

Evaluation of the suitability to European conditions of the WNTÉ control zone concept as set out in the OCE GTR

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WNTE Evaluation

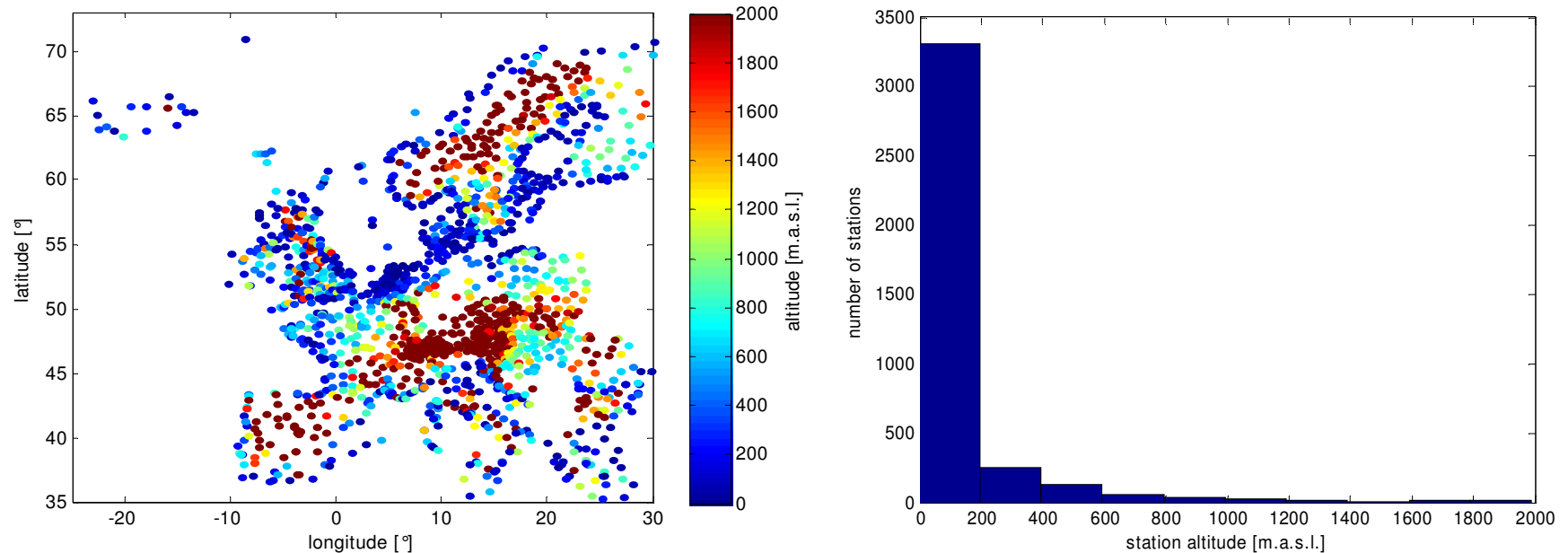
- **European driving conditions**
- **European ambient conditions**
- **Evaluation WNTE control zone and alternative approaches**

WNTE Ambient Conditions Proposal

- **Measurements valid if**
 - altitude < 1680 m above sea level
 - humidity between 7.14 and 10.71 g water per kg dry air.
Outside these conditions: correction factors for the emissions.
 - ambient temperature between 12 and approximately 35 °C (two options exist). Below 12 °C : correction factors, above about 35 °C correction factors (option A) or invalidity (option B)

