THE REAL URBAN EMISSIONS INITIATIVE

Explanation of the TRUE real-world passenger vehicle emissions rating system

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THE TRUE INITIATIVE

Studies have documented significant and growing discrepancies between the amount of NO_X emissions detected in diesel vehicle exhaust during type-approval tests and the amount that vehicles emit in "real-world" operation—on the road in normal driving. Excess real-world emissions are a significant issue, particularly in Europe where dieselization of the light-duty vehicle fleet is much higher than in other global regions. Poor real-world NO_X emissions control has contributed to persistent air quality problems in many European cities and has adversely affected public health. Directly emitted NO_X can have important public health impacts close to roads.

The FIA Foundation, the International Council on Clean Transportation, Global NCAP, Transport and Environment, and C40 Cities have established The Real Urban Emissions Initiative (TRUE). The TRUE initiative seeks to supply cities with data regarding the real-world emissions of vehicle fleets and equip them with technical information that can be used for strategic decision-making. TRUE will use a combination of measurement techniques to produce a granular picture of fleet-wide real-world emissions by make, model, and model year.

One of the key objectives of TRUE is to raise awareness of the magnitude and scope of excessive real-world vehicle emissions. To that end, TRUE is publishing a series of technical papers to document the methods that have been developed to evaluate real-world vehicle emissions. This is the second paper, focusing on development of a method to rate vehicles on real-world NO_X emissions as measured by remote sensing data (RSD) for public use.[1] The methods to measure emissions using remote sensing and to analyze the results were discussed in the first TRUE paper, "Determination of real-world emissions using remote sensing data".[2]

1 TRUE considers total NO_X emissions and does not separate NO and NO_2.

2 Please see the following link for the paper, "Determination of real-world emissions from remote sensing": https://www.trueinitiative.org/data/publications/explanation-of-the-true-rating-scheme

OVERVIEW OF TRUE RATING CONCEPT

The TRUE rating is a three-color categorization system designed to concisely inform the public of the relative magnitude of emissions from Euro 3 through Euro 6 vehicle models under a wide range of operating conditions and driving behaviors.

Factors included in the TRUE ratings include emission control system deterioration, defective parts, software that increases emissions in conditions outside of those typically covered by the regulation, and improvements by recalls and retrofits.

TRUE ratings use green, yellow, and red target symbols to indicate Good (green), Moderate (yellow), or Poor (red) emissions performance (see Figure 1).

Specifically, the ratings reflect these measurement findings:

Figure 1. TRUE ratings

(1) **Green rating:** vehicles with average NO_X emissions that stay below 90 mg/km over a wide range of driving conditions.

(2) **Yellow rating:** vehicles with average NO_X emissions between 90 and 180 mg/km over a wide range of driving conditions, as well as vehicles that do not clearly fall into (1) or (3).

(3) **Red rating:** vehicles with average NO_X emissions that stay above 180 mg/km over a wide range of driving conditions.

The TRUE rating currently covers only NO_X emissions. The rating will incorporate additional tailpipe pollutants, including particulate matter, carbon

monoxide, and hydrocarbon emissions, during future phases. The ratings are fluid and will be re-evaluated as more data are gathered.

TRUE VEHICLE EMISSIONS DATA SOURCES

A core element of the TRUE project is the ongoing collection of data on real-world emissions from in-use vehicles in cities. Data is obtained from two main sources: test results supplied by third parties, such as independent testing facilities or government laboratories, and vehicle tests commissioned by or carried out by the TRUE initiative itself. Emission measurements are made using two different but complementary techniques:

- Portable emissions measurement system[3] (PEMS) testing. PEMS testing uses sensors and analytical equipment mounted on a vehicle, typically in the trunk or boot, to directly measure the second-by-second emissions of a vehicle as it is being driven on the road or track.
- Remote sensing. This uses various non-intrusive spectroscopic methods to capture a snapshot of exhaust emissions as a vehicle drives through a beam of light at the sampling location, which would typically be a roadway with free-flowing traffic.

