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Implications of diesel emissions control failures to emission factors and road transport NO_x evolution

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HIGHLIGHTS

- Diesel Euro 5 car NO_x levels correctly represented by emission factors (EFs).
- Diesel Euro 6 car and Euro 5 light commercial vehicles NO_x twice as high as EFs.
- Euro 6 car emission performance varies a lot from vehicle to vehicle.
- Control of Euro 6 emissions critical to meet mid-term environmental targets.
- Measurement campaigns required to monitor in-use vehicle emission performance.

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ABSTRACT

Diesel NO_x emissions have been at the forefront of research and regulation scrutiny as a result of failures of late vehicle technologies to deliver on-road emissions reductions. The current study aims at identifying the actual emissions levels of late light duty vehicle technologies, including Euro 5 and Euro 6 ones. Mean NO_x emission factor levels used in the most popular EU vehicle emission models (COPERT, HBEFA and VERSIT+) are compared with latest emission information collected in the laboratory over real-world driving cycles and on the road using portable emissions measurement systems (PEMS). The comparison shows that Euro 5 passenger car (PC) emission factors well reflect on road levels and that recently revealed emissions control failures do not call for any significant corrections. However Euro 5 light commercial vehicles (LCVs) and Euro 6 PCs in the 2014–2016 period exhibit on road emission levels twice as high as used in current models. Moreover, measured levels vary a lot for Euro 6 vehicles. Scenarios for future evolution of Euro 6 emission factors, reflecting different degree of effectiveness of emissions control regulations, show that total NO_x emissions from diesel Euro 6 PC and LCV may correspond from 49% up to 83% of total road transport emissions in 2050. Unless upcoming and long term regulations make sure that light duty diesel NO_x emissions are effectively addressed, this will have significant implications in meeting future air quality and national emissions ceilings targets.

1. Introduction

Nitrogen oxides (NO_x) emission limits for diesel light duty vehicles (LDVs) in the European Union (EU) have dropped significantly since the first introduction of Euro standards in 1992. In the last 15 years alone, emission limits from 0.5 gNO_x/km at Euro 3 level (Year 2000) dropped to 0.08 gNO_x/km at Euro 6 level (Year 2015) for passenger cars (PCs). However, the type-approval driving pattern, specifically the New European Driving Cycle (NEDC), has since long been criticized in being unrepresentative of real-world conditions, involving only gentle accelerations, long constant speed modes, and a rather low maximum speed (Franco et al., 2013). Tests over the NEDC have for long been known to result to emission levels that significantly deviate from typical real-

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world levels (Franco et al., 2014).

Recent research evidence in the US (Thompson et al., 2014) and the follow up investigation in different countries (BMVI, 2016; DfT, 2016; Royal, 2016) revealed that specific diesel passenger cars implemented software and hardware means to actively modify their emissions control strategy under type-approval testing conditions (EPA, 2016). A type-approval test can be recognized by the vehicle in many ways. For example, the vehicle is preconditioned with a repeatable driving pattern while no wheel steering is involved for a long time. The strictly specified environmental conditions during vehicle soaking and testing also provide a narrow range of boundary conditions relevant to type-approval testing. Such indications could and have been used to trigger an alternative emissions control strategy. Basically, any minor variation of the test protocol yielding a large increase in NO_x emission can be construed as a form of inappropriate test optimization. Typically, outside of type-approval operation and environmental condition ranges, the EGR rates are reduced and, in SCR systems, urea solution delivery decreases or ceases. In case of LNT systems, it is the regeneration frequency that significantly drops. These actions, often defended as measures for engine protection, usually result in increased NO_x but lower fuel consumption, CO_2 and possibly also lower HC and CO emissions.

In the EU, regulatory initiatives try to close such loopholes. The World harmonized Light duty Test Procedure (WLTP) is scheduled to replace NEDC and to bring all testing parameters closer to reality. Most importantly, Real Drive Emissions (RDE) testing has to be conducted to grant an emissions type-approval. Euro 6 RDE-approved vehicles will need to comply with emission limits with a conformity factor when tested on the road using portable emissions measurement systems (PEMS).

