*Memorandum*

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**To**
The Ministry of Infrastructure and Water Management

**From**

**Subject**
High $NO_x$ emissions of heavy-duty vehicles driving in urban areas and directions for a real driving emissions test

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## Summary
Evaluation of a large dataset with real-world emissions of Euro VI heavy-duty vehicles showed that, despite the progress made in controlling average $NO_x$ emissions, these vehicles have much higher $NO_x$ emissions when operating in urban environment. A direction is suggested to address the problem of high $NO_x$ emissions of driving on urban roads. Regulation of $NO_x$ emissions of heavy-duty vehicles should explicitly include all normal driving conditions in the on-road emissions test using PEMS (Portable Emissions Measurement System). This is presently not the case.

This means:
- No exclusion of data from tests or complicated evaluation rules that invalidate tests done at normal use of a vehicle.
- Testing vehicle types on their normal usage profiles.
- Explicitly controlling the emissions of low load (urban) driving, short trips, cold starts, idling and auxiliary use.

## $NO_x$ problem at low driving speeds
Road transport is an important source of air pollutants and contributes significantly to emissions of harmful nitrogen oxides and particulate matter. Air pollution by road vehicles is particularly important if the emissions occur in areas with a high density of the population, where people live and work[1]. To reduce air pollution, EU emissions standards for road vehicles gradually became more stringent. Vehicle manufacturers managed to comply with the standards by introducing advanced emissions control technologies. This has led to a substantial decrease of the emissions over the last decades[2]. Several studies [3], [4] , however, reported a lagging decrease of the pollutant emissions under specific driving conditions of heavy-duty vehicles (HDVs) because the selective catalytic converter for the reduction of $NO_x$ (SCR) still does not always work optimally.

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[1] European Environment Agency, “Emissions of air pollutants from transport,” 11 May 2021. [Online]. Available: https://www.eea.europa.eu/data-and-maps/indicators/transport-emissionsof-air-pollutants-8

[2] https://www.eea.europa.eu/ims/exceedance-of-air-quality-standards

[3] Vermeulen et al., Dutch In-service emissions testing programme 2015 - 2018 for heavy-duty vehicles: status quo Euro VI $NO_x$ emissions, TNO report TNO 2019 R10519, 10 April 2019

[4] Grigoratos, T. et al., Real world emissions performance of heavy-duty Euro VI diesel vehicles, Atmospheric Environment 201 (2019) 348-359

For heavy-duty vehicles various sources reported that the tail pipe emissions levels of $NO_x$ are skewed towards driving at lower speeds, which means that higher levels of $NO_x$ are observed when heavy-duty vehicles drive at these low speeds. Given the importance of air-pollution caused by road transport in populated areas, it is necessary to investigate if the high emissions of $NO_x$ occur when driving on urban roads, in urban areas and what the level of the $NO_x$ emissions is in this situation. Therefore, a database with emissions data of heavy-duty vehicles obtained under normal use in the Netherlands has been analysed to determine the activity and the level of $NO_x$ emissions of HDVs driving in urban environment.

**Database with years of data for evaluation**

In the in-use testing programme for heavy-duty vehicles TNO measures and monitors for the Dutch Ministry of Infrastructure and Water management the exhaust gas emissions of heavy-duty vehicles on a regular basis to investigate how much the vehicles emit in real world usage. Amongst others, this data is used to model the so-called official national emissions factors which are to represent typical real world emissions of road vehicles in-use. A database with emissions data of 37 vehicles with Euro VI certified engines, operating for weeks to months in normal use in the Netherlands and abroad, is available for analyses. The database contains in total 4.6 years and $1.9 \times 10^6$ km of data (average speed = 47 km/h) of various types of HDVs, such as long haulage vehicles, distribution trucks, refuse collection vehicles, buses and construction vehicles as operated in their daily duty. The database includes, next to emissions data, GPS and data from the vehicle that allows the attribution of the emissions to road type.
For the exercise the road types *urban, rural and motorway* were distinguished for all vehicles. This distinction was made by coupling GPS location to Open Street Maps to determine the speed limit for each relevant road, and thereby which road types should be assigned to the data. Remark is that speed limits for driving on private roads or terrains, driving in tunnels and data without GPS signal due to signal loss, could not be assigned. Overall usage was categorized as *refuse collection, city and regional bus operation, local, national and international distribution (long haulage), construction and other use*. For the various types of heavy-duty vehicles in the database the shares of driving and the $NO_x$ emissions were determined over the three road types and for roads that couldn't be categorized for all vehicles.