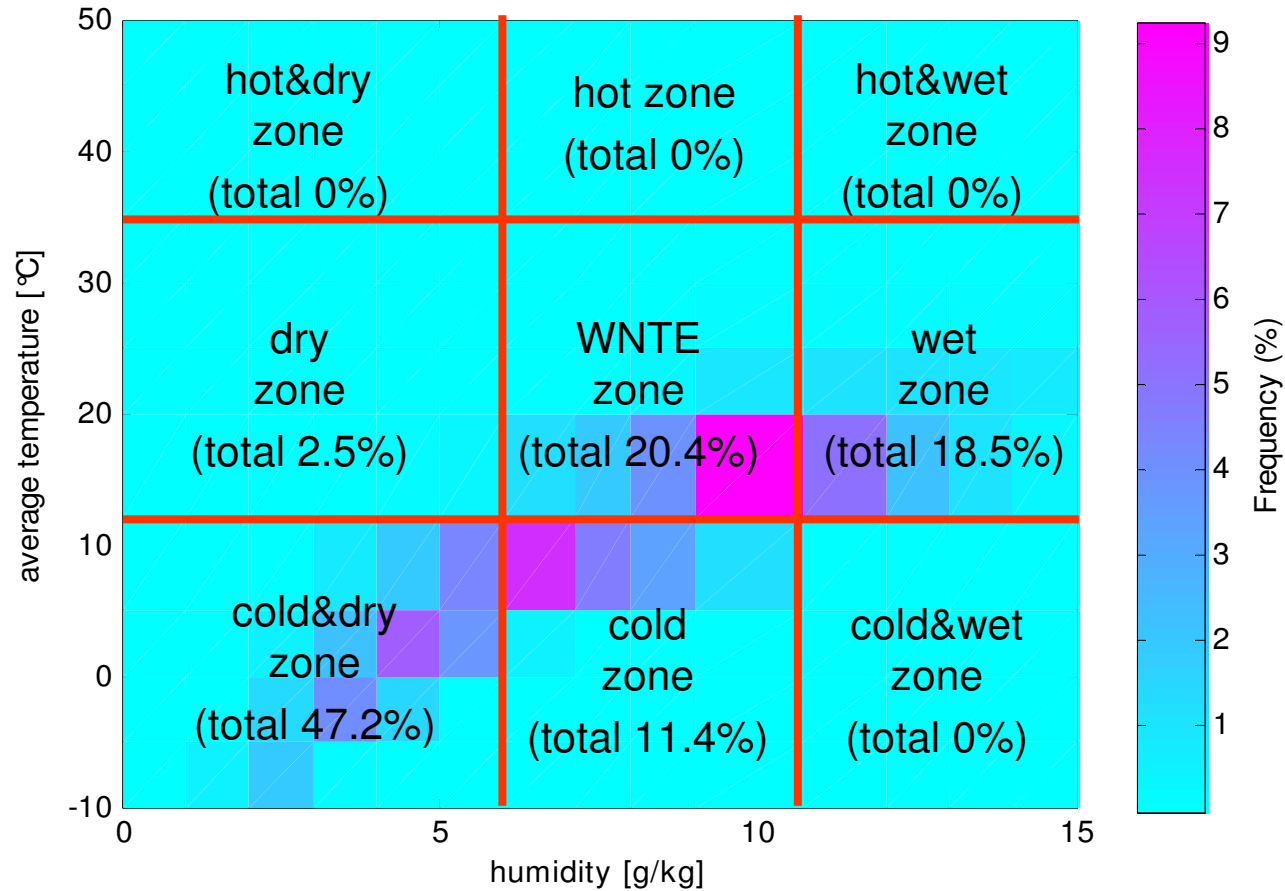
Analysis of Ambient Conditions in Europe

- Main alp-crossing transitions Brenner (1375 m), Frejus (1312 m) and Gotthard (1175 m) lie below the proposed 1680 m
- Weather: Analysis of daily European weather stations data of the year 2005 (source: NOAA)



