VEHICLE EMISSIONS

ITF-SEDEMA workshop in Mexico City | Norbert Ligterink

HOT AIR, HIGH HOPES, AND LITTLE EXPECTATIONS FOR NO_x

- **Diesel passenger cars** have shown no substantial reduction of NO_x emissions in the last 25 years, despite stricter emission limits and legislation
  - forthcoming RDE on-road testing legislation, in the making since 2007/2010
  - are future clean cars the upside of the Volkswagen scandal?
- **Euro-VI trucks and busses** have shown a very large reduction of NO_x emissions, compared to very poor urban performance of Euro-IV and Euro-V
  - the results of legislative on-road tests (In-Service Conformity)
  - some risks of higher emissions remain, especially for urban vehicle usage

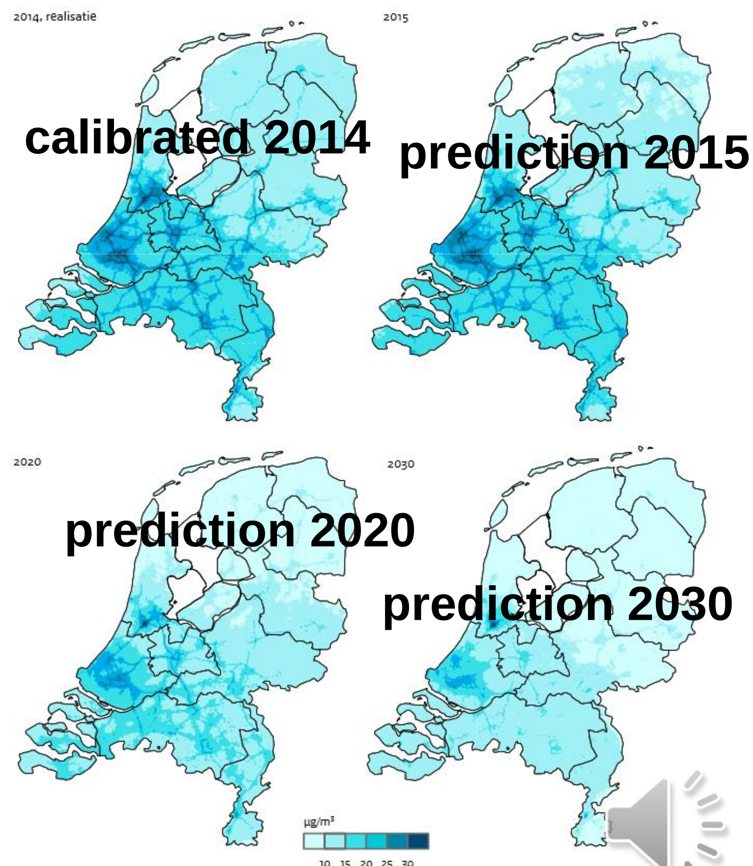
- **NO_x = NO + NO_2** is "burned air" (nitrogen oxides) above 2000^o C combustion.
  - normal combustion ~ 2000 ppm NO_x = 100,000 x NO_2 air-quality limit
  - 100 ppm is "reasonable", Euro-VI SCR systems: 98% reduction (40 ppm)

DUTCH AIR-QUALITY MODEL

EMISSION MEASUREMENTS FOR EMISSION FACTORS

- vehicle testing since the 1970's, in-use compliance program since 1987:
    - emission factors for vehicle categories since the 1990's
    - effectiveness of stimulation programs (retrofit, advanced technologies)
- Dutch air-quality model has a legal status:
    - additional exceedances are not allowed: building projects can be stopped for clean air.

NO_2 concentrations



VEHICLE EMISSION TESTING

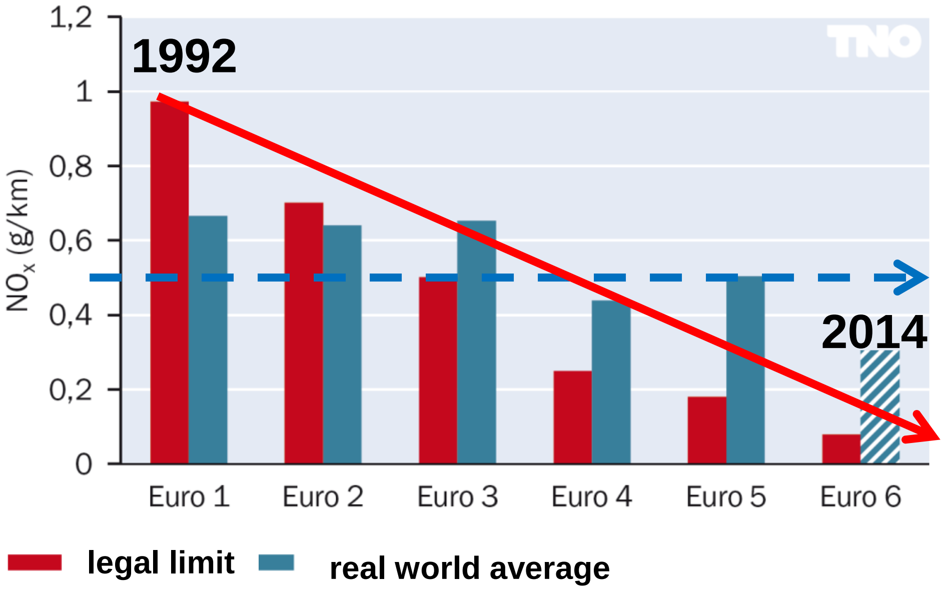
A LONG HISTORY OF GOVERNMENTAL MITIGATION MEASURES

- Real-world technology performance is the link to air-quality:
  - Factory values do not always reflect the in-use performance, the durability, and the maintenance issues