**Heavy-duty vehicles usage**

City buses obviously drive most on urban roads, followed by refuse collection vehicles. The share of rural and motorway driving can be higher for regional buses and refuse collection vehicles which also service small towns and villages. The latter may also have to take a motorway drive to return garbage to the depot. For long haulage trucks drive the lowest fraction on urban roads. For local, regional and national distribution, fractions of urban driving are higher than for long haulage and shows more variation. In the Netherlands this distribution is done with a variety vehicle types, from small rigid truck to tractor semi-trailers. These vehicles service for instance companies, distribution centres and shops that often happen to be located in urban regions.

Construction vehicles also service urban areas, the amount of time depending on the location of the constructions site. For all vehicles, a varying part of the driving can't be attributed to a registered road type, but it is observed from the GPS locations that most of this driving is at private yards such as distribution centres, depots or construction yards. Additionally, a small share represents data with GPS signal loss for which no location could be defined.

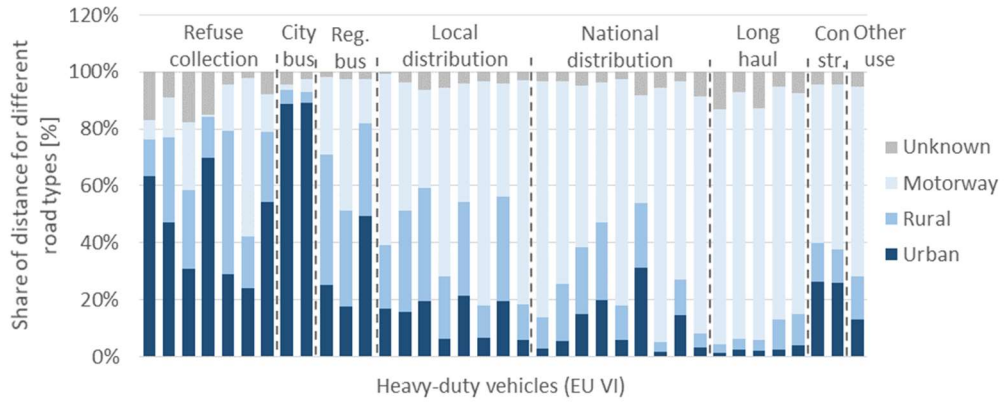


*Figure 1: 36 trucks with share of the total distance driven for different road types urban, rural and motorway and vehicle usage categories. 'Unknown' is data can't be assigned to a road type, most of this data probably concerns private yards or roads.*

Looking at trip distance of heavy-duty vehicles it appears that for the whole database almost 50% of the trips (key-on to key off) are shorter than 10km. Analyses showed that for a lot of the vehicles these trips are for instance for manoeuvring around a depot, shunting trailers and short trips for servicing the vehicle.

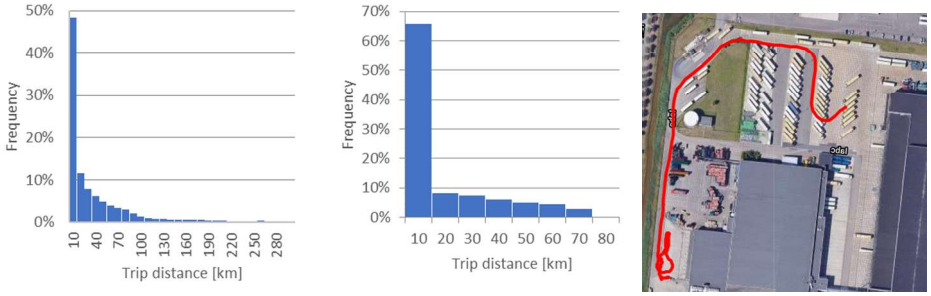


*Figure 2: Left: frequency distribution of trip distance of the entire database. About half of the trips are shorter than 10km. Middle: example of the frequency distribution of trip distance of a tractor semi-trailer used for supermarket distribution. Right: example of typical short trip of a tractor semi-trailer, manoeuvring on a distribution yard.*

### $NO_x$ emissions on urban roads

When $NO_x$ emissions levels of driving on urban roads are analysed, it can be observed that on urban roads almost all vehicles emit more $NO_x$ than the type-approval limit value of 460 mg/kWh for a Euro VI engine, and that in most cases these emissions are substantially higher than on motorways.