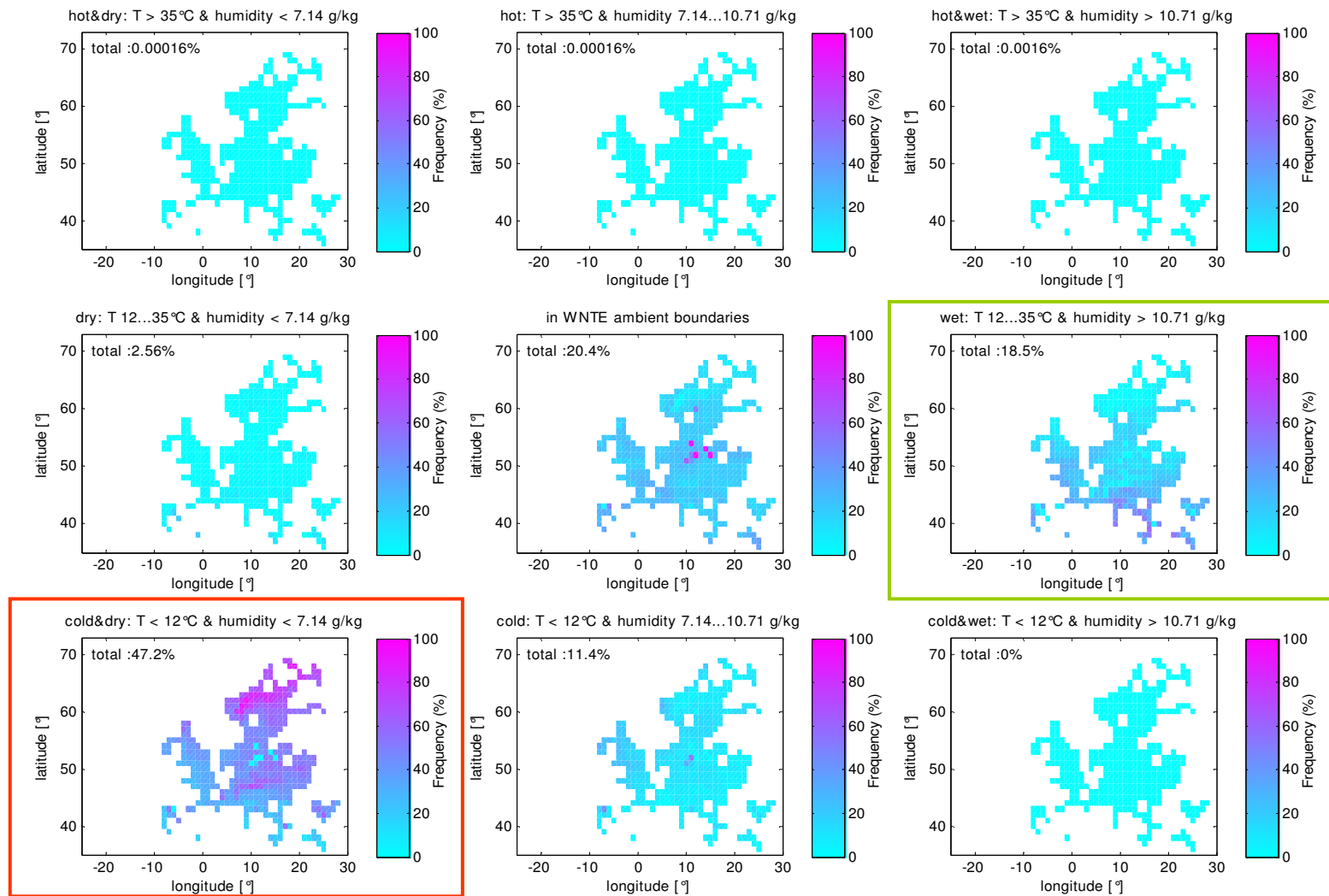
- Average daily temperature of all stations: 9.6 °C

Frequency Distribution of Temperature and Humidity



→ Only 20.4% of average temperatures in 2005 lied within the proposed WNTe conditions