- Simulation of emission control technologies:
  - Successes:
    - Three-way catalysts from 1987 prior to Euro-1 in 1992
    - Diesel particulates filters from 2006 prior to Euro-5 in 2009
  - Failures:
    - Retrofitting particulates filters: non-effective with high NO_2 fractions
    - Simulating heavy-duty Euro-V: poor urban performance of SCR
    - Simulating cars Euro-6: few models available, no-improvement for NO_x

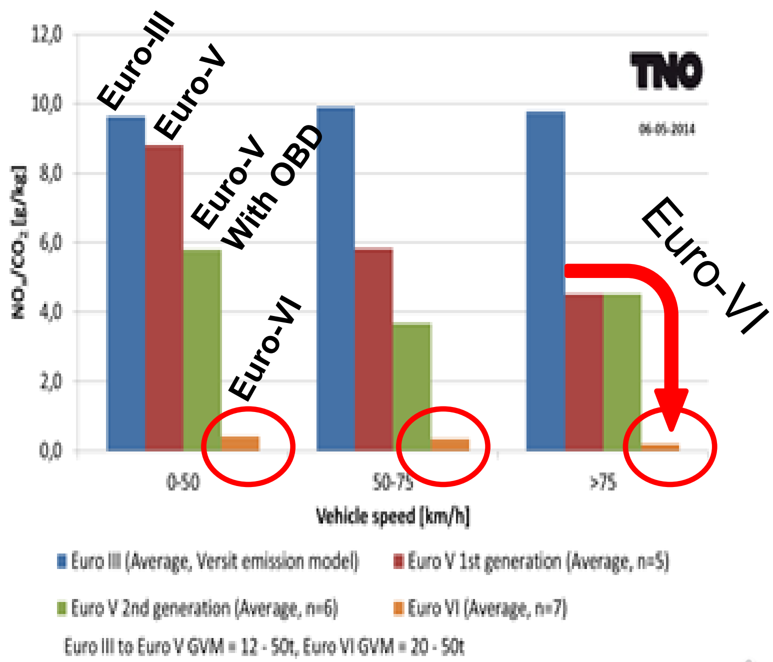
DIESEL PASSENGER CARS

NO_x EMISSION FACTORS



DIESEL TRUCKS

NO_x EMISSIONS AT DIFFERENT VELOCITIES



FROM EMISSION MEASUREMENTS TO AVERAGE LOCAL EMISSION FACTORS

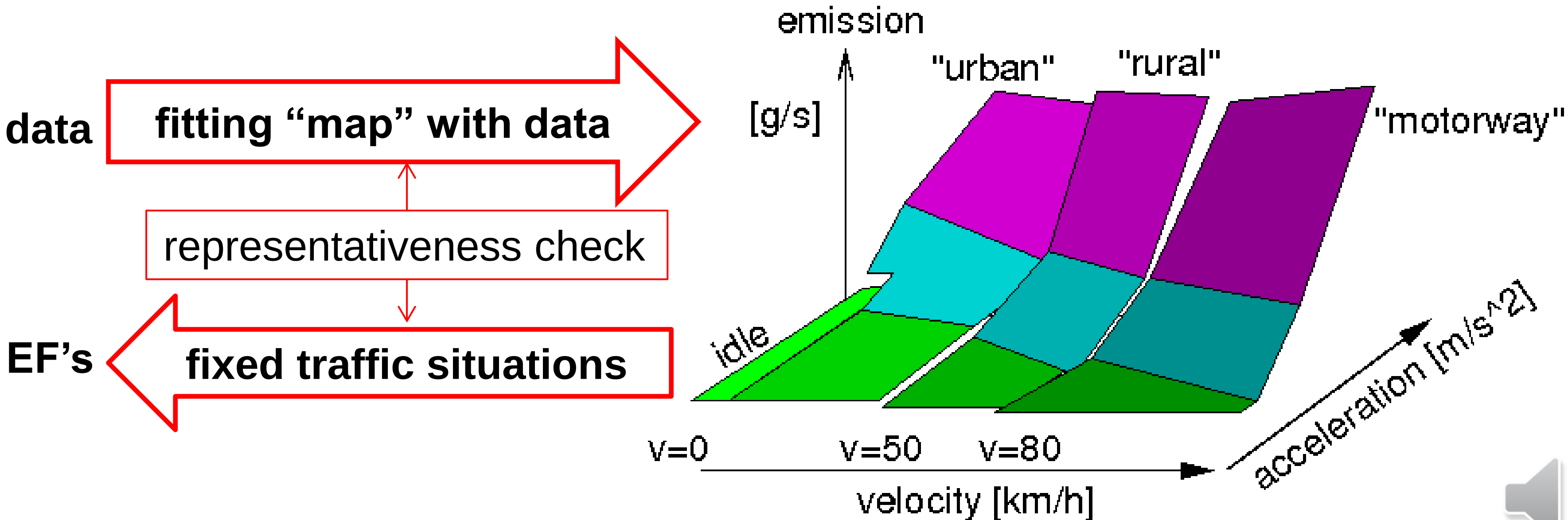
Local vehicle emissions depend on:

- **road type**
  - speed limit (increasing emissions above 100 km/h)
    - speed limit enforcement
    - Between 80-100 km/h: highest road capacity
  - congestion level (high congestion = high emissions)
- **traffic intensity**
- **fleet composition**
  - fraction heavy-duty, presence of (busy) bus lines
  - vehicle fleet, petrol/diesel split (e.g., older in urban areas)
- **driving behaviour:**
  - actual velocity, driving dynamics, braking
- **vehicle state**: maintenance and deterioration/aging

