMS.

Category 4 tests are conducted during real-world operation and measured by remote sensing.

10 Tests with very low load and speed cycles after a cold start, which can cause delayed light off of the catalyst leading to elevated emissions, are not evaluated in this analysis.

11 Manufacturers have claimed that the EGR modulation rate might decrease at high ambient temperatures in order to avoid overheating of the engine (European Commission 2017). However, this is only of concern when high ambient temperatures are combined with very high engine loads. For any of the testing conditions discussed in this paper, high ambient temperatures should not affect the physical response of the engine and emission control system. In fact, the cold start is shorter at high ambient temperatures, emissions may be expected to decrease with higher ambient temperatures.

APPENDIX C

This appendix summarizes the tests conducted in each of the official government reports and their full definitions.

Table C1. Test cycles conducted in each Member State market surveillance report

Source	Cat. 1	Cat. 2a	Cat. 2b	Cat. 2c	Cat. 3
Ministre wallon de l'Environnement. (2016)		Real-world speed trace			
Ministre de l'Environnement, de l'Energie et de la Mer (2016)	D1	D2 D3			
IFPEN (2017)	D1	D2 D2 cold – unofficial			
Bundesministerium für Verkehr und digitale Infrastruktur (2016)		NEDC 10°C hot NEDC reverse hot PEMS NEDC road NEDC +10% PEMS NEDC -10% PEMS		NEDC hot	RDE+
Ministero delle infrastrutture e die trasporti (2016)		Urban NEDC 70 hot track NEDC 70 cold track NEDC reverse cold		NEDC hot NEDC reverse hot	
Joint Research Centre (2016)	NEDC 4x4	NEDC 10°C cold NEDC 4W 10°C cold NEDC 4W 10°C hot NEDC 4W Mod 10°C cold NEDC 4W Mod 10°C hot NEDC 4W Mod cold NEDC 4W Mod hot WLTP 4W 10°C cold WLTP 4W cold WLTP 4W hot WLTP HRL cold WLTP HRL hot WLTP LRL 30°C cold WLTP LRL 30°C hot WLTP LRL 4W 30°C cold WLTP LRL 4W cold WLTP LRL 4W hot WLTP LRL hot		NEDC 4W hot NEDC hot	RDE+
Martini et al. (2018)	NEDC	NEDC +10% NEDC +load hot NEDC 10°C cold NEDC modified UDC WLTP WLTP Hot WLTP 10°C WLTP 30°C	NEDC Cold w/o conditioning NEDC 30°C cold	NEDC hot	RDE+
Clairotte et al. (2020)	NEDC				
RDW (2016)		NEDC hot track NEDC +10% track NEDC -10% track NEDC reverse hot track NEDC +load hot track NEDC running engine track NEDC ≤ 20°C cold track NEDC ≥ 25°C cold track			RDE+
RDW (2017)		NEDC hot track NEDC +10% NEDC +10% track NEDC -10% track NEDC reverse hot track NEDC +load hot track NEDC running engine track NEDC ≤ 20°C cold NEDC ≤ 20°C cold track NEDC ≤ 20°C hot NEDC ≤ 20°C hot track NEDC ≥ 25°C cold track	NEDC ≥ 25°C cold	NEDC hot NEDC running engine	RDE+
Department for Transport (2016)		NEDC hot track NEDC +10%*		NEDC hot NEDC double hot* NEDC reverse hot*	RDE+
Department for Transport (2018)	NEDC	NEDC hot track NEDC double hot track NEDC +10% NEDC +10% track NEDC reverse hot track WLTP		NEDC hot NEDC double hot NEDC reverse hot	RDE+
Department for Transport (2019)	NEDC	WLTP track		NEDC hot	RDE+

Note: Data from the UK reports are extracted from the figures. The Department for Transport (2016) report references three tests, NEDC +10%, NEDC double hot start, NEDC reverse hot start, for which results are not presented (*).

Category 1 – Modifications that should not change the response of the engine and emission control systems:

- **NEDC:** New European Driving Cycle, as defined in UN regulation 83
- **D1**: NEDC with modified parameters, such as the position of the engine hood, making the non-motor wheels turn by running the test on a 4x4 dynamometer, by going into reverse gear during the test, after the first threshold of 15 km/h, modifying the preconditioning cycle, and not charging the battery.
- **NEDC 4x4**: NEDC on a 4x4 dynamometer

Category 2a – Modified test conditions that can cause minor or temporary emission increases:

- **D2:** straight after D1, hot NEDC ran with modified urban driving cycle (UDC) but identical Extra-Urban driving cycle (EUDC)
- **D2 cold – unofficial:** cold start NEDC ran with modified UDC but identical EUDC (unofficial test)
- **D3**: NEDC on a test track, measured with PEMS
- **NEDC hot track:** hot start NEDC on a test track
- **NEDC double hot track:** two consecutive hot start NEDC on a test track (A represents measurements from first cycle, B is second cycle, A+B is combined measurement)
- **NEDC running engine track:** NEDC started with running engine (no start) on a test track
- **NEDC +10%:** NEDC with speed increased by 10% and engine at operating temperature
- **NEDC +10% PEMS:** NEDC on flat road with speed increased by 10% and engine at operating temperature, measurements with PEMS
- **NEDC +10% track:** NEDC on a test track with speed increased by 10% and engine at operating temperature, measurements with Smart Emission Measurement System (SEMS)
- **NEDC -10% PEMS:** NEDC on flat road with speed decreased by 10% and engine at operating temperature, measurements with PEMS
- **NEDC -10% track:** NEDC on a test track with speed decreased by 10% and engine at operating temperature, measurements with SEMS
- **NEDC +load hot**: NEDC with engine at operating temperature with additional energy consumers (ex. lights, air conditioner)
- **NEDC +load hot track**: NEDC with engine at operating temperature with additional energy consumers (ex. lights, air conditioner) on a test track
- **NEDC 70 cold track**: cold start NEDC on track, measurements with PEMS, top speed capped at 70 km/h instead of 120 km/h and test duration 1030 seconds instead of 1180 seconds
- **NEDC 70 hot track**: hot start NEDC on track, measurements with PEMS, top speed capped at 70 km/h instead of 120 km/h and test duration 1030 seconds instead of 1180 seconds
- **NEDC modified UDC**: NEDC with modified UDC
- **NEDC reverse cold**: cold start NEDC, EUDC then UDC
- **NEDC reverse hot track:** hot start NEDC, EUDC then UDC on a test track
- **NEDC reverse hot PEMS**: hot start NEDC, EUDC then UDC on road, measurements with PEMS

- **NEDC road**: NEDC on flat road with engine at operating temperature, measurement with PEMS
- **NEDC 10°C cold**: cold start NEDC at 10°C ambient temperature
- **NEDC 10°C hot**: hot start NEDC at 10°C ambient temperature
- **NEDC ≤ 20°C cold:** cold start NEDC at ≤ 20°C ambient temperature
- **NEDC ≤ 20°C hot:** hot start NEDC at ≤ 20°C ambient temperature
- **NEDC ≤ 20°C cold track:** cold start NEDC at ≤ 20°C ambient temperature on a test track
- **NEDC ≤ 20°C hot track:** cold start NEDC at ≤ 20°C ambient temperature on a test track
- **NEDC ≥ 25°C cold track:** cold start NEDC at ≥ 25°C starting ambient temperature on a test track
- **NEDC 4W mod cold:** cold start modified cycle NEDC on a 4WD dynamometer
- **NEDC 4W mod hot:** hot start modified cycle NEDC on a 4WD dynamometer
- **NEDC 4W 10°C cold:** cold start NEDC on a 4WD dynamometer at 10°C ambient temperature
- **NEDC 4W 10°C hot:** hot start NEDC on a 4WD dynamometer at 10°C ambient temperature
- **NEDC 4W mod 10°C cold:** cold start modified cycle NEDC on a 4WD dynamometer at 10°C ambient temperature
- **NEDC 4W mod 10°C hot:** hot start modified cycle NEDC on a 4WD dynamometer at 10°C ambient temperature
- **Urban:** Urban part of the Common Artemis Driving Cycle (CADC)
- **Real-world driving cycle:** lab test based on trace from real-world operation
- **WLTP:** worldwide harmonized light vehicle test procedure
- **WLTP hot:** WLTP with engine at operating temperature
- **WLTP 4W cold:** cold start WLTP on a 4WD dynamometer
- **WLTP 4W hot:** hot start WLTP on a 4WD dynamometer
- **WLTP 10°C:** WLTP at 10°C ambient temperature
- **WLTP 30°C:** WLTP at 30°C ambient temperature
- **WLTP 4W 10°C cold:** cold start WLTP on a 4WD dynamometer at 10°C ambient temperature
- **WLTP LRL 30°C cold:** cold start low road load WLTP at 30°C ambient temperature
- **WLTP LRL 30°C hot:** hot start low road load WLTP at 30°C ambient temperature
- **WLTP LRL 4W 30°C cold:** cold start low road load WLTP at 30°C ambient temperature
- **WLTP LRL hot:** hot start low road load WLTP
- **WLTP LRL 4W cold:** cold start low road load WLTP on a 4WD dynamometer
- **WLTP LRL 4W hot:** hot start low road load WLTP on a 4WD dynamometer
- **WLTP HRL cold:** cold start high road load WLTP
- **WLTP HRL hot:** hot start high road load WLTP

Category 2b – Test changes that should not change the physical response of the engine and emission control system:

- **NEDC ≥ 25°C cold:** cold start NEDC at ≥ 25°C ambient temperature
- **NEDC 30°C cold:** cold start NEDC at 30°C ambient temperature
- **NEDC cold w/o conditioning:** cold start NEDC without temperature conditioning

Category 2c – Hot starts:

- **NEDC hot:** NEDC with engine at operating temperature
- **NEDC running engine:** NEDC started with running engine (no start)
- **NEDC 4W hot:** hot start NEDC on a 4WD dynamometer
- **NEDC reverse hot:** hot start NEDC, EUDC then UDC
- **NEDC double hot:** two consecutive hot start NEDC (A represents measurements from first cycle, B is second cycle, A+B is combined measurement)