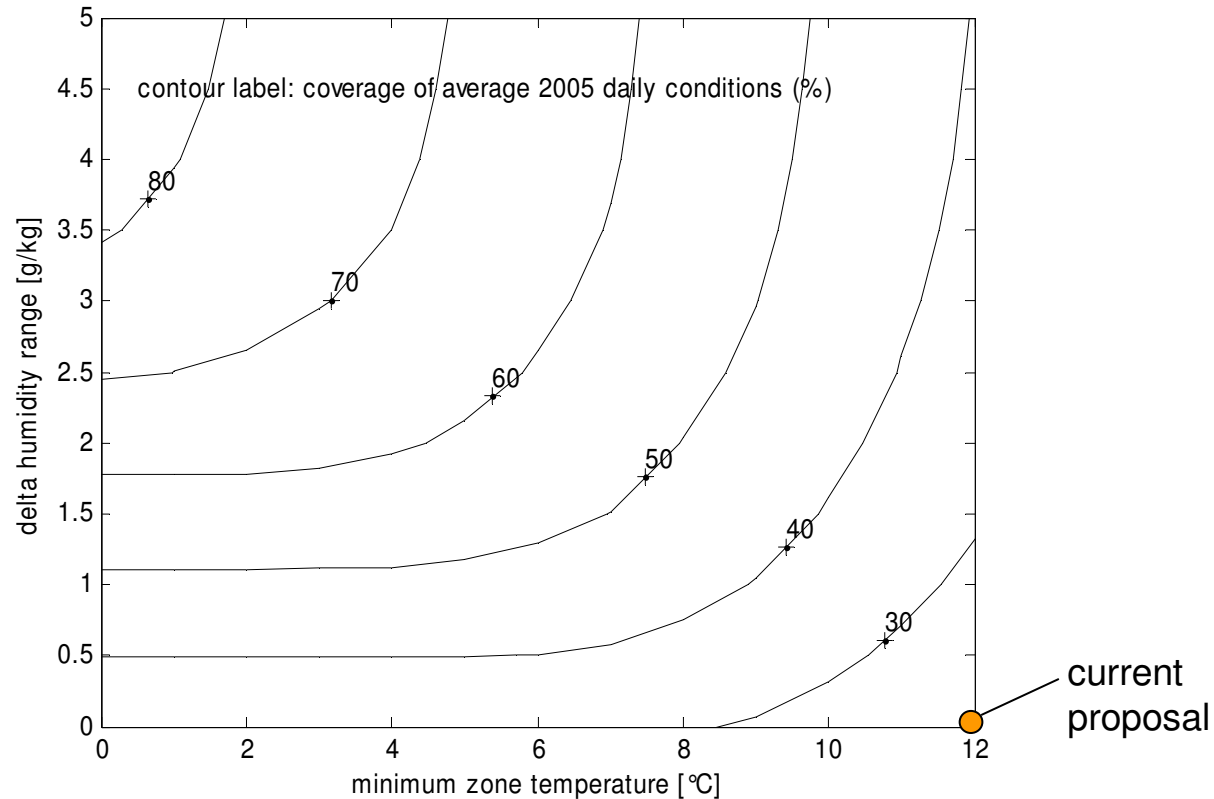
Geographical Distribution of the Weather Conditions