The TRUE project has already compiled large databases of PEMS and remote sensing real-world emissions data from third-party institutions. PEMS data has been collected on more than 200 vehicles tested by the governments of France, the United Kingdom, the Netherlands, Belgium, and Germany. A database of more than 700,000 remote sensing measurements has also been collected as part of the CONOX project.[4] The CONOX project is being conducted under the umbrella of the European research network on mobile source emissions,[5] which includes a dedicated working group on remote sensing. Various remote sensing research groups have worked together to pool and analyze remote sensing data collected at various locations in France, Spain, Sweden, Switzerland and the United Kingdom since 2011. Data from the various measurement campaigns has been compiled and supplied by the Swedish Environmental Research Institute (IVL).[6]

The TRUE initiative has commissioned additional data collection, including remote sensing measurements in London and Paris in late 2017 and early 2018. These remote-sensing measurement campaigns will eventually yield a database of more than 200,000 additional vehicle records. Data collection will continue as the TRUE initiative grows and expands its network of data providers.

Remote sensing is most crucial to the TRUE initiative. Using this technology, it's possible to measure emissions from thousands of vehicles in a single day. The snapshot of the exhaust plume content collected from a passing vehicle is equivalent to about one second's worth of emissions data for a single operating condition, but over time many hundreds or thousands of such snapshots for a given vehicle group can be collated at multiple locations. The result is a realistic picture of the exhaust emissions of that vehicle model over time and over a range of operating conditions, such as at different ambient temperatures, vehicle speeds, and so on.[7]

PEMS testing complements the remote sensing data because the data obtained from a PEMS test—typically several hours of measurements—gives a very detailed picture of the emissions performance of a specific vehicle over one specific trip and set of conditions. It would be prohibitively expensive to use PEMS testing to measure emissions of all the different vehicle models on the road. PEMS testing excels at in-depth investigations of individual vehicle models. The TRUE initiative intends to employ PEMS testing to investigate vehicles that stand out as high emitters based on data from remote sensing.

It is important to note that, while the data are checked for bias, no boundary conditions are placed on the data utilized to determine the TRUE rating, as data is accepted from vehicles being driven over any driving conditions and over any ambient conditions that

3 Or any other portable solutions like mini-PEMS or sensor-based equipment.

4 The project defines CONOX as:
- COmprehending NO_x remote sensing measuring
- COmbining NO_x remote sensing measurements
- COmparing NO_x real driving emissions
- COllaborating on NO_x real driving emission measurements

5 ERMES, http://www.ermes-group.eu/web/

6 Please see "Determination of real-world emissions from remote sensing": https://www.trueinitiative.org/data/publications/explanation-of-the-true-rating-scheme for a detailed explanation of the CONOX project and the data obtained.

7 Further information on remote sensing technology and its different applications can be found here: https://www.theicct.org/publications/vehicle-emission-remote-sensing

may be found in the real world. Pre-defined testing protocols are vulnerable to cheating. While the RDE test protocol[8] is much broader than laboratory tests, it still excludes a certain portion of real-world operating conditions. The TRUE rating utilizes the best available data from a range of independent testing organizations and laboratories.

CALCULATING REAL-WORLD EMISSIONS VALUES

The first step in the development of the TRUE rating is to use the remote sensing emissions data to systematically determine an average real-world emissions factor. The methodology we use for doing this is described in detail in a previous TRUE paper[9] and summarized below.

Data from remote sensing are reported as molar ratios of pollutants to CO_2. The desired unit is ultimately pollutant mass per kilometer (g/km), which is calculated in a two-step process. The first step is to convert to pollutant mass per fuel burned mass (g/kg) using a carbon balance method. This is done utilizing the measured amount of carbon monoxide (CO) and hydrocarbons (HC) relative to tailpipe CO_2, in addition to the assumed/known carbon weight fraction of a given fuel. The second step is to convert to a unit of pollutant per distance (in g/km). This can be done by utilizing the average real-world fuel consumption of a given vehicle model or group of models. It is also of key importance that a sufficient quantity of remote sensing measurements are used when calculating average emissions using this technique. Lastly, we ensure that average measurement and driving conditions are sufficiently similar across different vehicle families to yield comparable emissions results for all vehicle groups.