EMISSION MODEL NEEDED TO NORMALISE MEASUREMENTS TO TRAFFIC SITUATIONS FOR AIR-QUALITY

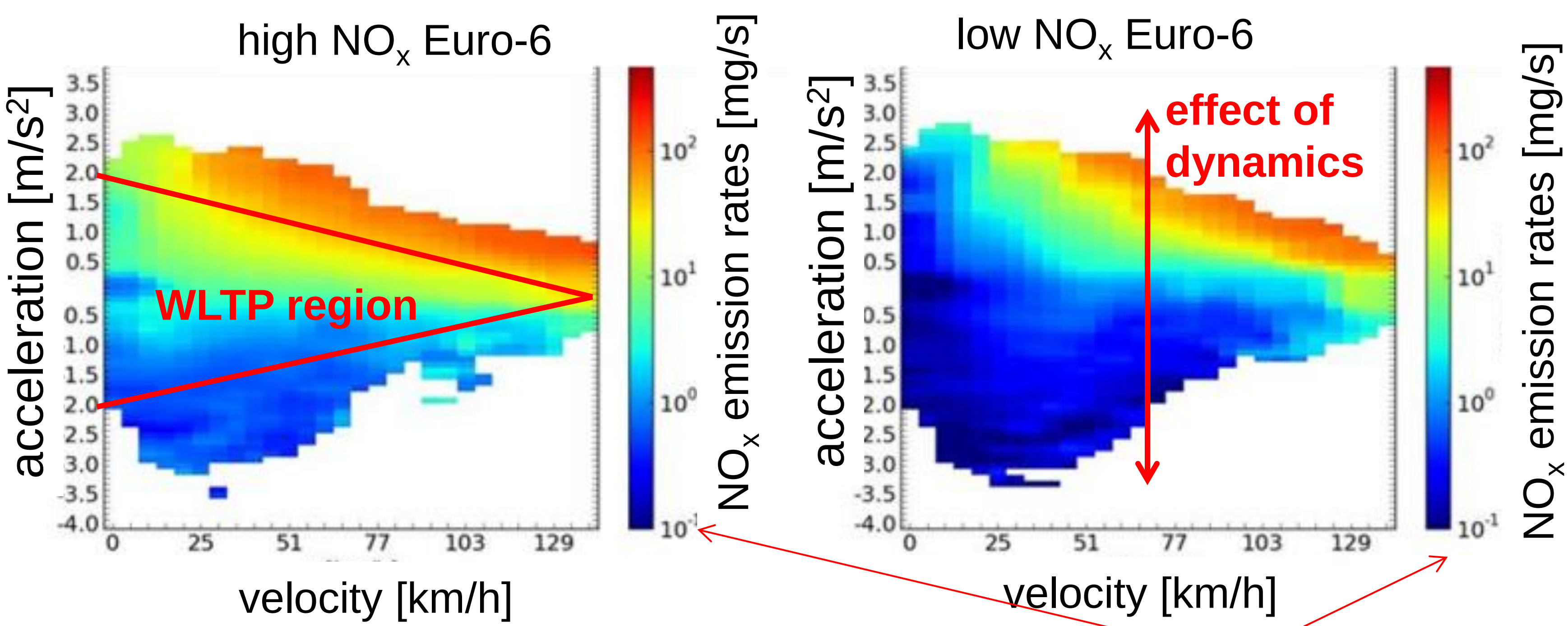
VERSIT+: TNO EMISSION MODEL
TO GENERATE NATIONAL EMISSION FACTORS

- **General philosophy**:
  - **representative** measurements for the different traffic situations
  - collecting enough data for **statistical significance** (> 600 km)
  - **limited modelling**, only based of velocity and acceleration



EMISSIONS VARY MORE WITH DYNAMICS THAN WITH VELOCITY, ESPECIALLY FOR CLEAN VEHICLES

standardized plots of NO_x emission rates for (more) fair comparisons



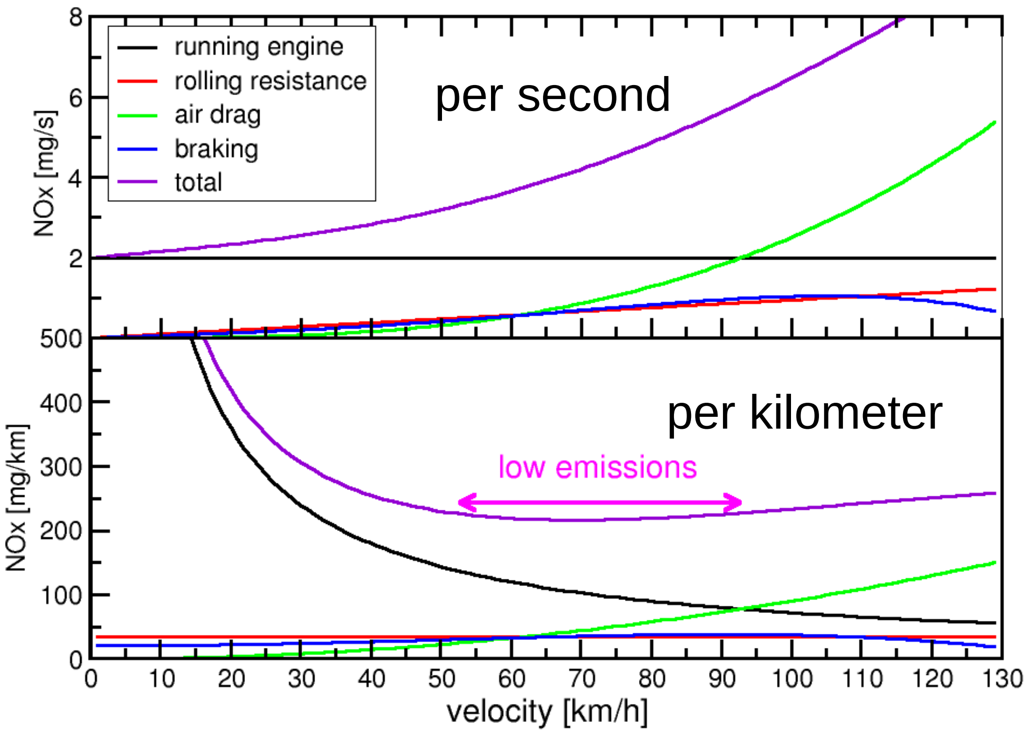
logarithm scale, 100-fold increase!