northern European and alpine countries are often cold and dry

southern European countries are often wet

Influence of Widening the Zone



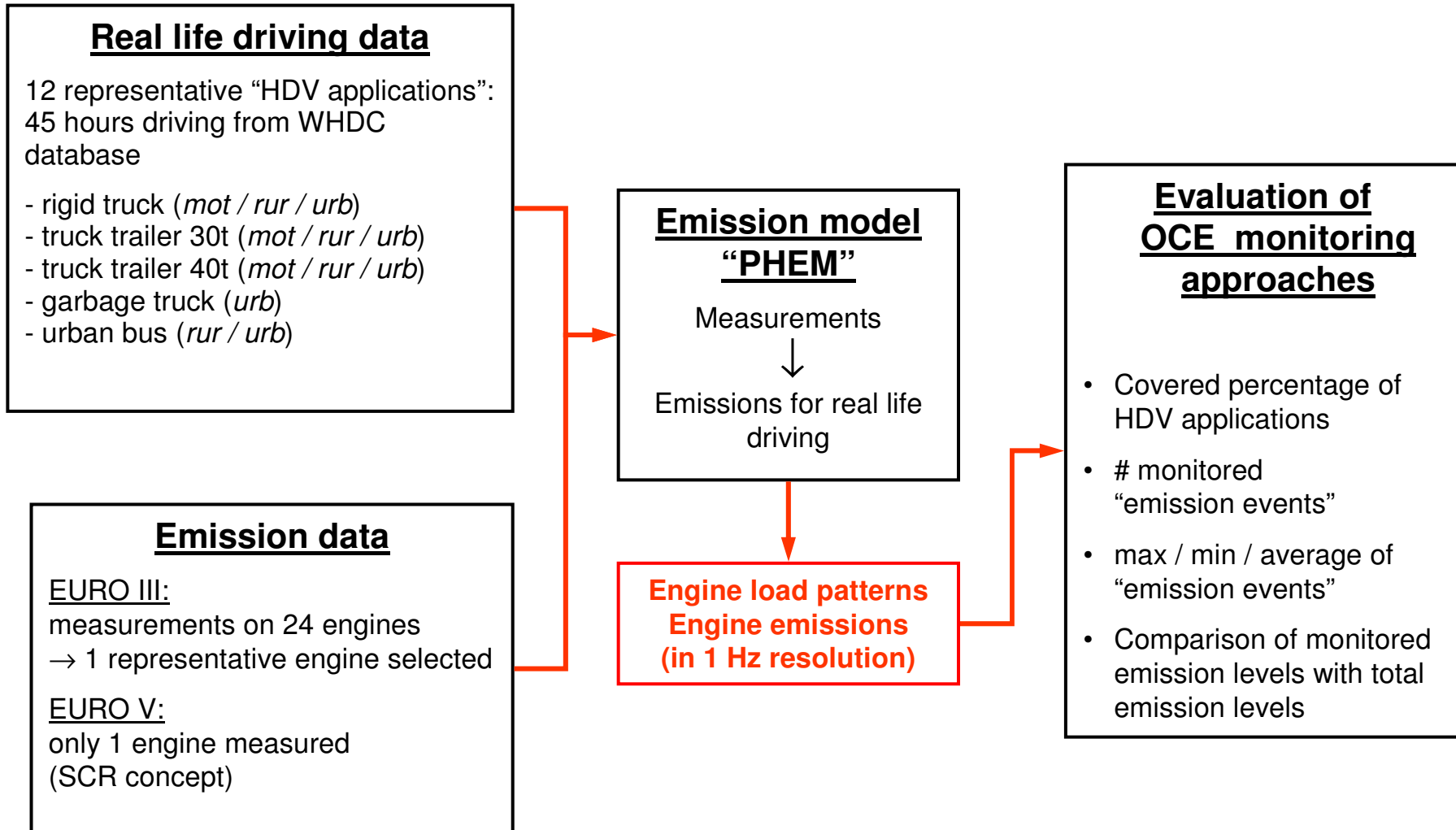
→ If the minimum zone temperature would be lowered to 5°C and the humidity range would be widened by 3 g/kg, about 65 % of the average European conditions could be covered (instead of ~ 20% with the current proposal) without the use of correction factors.

Evaluation OCE monitoring approaches

Requirements OCE monitoring approach:

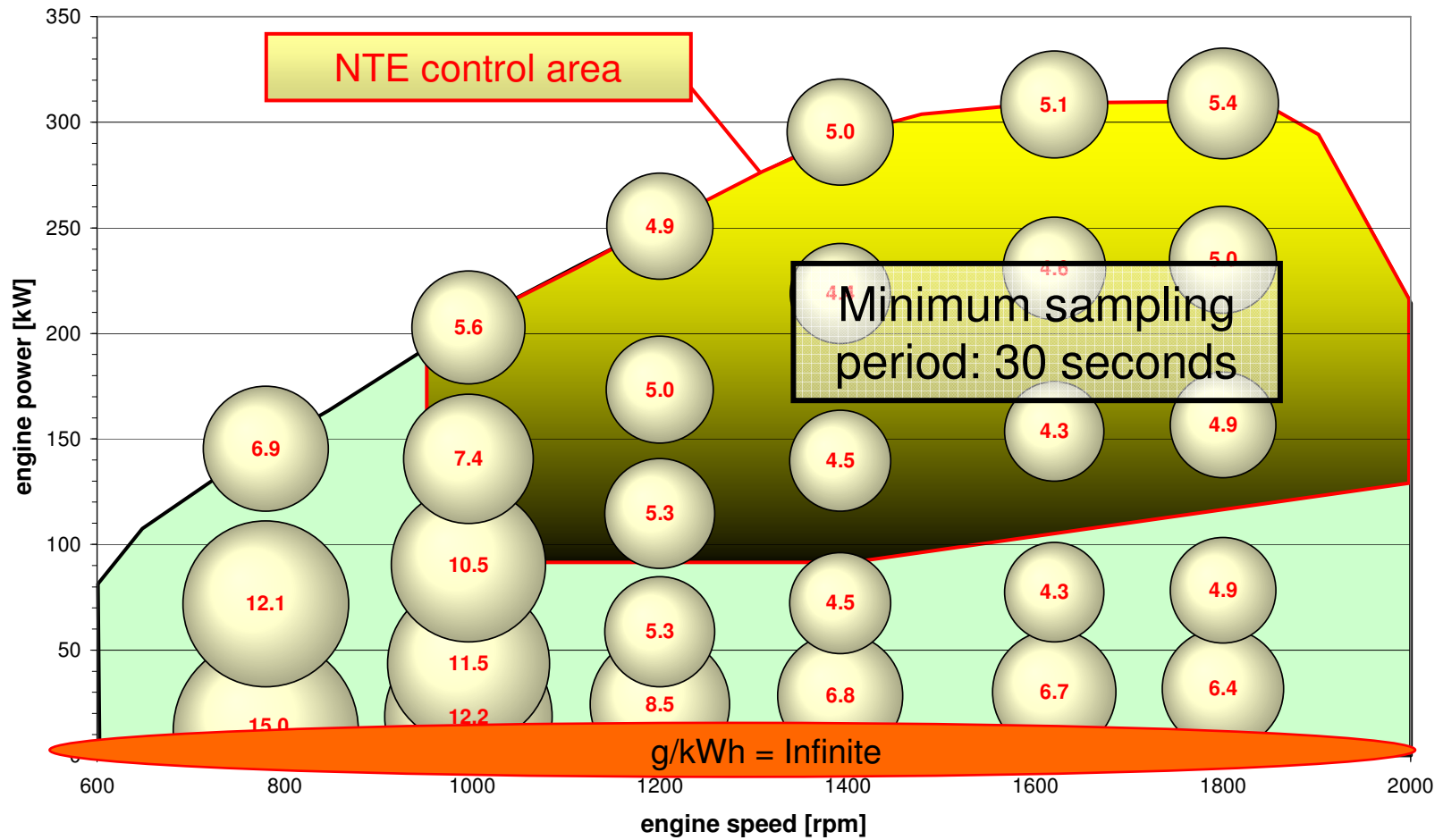
- include all relevant operating conditions
- shall be able to detect defeat strategies
- compliant with PEMS