Figure 2 compares the distance-specific NO_X results (g/km) for all vehicle families that are present in both the PEMS and remote sensing datasets. The results are almost identical for both Euro 5 and Euro 6 diesels, suggesting that the average result for emissions from both PEMS and remote sensing are comparable.

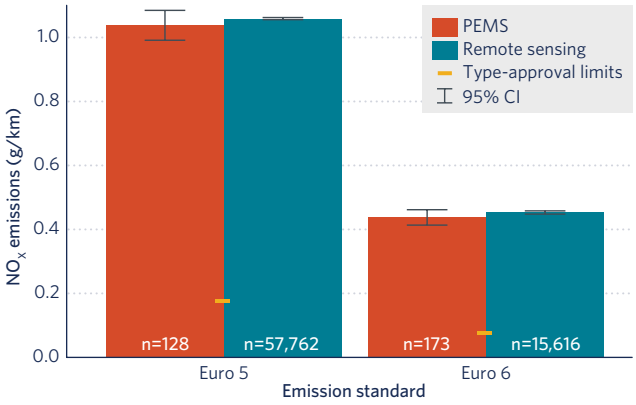

Figure 2. Average NO_x emissions (g/km) of Euro 5 and 6 diesel passenger cars measured from emissions testing campaigns with PEMS and calculated from remote sensing data. Error bars represent the 95% confidence interval of the mean.

CONVERTING REAL-WORLD EMISSIONS TO TRUE RATINGS

To balance the desire to accurately rate as many vehicles as possible within the constraints of data quantity, vehicles are grouped into vehicle families for the purpose of rating them. The vehicle family grouping and rationale were described in great detail in the earlier TRUE study.[10] In summary, we have determined that vehicle families with the same manufacturer group, fuel type, engine displacement, and Euro standard exhibit real-world emissions of a similar level. Therefore, all vehicles within a given family receive the same rating. Note that this means that multiple vehicle models can be included in each vehicle family. With this grouping methodology, more than 90% of EU car registrations from Euro 3 to 6 can be covered by monitoring around 700 vehicle families.

In-use emissions of individual vehicles could still vary within a vehicle family. For example, differences in the mass and shape of a given vehicle model could affect the average load on the engine and consequently the average emissions. For example, SUVs have higher weight and air drag with the same engine and therefore higher CO_2 emissions. That being said, the TRUE rating is meant to be statistically representative of the average emissions measured for a given vehicle family.

8 The Real Driving Emissions (RDE) test protocol is a PEMS-based emissions type-approval test to which the EU is transitioning between September 2017 and September 2019.

9 Please see the following link for the paper "Determination of real-world emissions from remote sensing": https://www.trueinitiative.org/data/publications/explanation-of-the-true-rating-scheme

10 Please see the following link for the paper "Determination of real-world emissions from remote sensing": https://www.trueinitiative.org/data/publications/explanation-of-the-true-rating-scheme

For determination of the TRUE rating we first analyze the remote sensing data for a given vehicle family. We then determine average emissions as well as confidence intervals from all remote sensing data we have collected for that vehicle family. This allows us to determine the ranking and color rating of the vehicle. While the current ratings are based solely upon the remote sensing data, PEMS data could be used to supplement the remote sensing data in the future, especially in cases in which the given vehicle family has low market penetration.

The cutoff point for a green rating, representing the lowest-emitting vehicles, is set at 90 mg/km NO_X, corresponding to the on-road Euro 6d limit for petrol vehicles. Officially, this includes a 50% margin above the 60 gm/km type-approval limit to account for on-road measurement uncertainty. The cutoff for the yellow rating is set at 180 mg/km NO_X, two times the limit for the green rating and equivalent to the Euro 5 type-approval limit for diesel cars. The TRUE rating currently covers only NO_X emissions from passenger cars. The rating will incorporate additional pollutants as well as results from light-commercial vehicles during coming phases of the project.