THE ENGINE AND THE AIR DRAG

TWO SOURCES OF ADDITIONAL EMISSIONS PER KILOMETER TRAVELLED

For a properly functioning vehicle emissions are proportional with the engine work.

In this case the contributions can be separated roughly in four main parts.



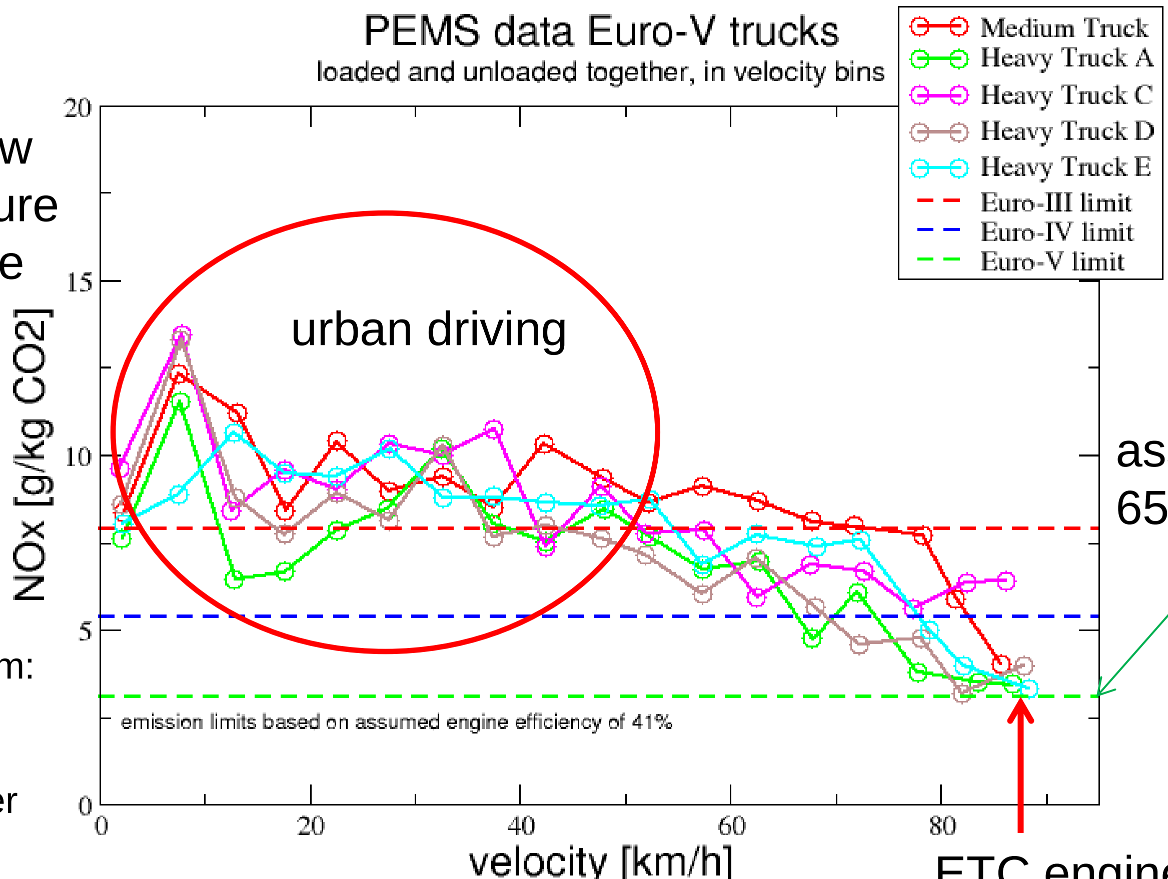
THE ROAD TO ON-ROAD TESTING
FROM HEAVY-DUTY IN SERVICE CONFORMITY TESTING

- Heavy-duty legislation is based on engine test (not vehicle), so testing in-service compliance required "*taking the **engine** out of the **vehicle***" for testing.
- From 1988 TNO performed heavy-duty in-service conformity **engine** tests
- From 1996 TNO tested **vehicles** on the chassis dynamometer corrected back to ESC **engine** test
- From 2008 both EU and USA developed legislation to perform in-service conformity tests on-road with **vehicles** and portable emission measurement system (PEMS) equipment (part of Euro-VI)
- In 2009 Dutch emission factors for Euro-V trucks in urban driving were upped with a factor 3 based on the first on-road PEMS testing of Euro-V trucks.

  → SCR system did not function in urban conditions: low engine load outside engine test conditions.

