Real World Emissions from Road Vehicles: Results from Remote Sensing, Emission Measurements and Models

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Introduction

Rational policy making needs robust information, for instance how big emissions from road transport are and what their impact on local and regional air pollution is. Emission factors are a key parameter for the necessary calculations, and their uncertainty largely determines the uncertainty in the inventory. The emission factors have been largely based on chassis dynamometer tests over defined driving cycles. However, there is an unknown uncertainty how well laboratory measured emission factors match actual on-road emissions. This question has become more pressing in Europe with the recognition that NO_x emissions from diesel (light duty) vehicles are under real-driving conditions several times higher than and largely decoupled from emissions over homologation tests (Weiss et al. 2011; Hausberger 2010; Carslaw et al. 2011). Together with almost a tripling of the use of diesel cars over the past two decades this is made responsible for persistent air quality problems in cities throughout Europe (Kiesewetter et al. 2014; Hueglin, Buchmann, and Weber 2006; Carslaw et al. 2011).

In recent years direct on-road measurement techniques like PMES and remote sensing have become available that might be helpful and complementary to improve both our understanding and the robustness of accurate vehicles emission factors. One of these techniques is on-road vehicle emission remote sensing.

With remote sensing an optical instrument is placed at a suitable roadside. The concentrations of certain pollutants are measured in the exhaust plume of vehicles passing. Subtract the background concentrations to get the concentration increment that can be attributed to that vehicle. Ratio the incremental pollutant concentration over the incremental concentration of CO_2 to obtain fuel dependent exhaust emission factors. Perform the measurements for several days to obtain several thousand individual emission records. The speed and acceleration of the vehicle are usually recorded as well, so that the emission factors can be linked to driving characteristics of the vehicle. From simultaneous number plate readings you can retrieve the registration data, and hence the technical information on the vehicle, most notably its model year and the emission limit compliant, the engine power and vehicle weight.

On-road remote sensing has been developed in the USA since the late 1980'ies by (G. A. Bishop et al. 1989). Nowadays on-road remote sensing is used on a regular basis as a screening tool to supplement or substitute regular Inspection & Maintenance (I&M) tests, for instance in the states of Colorado, Michigan and Texas. In Europe various groups have also been active, sometimes dating back to the early 1990'ies. For instance in Gothenburg/Sweden (Sjödin and Jerksjö 2008), the Netherlands (Kraan et al. 2012), various cities in the UK (Carslaw et al. 2013; Carslaw et al. 2011; Carslaw and Rhys-Tyler 2013), routine measurements since the year 2000 in Zurich/Switzerland (Chen and Borken-Kleefeld 2014), various Spanish cities (Technet 2009; Technet 2010). While much is still under development, there are already a number of important findings and interesting prospects how on-road remote sensing can help improve our understanding of vehicles' on-road emission behaviour and consequently of even better emission factors.

Applications of vehicle on-road emission remote sensing

This talk illustrates some applications of vehicle on-road emission remote sensing and sketches some potential for fertile interaction with vehicle emission models, as well as desirable steps for a more comprehensive approach, cf. also (Borken-Kleefeld 2013). For example:

- Determining level and trend of on-road emissions from the fleet of vehicles driving; this is useful as reference for emission factor models to cross-check whether their fleet composition is accurate.
- Determining level and trend of on-road emissions of vehicles by model year or emission control stage, for instance Figure 1.