A number of decisions based on priorities were made in the design of the program. For example, a three-color rating system was chosen for simplicity and consumer understanding instead of presenting numerical emissions values for every vehicle model. Vehicles were grouped into families that share the same engine to obtain higher fleet-wide coverage and reduce complexity. Data was collected over a wide range of driving conditions and ambient conditions with no exclusions[11] instead of using a standardized test to account for all factors affecting vehicle emissions.

The ratings include the statistical reliability of the real-world emissions estimate. If average emissions are significantly lower than 90 mg/km or higher than 180 mg/km at a 95% confidence level,[12] the rating is respectively green or red. If the result is not significantly lower than 90 mg/km nor higher than 180 mg/km, the result of the remote sensing analysis is a yellow rating. As Figure 3 illustrates for Euro 6 vehicles, some vehicle families end up close to the border between green/yellow or yellow/red. The ratings will be re-evaluated on a regular basis as new remote sensing and other emissions testing campaigns are conducted and may be adjusted based on the most current emissions data.

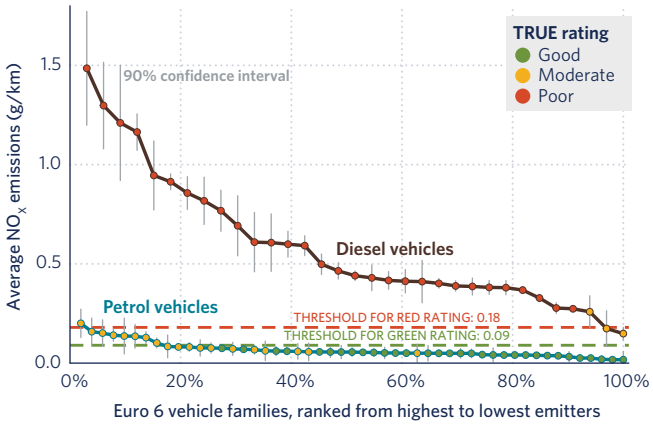

Figure 3. Diesel and petrol Euro 6 vehicle families. Indication of TRUE rating, thresholds, and 90% confidence

WHAT THE TRUE RATINGS REFLECT

While new vehicles are by definition certified to emissions levels at or below the legal limit, real-world vehicle emissions are often much higher for a variety of reasons: deterioration of emissions control systems, defective parts, software that increases emissions during normal driving or driving conditions outside of those covered by the regulation (defeat devices or off-cycle emissions)[13]. Emissions are also affected in a positive way by recalls and retrofits. The TRUE ratings reflect all these factors.

The TRUE rating currently reflects only NO_X emissions. In the future it will be expanded to cover other local air pollutant emissions, such as particulate matter (PM), carbon monoxide, and hydrocarbons (HC). TRUE ratings are meant to give guidance as to the real-world emissions performance of a given

11 Note that there are certain conditions in which exhaust gas concentrations and flow rate are too low to measure by remote sensing, such as during vehicle deceleration when the engine is being motored.

12 One-sided t-tests at 95% confidence level were conducted to determine whether average emissions of each vehicle family were significantly lower than 90 mg/km or significantly higher than 180 mg/km. These one-sided t-tests are essentially the same as 90% confidence intervals. For example, if the upper bound of the 90% confidence interval does not exceed 90 mg/km, emissions are significantly (at 95% confidence level) lower than the threshold.

13 Emissions of individual vehicles could also be affected by emissions system tampering or maintenance issues. Emissions from tampered or broken emissions control systems can be very high, so it might not take a lot of such measurements to have a significant impact on the TRUE rating. While we do not know how much tampering or maintenance issues affect the data results, it is important that the TRUE rating reflect all causes of real world emissions.

vehicle model and are neutral with respect to fuel and emissions standard.