ON-ROAD TESTS ON EURO-V TRUCKS
FROM 2009 TNO REPORT

in real-world low SCR temperature from low engine load



assumption:
650 g CO2 ~ 1 kWh

ETC engine load

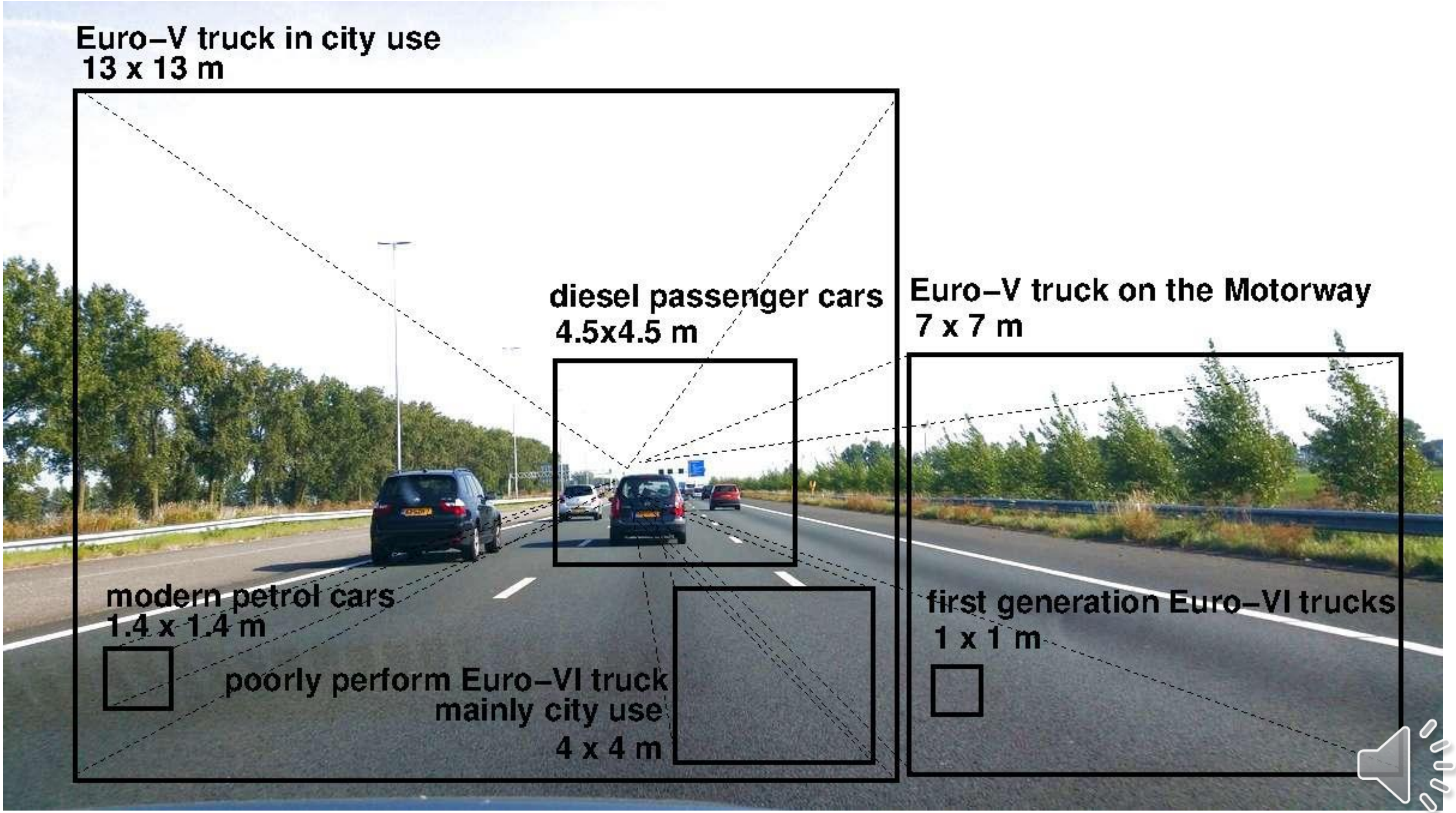
low engine load from:

- low velocity
- low payload
- high rated power

reference trip: urban-rural-motorway

NECESSARY DILUTION PER VEHICLE

WITH CLEAN AIR TO REACH 40 MUG/M³ AIR-QUALITY STANDARD



RDE LEGISLATION:
ON-ROAD TESTING FOR TYPE-APPROVAL

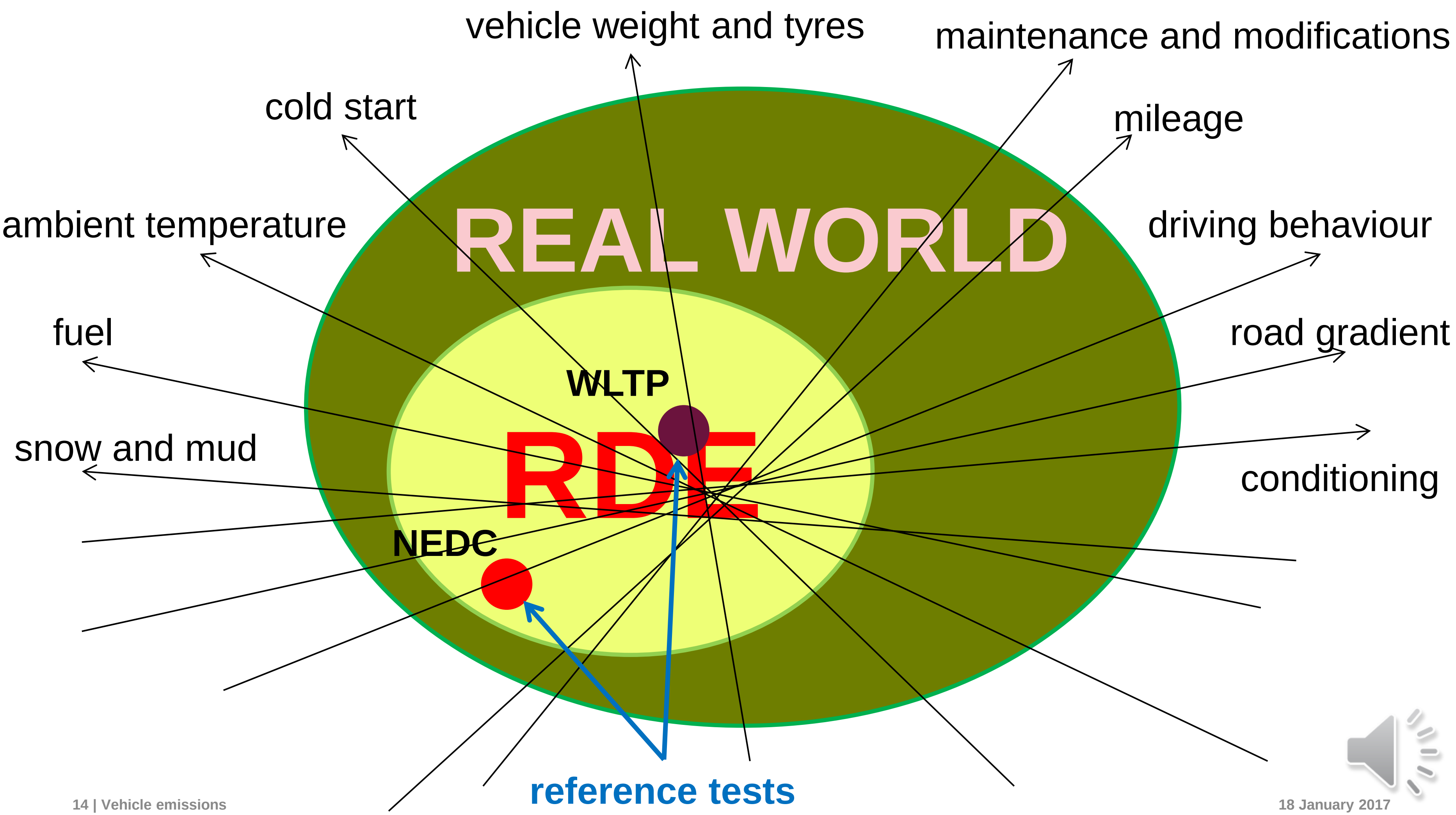
European regulation 715/2007:

article 14(3): *The Commission shall keep <u>under review</u> the procedures, tests and requirements referred to in Article 5(3) as well as the test cycles used to measure emissions. If the review finds that these are no longer adequate or no longer reflect real world emissions, they shall be adapted so as to adequately reflect the <u>emissions generated by real driving on the road</u>.*

→RDE legislation is the necessary revision foreseen in 2007 in Euro-5/6

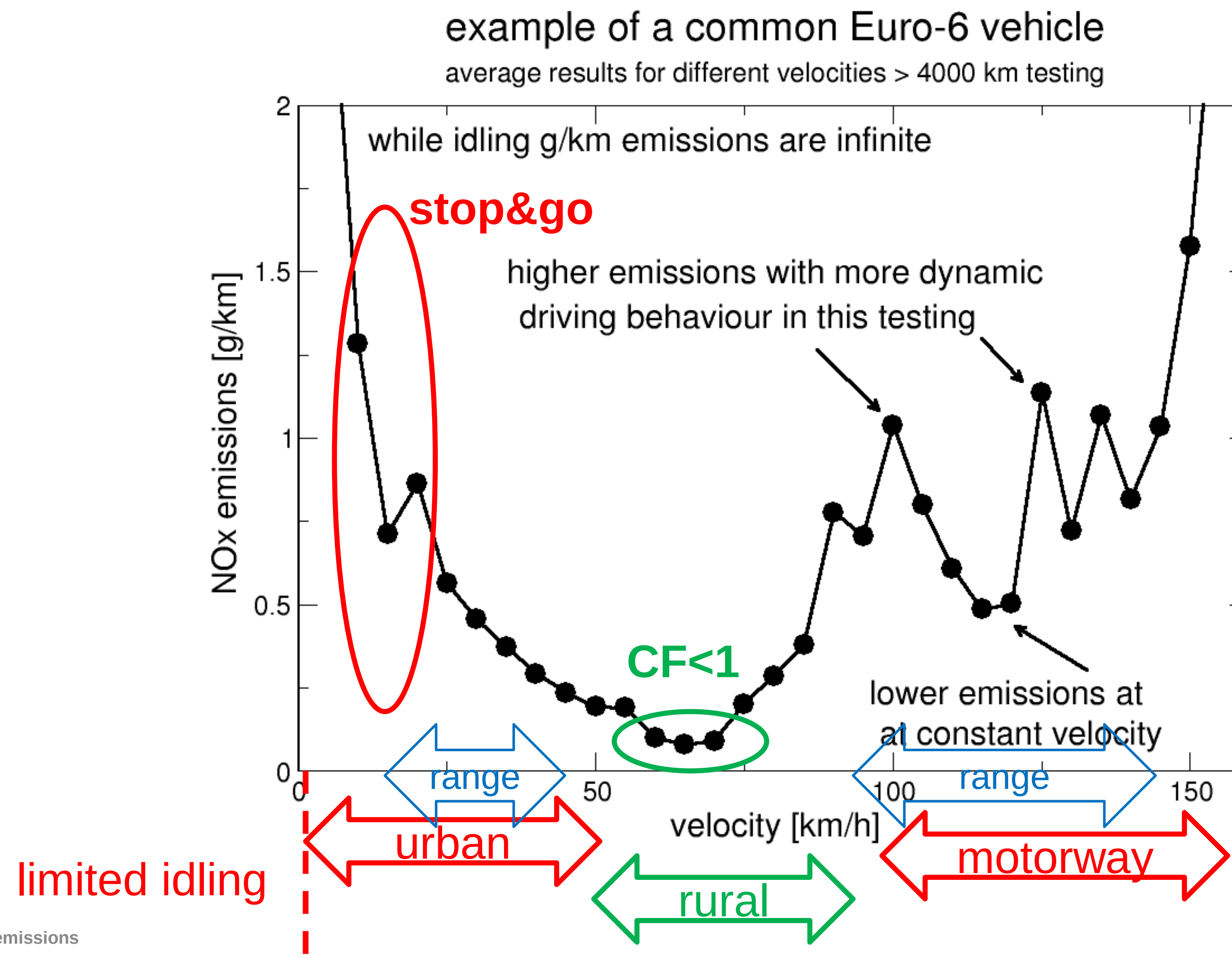
→default because of the high real-world emissions of Euro-5 (2010-2011)