This clearly shows the skewness of the $NO_x$ emissions, not only towards lower speeds and loads as observed in earlier investigations, but also towards driving on urban roads in densely populated areas.

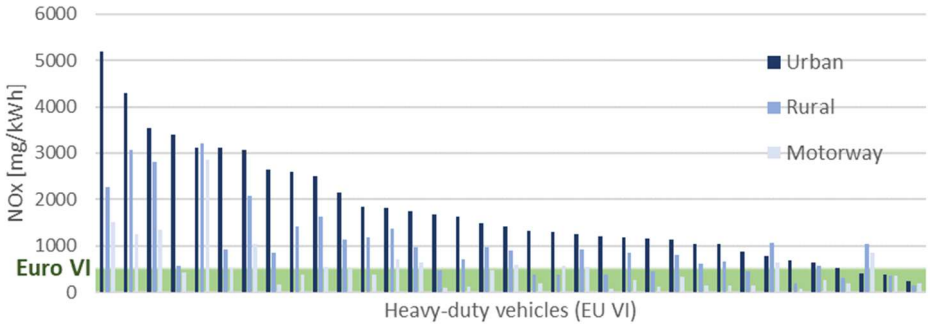


*Figure 3: average work specific $NO_x$ emissions for 36 HDVs, when vehicles drive on urban roads, rural roads and motorways. Sorted on highest urban $NO_x$ emissions.*

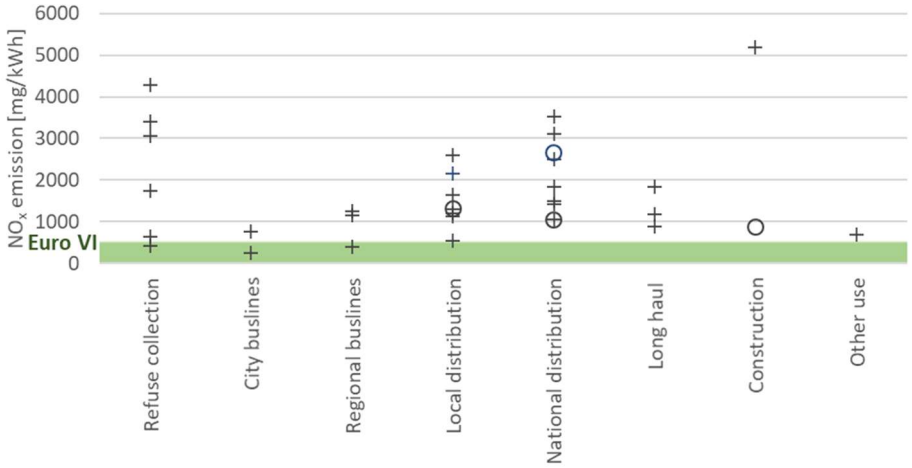


*Figure 4: average work specific $NO_x$ emissions when vehicles drive on urban roads. $NO_x$ emissions levels up to a factor 11 higher than the Euro VI limit value (upper edge of green area) were measured. Vehicles with Step-D certified engines are marked with a circle.*

The fact that $NO_x$ emissions levels are higher on urban roads leads to the situation that a substantial share of the $NO_x$ emissions of HDVs takes place in an urban environment. For city buses and refuse collection vehicles this is obvious, about 60 to 90% of the total $NO_x$ emission are emitted on urban roads. For vehicles for the transportation of goods operating in local, regional and national distribution services (from 12t rigid trucks to 44t tractor semi-trailers) the urban $NO_x$ emission is also substantial and ranges from 22% to 40%. For regional buses in the dataset this is 40%. For construction vehicles, the share of $NO_x$ emitted on urban roads is 60%. A significant share of $NO_x$ is emitted on uncategorized roads, such as at depots and yards.