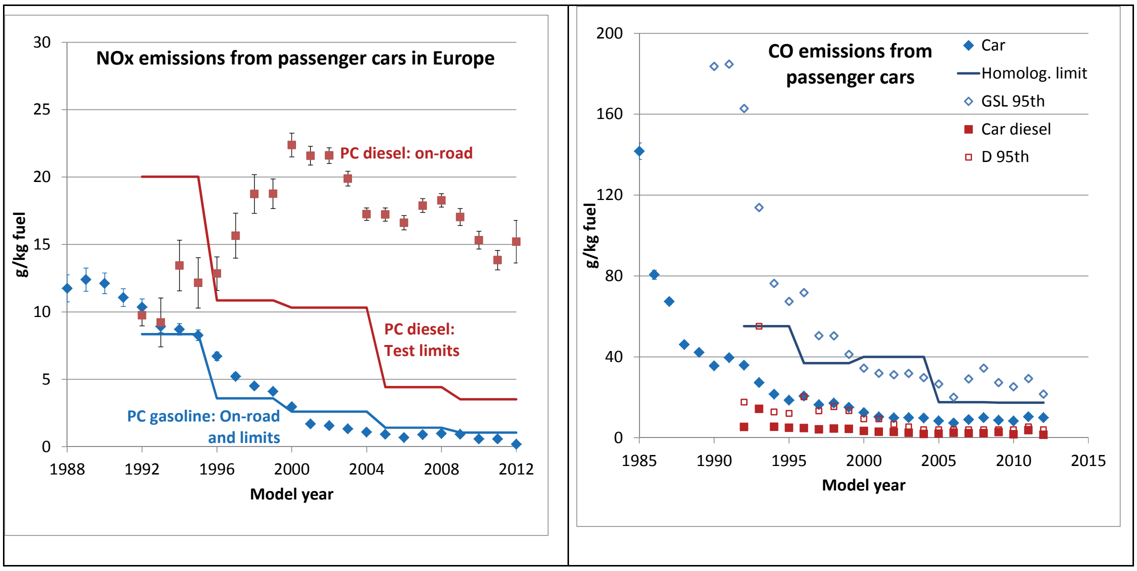

Figure 1: Average on-road NO_x (left) and CO (right) emission factors from gasoline and diesel cars by model year compared to equivalent test cycle limit value. Data from remote sensing at an uphill road in Zurich/CH (2000-2012) (Chen and Borken-Kleefeld 2014).

- Comparison of on-road emission factors with emission factors from emission models (Figure 2).

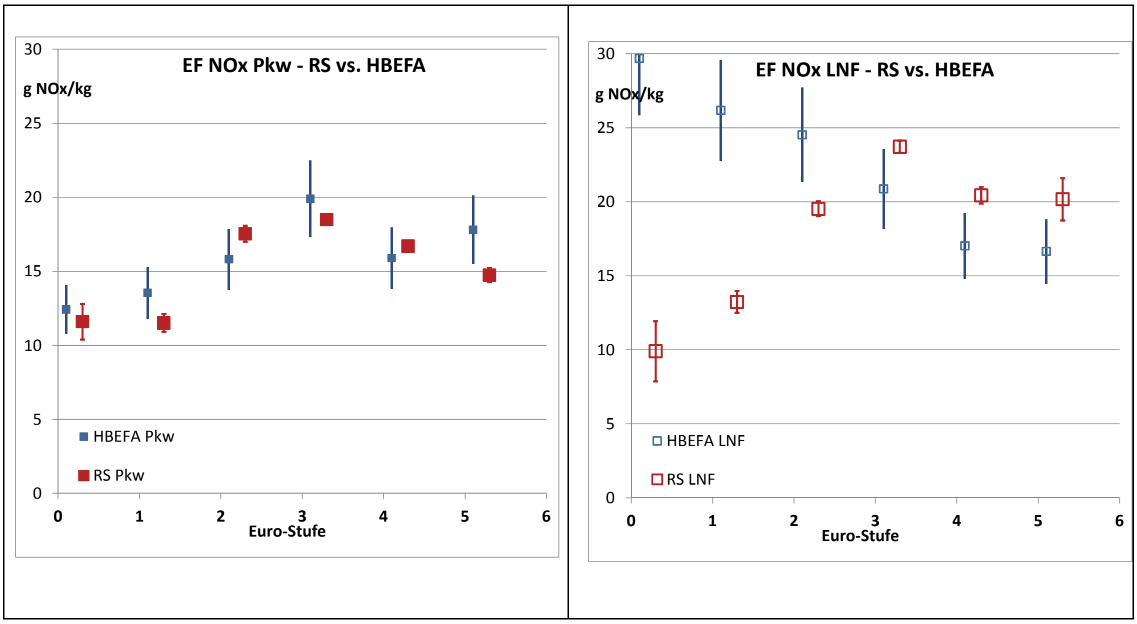

Figure 2: Comparing NOx emission factors between on-road remote sensing and HBEFA 3.2 for diesel passenger cars (left) and diesel light commercial vehicles (right), accounting for effects of engine load and age. Data from remote sensing at an uphill road in Zurich/CH (2000-2012) (Borken-Kleefeld & Chen, unpublished).