FACTORS FOR REAL-WORLD EMISSIONS



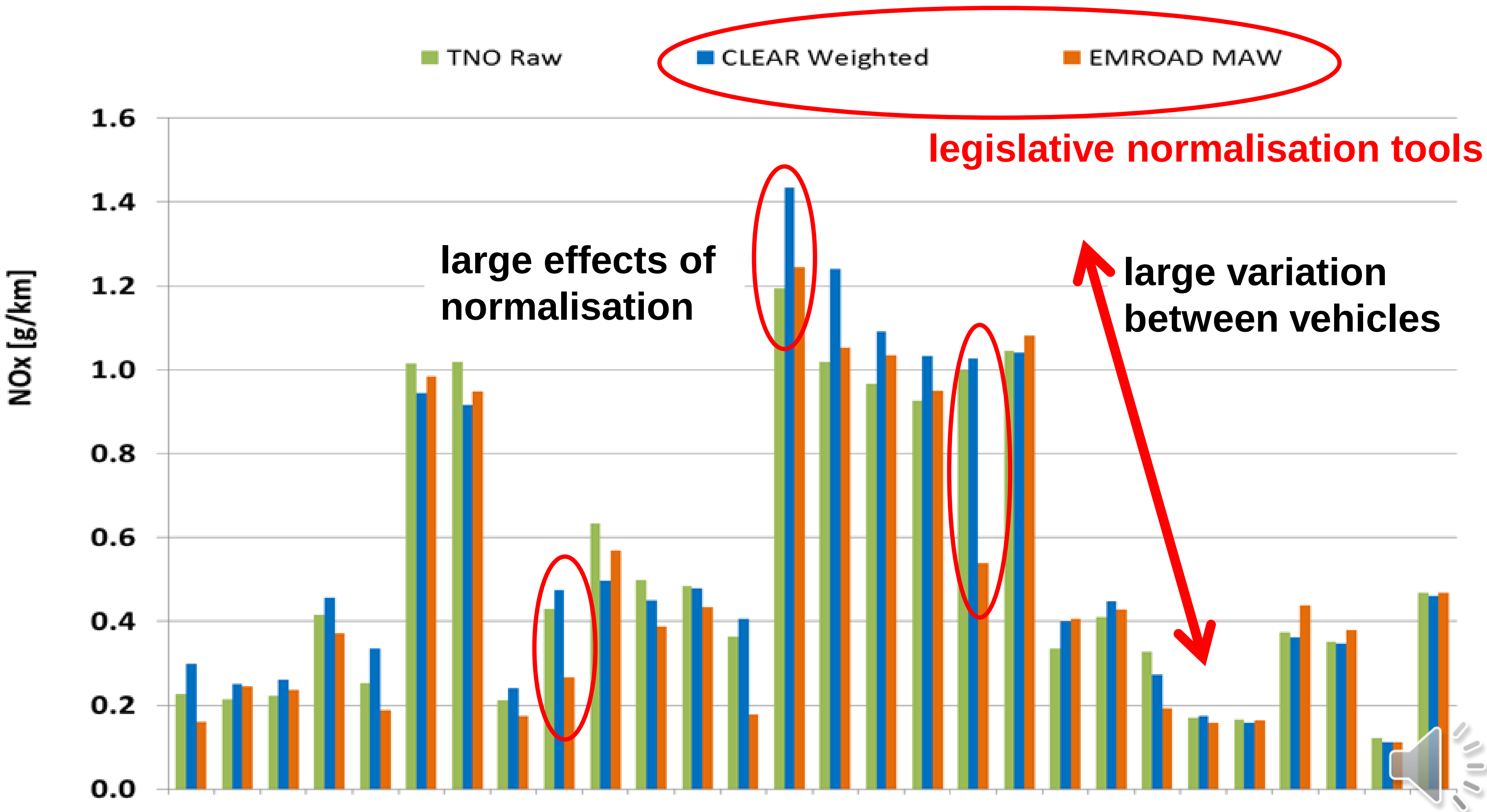
AVERAGING EMISSIONS MAY NOT SOLVE LOCAL PROBLEMS