The TRUE rating does not currently incorporate a large share of cold-start emissions. While the remote sensing data does not filter out cold starts, the typical emissions aftertreatment system usually reaches normal operating temperatures about 1 minute (for petrol vehicles) to 5 minutes (for diesel vehicles) after a cold start. Typical remote sensing locations measure emissions after the vehicles have been driven longer than this, although it would be possible to set up a remote sensing unit at the exit from a long-term parking facility. Cold starts can have a significant effect on all emissions from petrol and diesel vehicles. The cold start can contribute 80% of total emissions for a typical urban trip, especially for HC and CO emissions from petrol vehicles. It is possible that inclusion of cold-start emissions would reduce the percentage of vehicles with green and yellow TRUE ratings for NO_X.

The TRUE rating does not reflect emissions of CO_2, the primary pollutant causing global climate change. There is no direct link between NO_X and CO_2 emissions for vehicles with properly operating emissions control systems, and it is possible for a vehicle to emit low levels of NO_X but relatively high levels of CO_2, or high NO_x with relatively low levels of CO_2. We are exploring options for incorporating CO_2 emissions into the TRUE project at a later date, although in contrast to the other pollutants, doing so could not be based on remote sensing data using current technology.[14]

The TRUE rating does not indicate whether a particular model or group of models is in or out of compliance with EU vehicle emissions regulations. Vehicle emissions type-approval relies on a strictly defined test protocol. The TRUE rating does not use type-approval test protocols and includes emissions measured over a range of conditions that are not covered by regulations. For example, existing regulations in the EU limit requirements for vehicles to meet pollutant emissions limits in-service to five years or 100,000 km, whichever comes first, and strict requirements are set on maintenance and use of the vehicles for in-service testing. But the average age of vehicles on the road in the EU is 10.7 years.[15] Because the TRUE rating is based on remote sensing measurements of a large number and wide range of vehicles on the road, it captures vehicles that are significantly older than those covered by existing regulations. It also captures the full range of emissions-related maintenance and tampering issues.

By design, the TRUE rating is difficult if not impossible to defeat, or cheat, because it does not rely on a test with predefined driving cycles and test conditions and is not dependent only on results from RDE testing performed with PEMS equipment. Any time a set protocol is developed, manufacturers naturally design emissions control strategies to specifically target low emissions during the test. Vehicles are able to detect conditions when undergoing an RDE test and possibly adjust emissions control strategies accordingly.

At this time, we are not aware of any method of cheating remote sensing measurements because the equipment is completely separated from the vehicle and the vehicle has no way of detecting that it is being tested. Nevertheless, we continue to be alert for potential ways in which remote sensing analyzers could be deceived, especially if permanent remote sensing locations are established.

STRENGTHS OF THE TRUE RATING SYSTEM

The TRUE rating system can be leveraged by vehicle owners and car buyers to help them gain insight into the real-world emissions of a given vehicle model and use that information in their decision-making process.

The ability to adjust the rating over time is one of the core benefits of the TRUE rating system—the ability to monitor how vehicles behave in the real world with the flexibility to adjust over time as vehicles age and deteriorate and new data and information come to light. New real-world data will continue to be incorporated as more vehicle testing campaigns are performed.

For example, a Euro 6 vehicle family might receive a green rating today based on the latest remote sensing data. But perhaps five years from now data would demonstrate that the same vehicle family is deteriorating, meaning vehicle emissions do not stay low as the vehicle ages. Eventually the TRUE rating

14 Although remote sensing technology is capable of measuring CO_2 concentrations, as of the writing of this paper there is no verified method for directly obtaining real-world CO_2 values in g/km from remote sensing.

15 Source: http://www.acea.be/statistics/tag/category/average-vehicle-age

for that vehicle family could shift from green to yellow or red, depending on the amount of deterioration. Conversely, perhaps a manufacturer might conduct a recall to address a high-emissions issue. In such a case, the rating for a given family could actually improve from red to yellow or green over time.