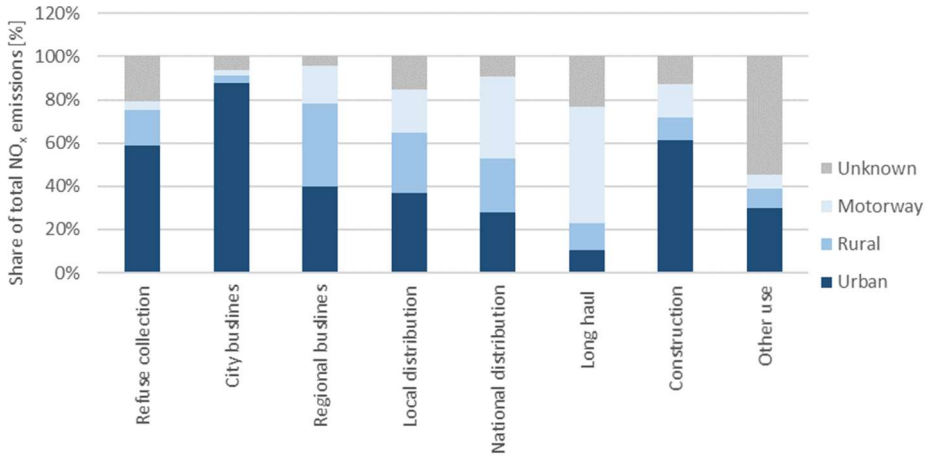


*Figure 5: share of total $NO_x$ emissions per road type for different types of usage of heavy-duty vehicles.*

The GPS data reveals that the actual ranges of operation of heavy-duty vehicles can be rather scattered and varying from vehicle to vehicle. From the evaluation of real world emissions data of HDVs with Euro VI certified engines it is apparent that the standard and the requirements have led to a skewed emissions behaviour for $NO_x$. The result is that the emissions are still high in urban driving conditions. The reason is that 'urban driving conditions' are a mix of all kinds of normal driving, which currently are not explicitly controlled by regulation. These conditions include short trips, manoeuvring, cold or semi-cold starts, low load operations, idling, start-stop and the use of auxiliaries. These are all dynamic and varying operations currently not part of tests. In addition, the regulation controls averaged emissions instead of spatial relevant emissions and the procedure targets mainly optimal conditions and exclude the more challenging conditions that often happen to be 'urban driving conditions'. To address the problem of high $NO_x$ emissions of driving on urban roads in areas with a high density of the population, regulation of $NO_x$ emissions should explicitly include these normal driving conditions. This is presently not the case [5, 6, 7].

To improve the situation some obvious options are at hand:

- No exclusion of data or complicated evaluation rules that invalidate tests done with normal use.
- Test vehicle types on their normal usage profiles.
- Explicitly control low load urban driving, cold start and idle emissions.

[5] Vermeulen, R.J., Ligterink, N.L.I., Evaluation of the EU real-world PEMS test for heavy-duty vehicles, TNO report, 15 November 2018
[6] Mendoza Villafuerte, P., Demuynck, J., Bosteels, D., Vermeulen, R. et al., "Real-World Emissions of Euro VI Heavy-Duty Vehicles," SAE Technical Paper 2021-01-5074, 2021, https://doi.org/10.4271/2021-01-5074.
[7] Felipe Rodríguez and Huzeifa Badshah, Real world $NO_x$ performance of Euro VI-D trucks and recommendations for Euro VII, WORKING PAPER 2021-26, July 2021