- Derivation of emission deterioration factors from long-term measurements, cf. (Borken-Kleefeld & Chen, these proceedings) and cross-check on long-term durability.
- Cross-check with modeled emission factors, e.g. from PHEM, (Hausberger et al. 2009)) under various engine load and driving conditions.

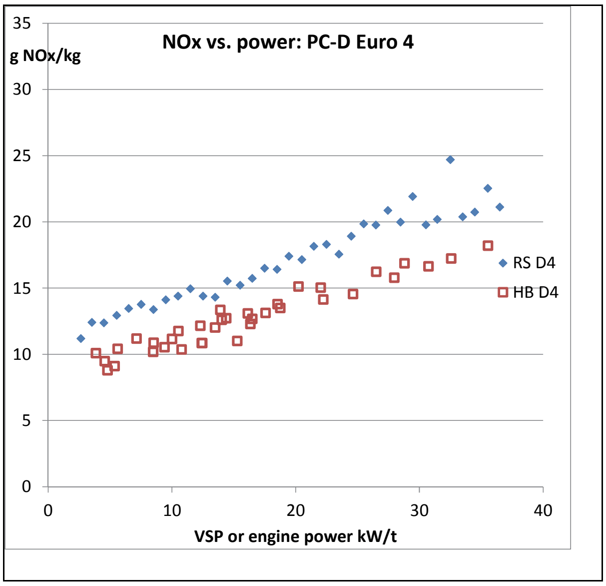

Figure 3: Unit emissions of NOx from diesel passenger cars of Euro 4 norm as a function of vehicle specific power (VSP) as measured from on-road remote sensing and as a function of rated engine power for various cycles in HBEFA 3.2. (Borken-Kleefeld, unpublished).

- Identification of high-emitters in the fleet, e.g. (McClintock 2007).

Caveats

There are a number of issues with on-road remote sensing that need to be treated with care before jumping to conclusions.

- There is hardly control over the instantaneous driving condition and the actual driver behaviour at the time of measurement. The measurement set-up needs to pre-empt error sources, and the data need to be processed with reasonable filters to ensure that only valid and not artificial records are treated further.
- Gas concentration calibrations during and between measurements are essential; inter-calibration between different instruments are required if results from various places are to be interpreted together.
- The measurement location influences the range of driving conditions measured, and the origins of the vehicles being measured. A variation in locations can be advisable to obtain a wide fleet coverage.
- The optics of the instrument needs to target the exhaust plume, which means usually a low path for light duty vehicles. For heavy duty vehicles this might need to be suitably adapted.
- The devil is in the details: A one-to-one comparison with emission factors measured or modelled elsewhere needs to account for differing fleet compositions, age structure and hence deterioration rates, engine loads, measurement principles, possible issues with time alignment, etc.

Mostly, the large number of records helps to obtain very sharp mean values (narrow 95th confidence interval) and still a reasonable statistics for variations around the mean.

Perspectives

Imagine, there are on-road measurements

- at carefully (or randomly) selected sites across Europe;
- capable to measure NO, NO_2 and $PM_{2.5}$;
- for light and heavy-duty vehicles; and
- consistent data are made available between research groups…

Looking at latest developments in the US on NO_2 and on heavy-duty remote sensing (Dallmann et al. 2012; Burgard et al. 2006; Gary A. Bishop et al. 2010), this perspective seems within reach of technology.

If desired, it's up for discussion to set the objectives, how to make the collaborations operational and from where to provide the resources needed. Such an undertaking would gain significant relevance if regulatory agencies provided an appropriate mandate. This could for instance complement the current discussion in Europe on surveillance of real-driving and not-to-exceed emissions from road vehicles. If successful and desired, this might also be applicable to non-road mobile sources, see for example (Ray et al. 2013; Popp, Bishop, and Stedman 1999).

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