Another strength of the TRUE rating system is its ability to capture a wide range of real-world conditions. A key principle of the TRUE project is that the term "real-world emissions" should not be defined in a prescriptive way. For regulatory purposes certain boundary conditions are applied to an emissions test to ensure that all vehicles are tested in the same way or within comparable limits. This means that boundary conditions are placed on things like driving speeds, acceleration rates, ambient temperatures, and vehicle age for the purposes of regulatory testing. But real drivers in real cities often experience conditions outside of these boundaries. It is very possible that a vehicle could have low emissions under some conditions but high emissions under others. Such a vehicle would be unlikely to receive a green TRUE rating. A vehicle receiving a green TRUE rating should have low emissions under a wide range of conditions. We do not see any rationale for excluding emissions under any likely driving conditions from our ratings.

The data includes measurements gathered at temperatures ranging from -5°C to 43°C and driving on both flat roads and grades and under a wide range of engine power and vehicle speeds. For each individual vehicle family a set of checks is performed to ensure that the data for that family includes at least 30 measurements over a wide range of conditions so that no vehicle family is unfairly judged.

SUMMARY OF KEY RESULTS

Thousands of vehicle models[16] have already been rated using the TRUE rating methodology described above. An overview of the initial ratings is shown below in Figure 4, although the ratings are fluid and may change as additional data is collected for each vehicle family. The figure shows the share of vehicle families receiving a green, yellow, or red rating grouped by fuel type and Euro standard. From Euro 3 to Euro 5, all diesel families are rated red. For Euro 6 vehicles, approximately a 10th of diesel families are rated yellow. In contrast to diesel vehicles, the TRUE ratings for petrol vehicles improve with each successive emissions standard. Only 3% of Euro 3 petrol vehicle families receive a green rating, but almost two-thirds of Euro 6 vehicle families are rated as green and none are rated as red.

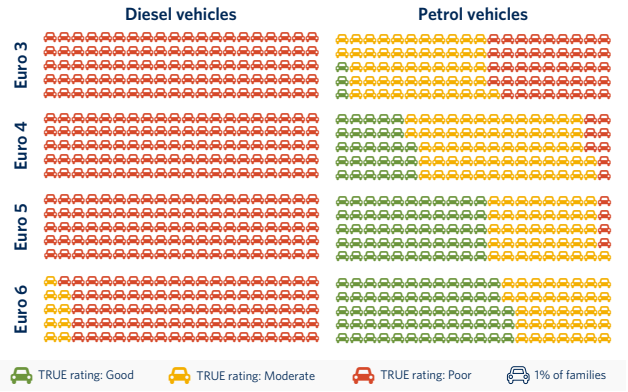

Figure 4. Share of passenger vehicle families receiving a green, yellow, or red rating grouped by fuel type and Euro standard.

CONCLUSIONS

A three-color TRUE rating system was developed to give the public an easy-to-use tool for identifying the lowest and highest emitting vehicles in the fleet. The TRUE rating can help car owners know whether their car is clean and can help potential buyers identify the cleanest available cars for purchase. The ratings represent, as best as is possible, measurements of real-world emissions. Only vehicles with low emissions over a wide range of driving conditions receive a green rating. The rating system currently covers NO_X emissions, but additional emissions will be added later. The ratings will be accessible from the TRUE website (www.trueinitaitive.org) and will be updated periodically as the most recent data is collected and incorporated.

16 As previously discussed, all vehicle models within a given vehicle family receive the same rating.

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For details on the TRUE rating and related questions, contact Rachel Muncrief, **rachel@theicct.org**. For more information on the TRUE project, visit **www.trueinitiative.org**.

The Real Urban Emissions Initiative (TRUE) is a partnership of the FIA Foundation, the International Council on Clean Transportation, Global NCAP, Transport and Environment, and C40 Cities.

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