The revelations on diesel NO_x emission control failures increased concerns on the evolution of air-quality in EU cities. The European Environment Agency estimates that 8–27% of EU population is exposed to NO_2 levels above limit values (EEA, 2015a). Scenarios executed in the framework of the revision of the Thematic Strategy on Air Pollution (Borken-Kleefeld, 2016) showed that potential failure of the Euro 6 standard to deliver real world emissions reductions would lead to persisting NO_2 exceedances in major EU cities in the years to come. Moreover, National Emissions Ceilings of NO_x were exceeded by 11 member states in EU in 2010 with the target still being exceeded by six of them in 2013. In the relevant study of the European Environment Agency (EEA, 2015b), the road transport sector was identified as one of the main contributing factors for the large number of NO_x exceedances.

Comprehensive emissions models are used primary to calculate emissions in air quality studies, and in the framework of integrated assessment studies for target-setting and monitor progress towards legally binding ceilings. Models deliver the emission factors (EFs) and the methodology required to estimate total emissions at a fleet level. The most widespread models in the EU include COPERT (Ntziachristos et al., 2009), HBEFA (Hausberger et al., 2009) and VERSIT+ (Smit et al., 2007). Emission factors in these models are being developed and discussed within the ERMES group, which operates under the auspices of the Joint Research Centre of the European Commission. These EFs originate from practically the same vehicle measurements dataset but their formulation differs. COPERT uses the average travelling speed as an input parameter, HBEFA uses traffic conditions distinguished per road typology and level of service, while VERSIT+ uses both speed and mean positive acceleration classes to assign appropriate EFs. Because of the same original data sources, EFs are broadly consistent between the different models, with any deviations occurring due to variability in the frequency of model updates, the exact formulation of EFs in each model and the variance in operation conditions in case models are used in different national conditions.

The compromised emission control of diesel vehicles may have significant impacts on the EFs used in these models and, in turn, to the monitoring and reporting approaches of the member states. This study first examines the short-term impacts of the failed diesel emissions control on road vehicle emissions factors. Second, it estimates the longer-term implications to road transport emissions, depending on the effectiveness of upcoming emission standards. The results of the study aim to inform model and EF users on the uncertainty of current EFs and, also, the research and policy community on the implications to road emissions evolution of continuous failures to deliver actual emissions reductions on the road.

2. Methodology

2.1. Validation of current EFs

The primary objective of this study to identify whether currently used EFs of popular emission models adequately reflect reality. Emission factors of latest vehicle technologies (Euro 6) in existing models often come from approximations and engineering assessment on the basis of previous technology steps. This is because it takes time to collect a representative sample, measure and process information to develop EFs, while there is the immediate need to report emissions from such vehicles as soon as they become commercially available. In order to check the representativity of EFs, we collated test data from recently published studies and latest measurements conducted at the authors' research facilities. The collated information was not used to produce new EFs, as this requires more time, but was used to compare against average current EF levels. The new dataset formed differs from the data that has gone into developing the currently used EFs, hence this allows for a proper validation.

Sources that have been used in the data collation process included published work conducted by TNO (Ligterink et al., 2012; Kadijk et al., 2015a,b, Kadijk et al., 2016), JRC (Fontaras et al., 2014) and in-house data from the Lab of Applied Thermodynamics (LAT) on emission levels of Euro 5 and Euro 6 vehicles measured on the road with PEMS. Also, Common Artemis Driving Cycles (CADC) (Andrè, 2004) and ERMES cycle measurements conducted in the labs of Dekra and Horiba, as well as LAT and the Technical University of Graz have been used. CADC do not follow type-approval protocols and settings and for this reason they are often referred to as 'real-world' cycles (Franco et al., 2013). In the collated dataset, all lab tests have been conducted at room temperatures between 20 and 28 °C while the majority of PEMS tests was conducted over a broader range of 3–25 °C, with only three tests partly reaching as low as −1 °C.

An overview of the data collected from each source is shown in Table 1. In total, the vehicle sample collected contained 22 Euro 5 PCs and 14 LCV ones. These correspond to more than 300 individual tests for Euro 5 diesel PCs and light commercial vehicles (LCVs) both in the lab and on the road using PEMS. All tests, either in the lab or on road have been conducted with an engine starting from a normal operation temperature (hot-start). In case of Euro 6 PCs, the sample consisted of 17 vehicles. Although this may sound as an adequate number, more tests will be required in the future before precise EFs are derived, in order to reflect the versatility in emission control technologies used in the Euro 6 step, the impact of the RDE regulation and in order to be able to reflect the impact of ambient conditions on emissions control effectiveness.

The collection of test values over different driving conditions allowed to compare with EFs distinguished into urban, rural, and highway driving. This is important, as the effectiveness of emission control may vary depending on the portion of the engine map utilized and the mean exhaust gas temperature in each condition.