DEFINED URBAN RDE EMISSION LIMIT IS VERY WELCOME



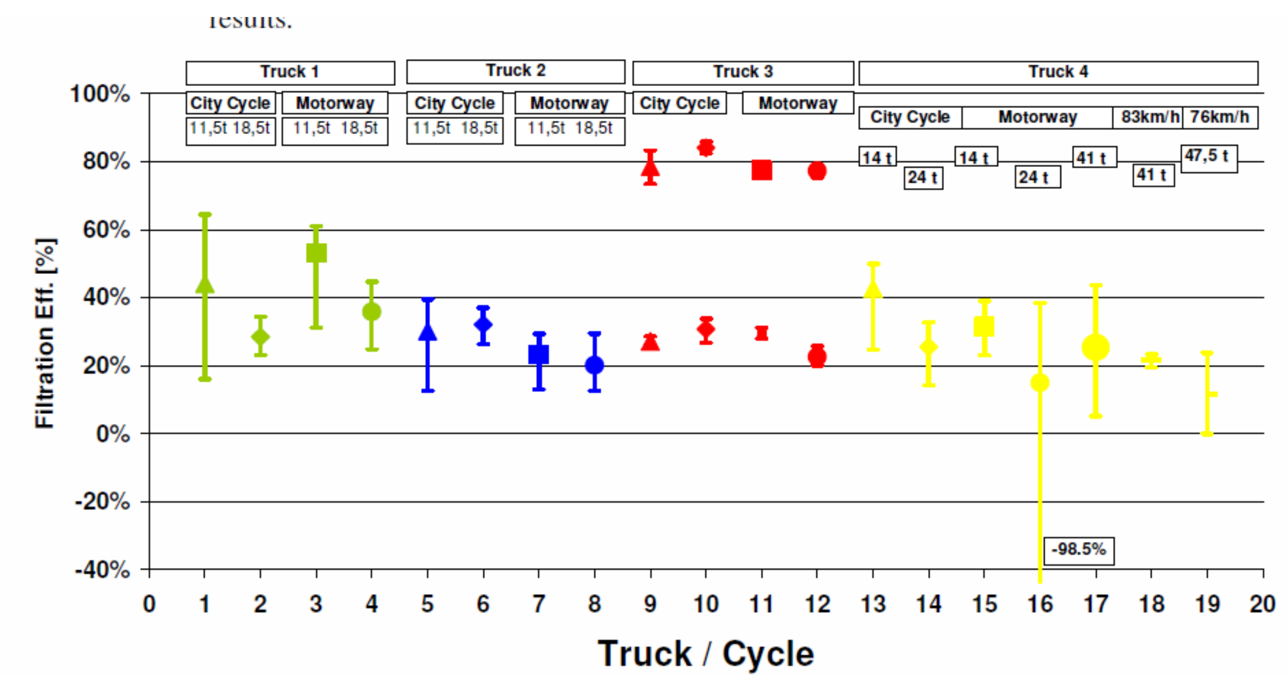
TNO RDE RESULTS 2015-2016

VEHICLE MAKES AND MODELS TO BE REPORTED OCTOBER 2016



RETROFITTED PARTICULATES FILTERS

- Tested in the laboratory in 2009 with real-world cycles from monitoring programs of payload and exhaust gas temperatures.
- Large variation between filtration efficiencies of new filters, with an average of 37%:

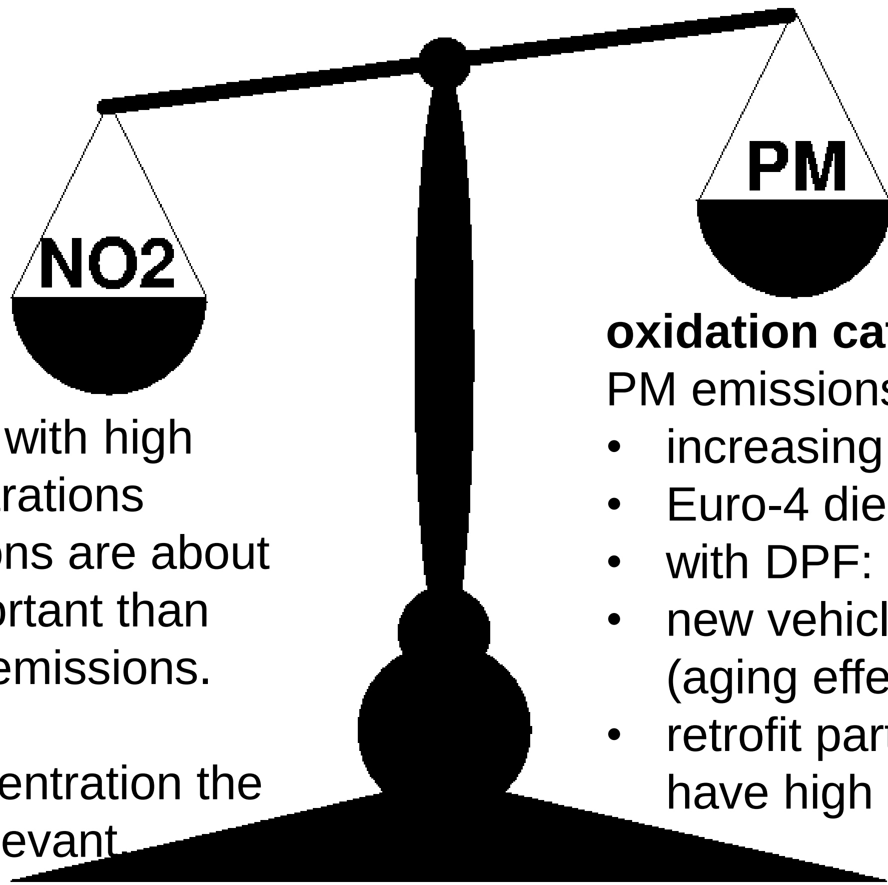


TNO report 03641 (2009) submitted to Dutch Parliament

NO_2 FRACTION IN NO_x FROM CATALYSTS

(AND WHY MOST RES MEASUREMENTS TELL ONLY A PART OF THE STORY)

many road-side studies measure only NO, not NO_2



At roadside locations with high ambient NO_2 concentrations the local NO_2 emissions are about **five times** more important than the local vehicle NO emissions.

For background concentration the NO_2 fraction is not relevant

oxidation catalysts to reduce PM emissions (and other benefits):

- increasing NO_2 emissions
- Euro-4 diesel: 55% NO_2/NO_x
- with DPF: 30% NO_2/NO_x
- new vehicles → higher NO_2 (aging effect)
- retrofit particulate filters may have high NO_2 fractions

Ambient NO to NO_2 conversion depends on many aspects: usually fitted from data

GOOD PRACTICE GUIDE
FOR IMPROVING URBAN AIR-QUALITY

- On-road testing in real world usage is essential to determine the vehicle emissions
  - Especially retrofit technologies and busses should be tested in vivo

- Multi-prong plan is needed to improve air-quality effectively:
  - Stimulate affordable clean new vehicles
  - Scrap dirty old vehicles with large local impact
  - Balance both with retrofitting and modality shifts
  - Reduce congestion to free-flow traffic between 50-90 km/h
  - Public awareness

- Think “long term” to keep it realistic and to limit eventual traffic increase

THANK YOU FOR YOUR ATTENTION