Category 3:

- **RDE+**: test on the road, typically conducted with PEMS. A few tests do not follow the official RDE guidelines (e.g., tested outside of ambient temperature window or measured using SEMS)

APPENDIX D

An example of good correspondence between Member State real-world surveillance testing and remote sensing emission measurements averages is shown for the 1.6L Nissan Qashqai and Renault Talisman. These vehicles have the first and fifth highest ERs of all Euro 6 vehicles in this analysis. Multiple tests were run on these vehicles from Categories 1, 2a, 2c, 3, and 4 (Figure E1). All category tests had very high ERs and CFs, exceeding all of the extreme thresholds on average. Average emissions and CF for Member State Category 3 tests were very similar to average remote sensing measurements.

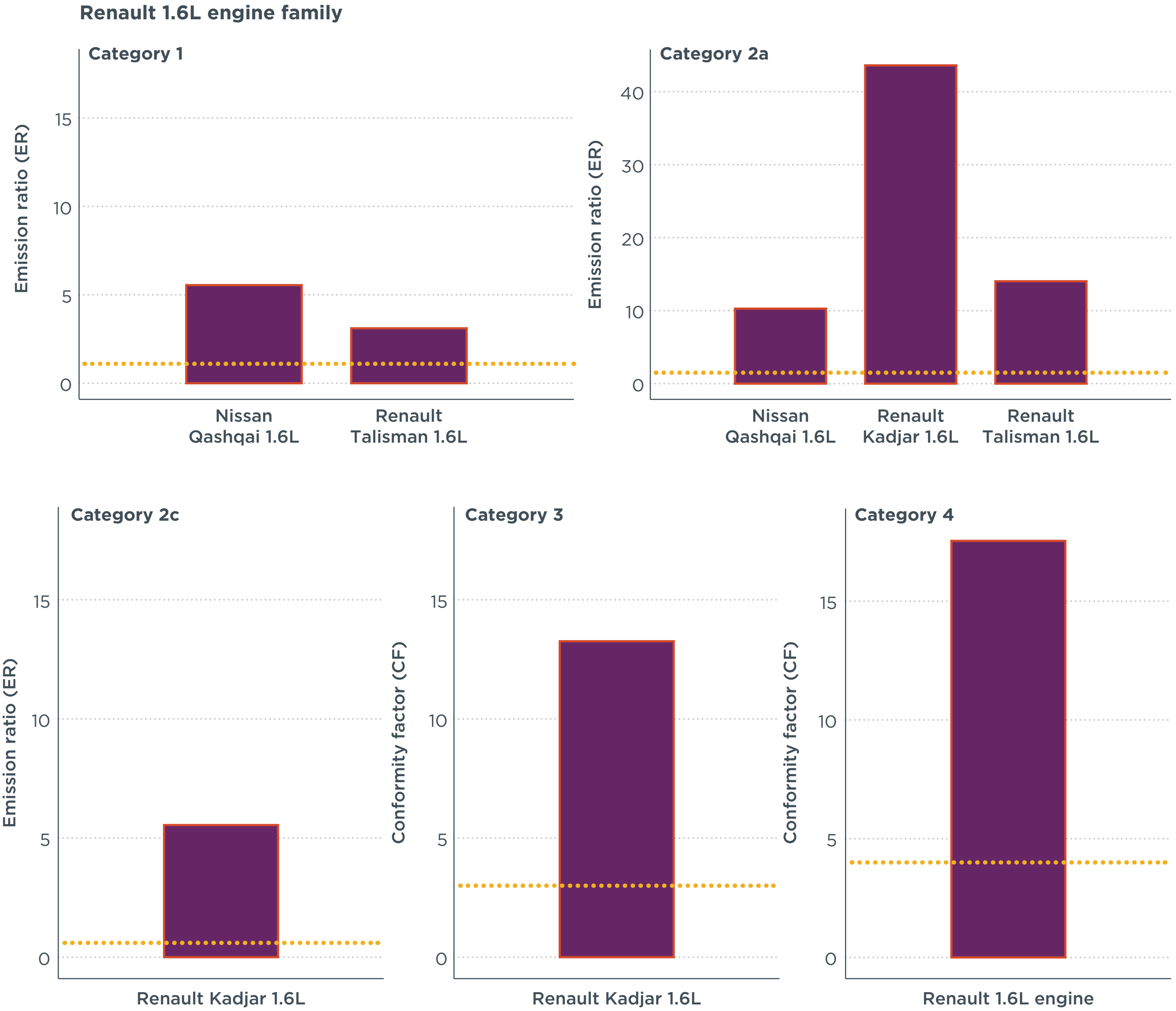


Figure D1. Tests results by vehicle model for one vehicle engine family (Renault 1.6L Euro 6 engine). The yellow dotted lines show the suspicious thresholds. Nearly all tests exceed the extreme threshold of their respective categories.