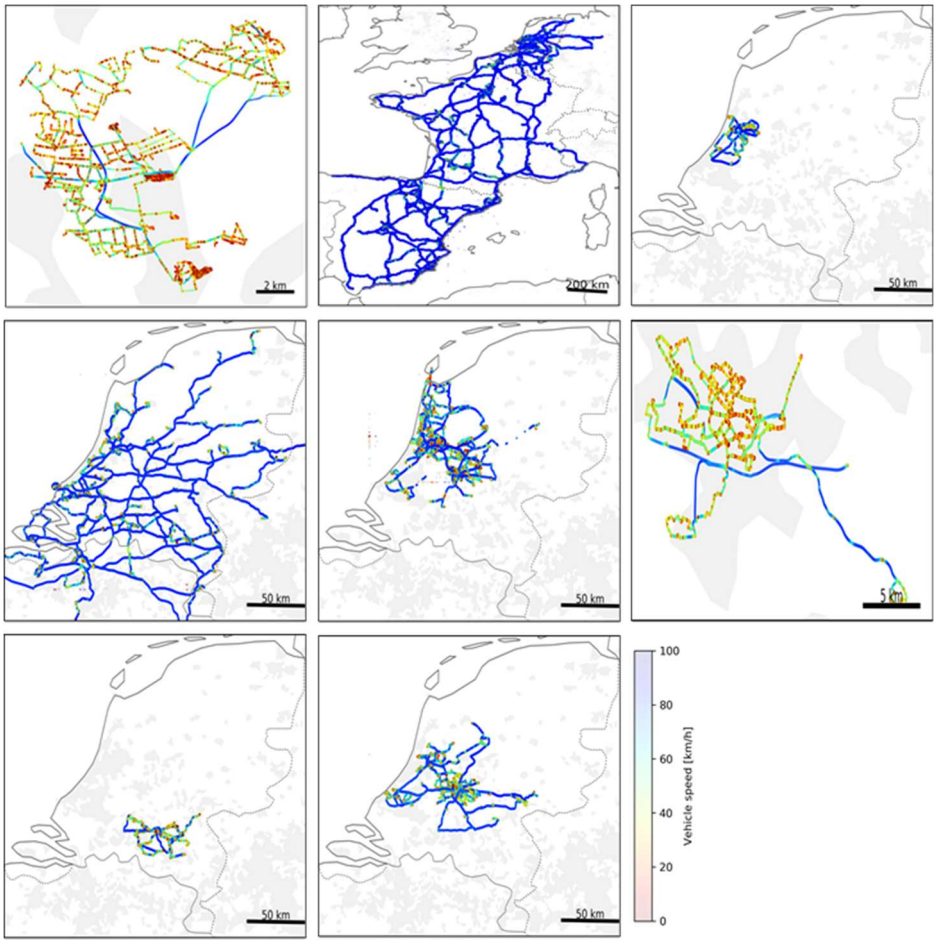


*Figure 6: typical examples of GPS-based position and speed of heavy-duty vehicles for different kinds of usage. Top left: refuse collection in a city, top middle: long haulage, top right: local distribution, middle left: national distribution, middle: regional distribution, middle right: city bus, below left: regional bus, below middle: construction.*

## Conclusions

Despite the progress made in controlling $NO_x$ emissions from heavy-duty diesel vehicles, a large fraction of the fleet has high $NO_x$ emissions in daily operation due to insufficient SCR performance, particularly when operating in urban environment. Especially low operation temperature of the SCR is a problem that may occur when heavy-duty diesel vehicles drive at low speeds such as in urban traffic. Evaluation of a large dataset showed that indeed $NO_x$ emissions are highest on urban roads and substantially exceed official test cycle limits whereas on motorways the $NO_x$ emissions are generally much lower. This skewness means that for most trucks a substantial share of the $NO_x$ emissions take place in an urban environment. The current EU emissions regulation fails to control this. The $NO_x$ emissions are still high on urban roads, where the emissions should be low because of the high density of the population.

Dedicated tests can address specific issues with high emissions like low engine load, idling, short trips and operating auxiliary equipment from the main vehicle engine, e.g., loading with a crane of a tail lift. Currently, such vehicle operations are largely excluded from testing due to the limited power demand. Or, the testing is prohibitively long and complex due to the work-based evaluation approach. The In-Service Conformity testing should encompass all normal use, rather than be based on some specific use of the vehicle. Only with wide range of testing conditions, the emission control systems will be robust for the different operations in the urban environment. Moreover, shorter, simpler, and dedicated tests will surface the specific issues with high emissions, as observed in normal vehicle usage.