Methodology



WNTE current draft

Brake specific NOx emissions [g/kWh] / EURO III

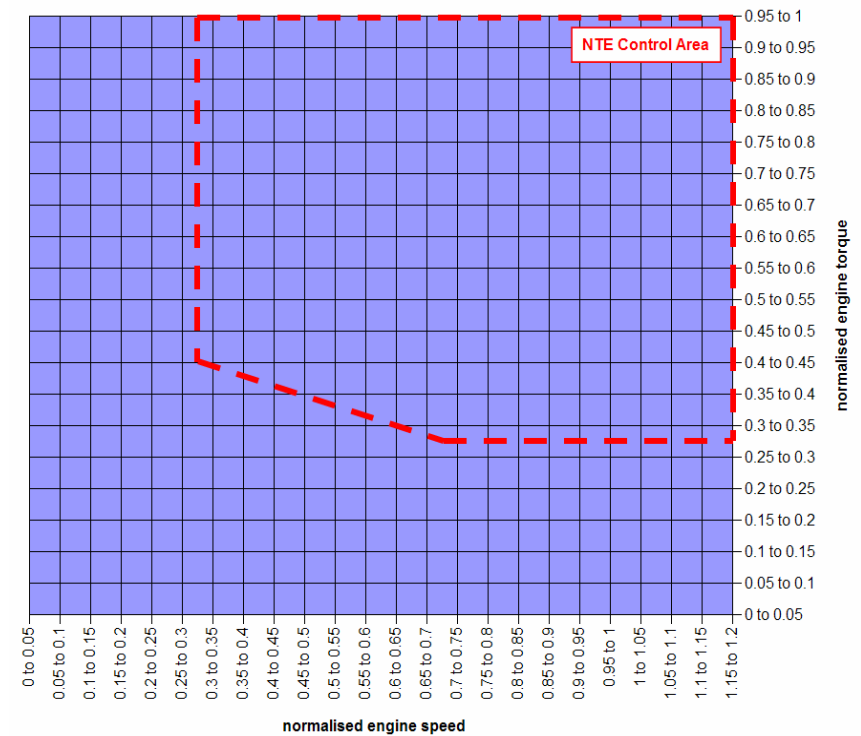
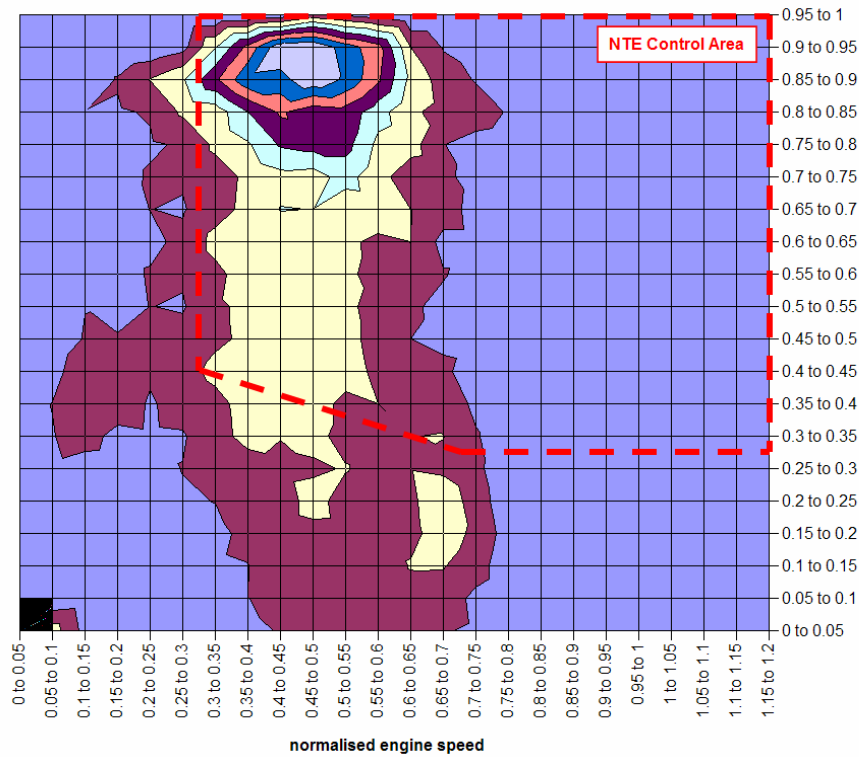


Distribution of NOx emissions

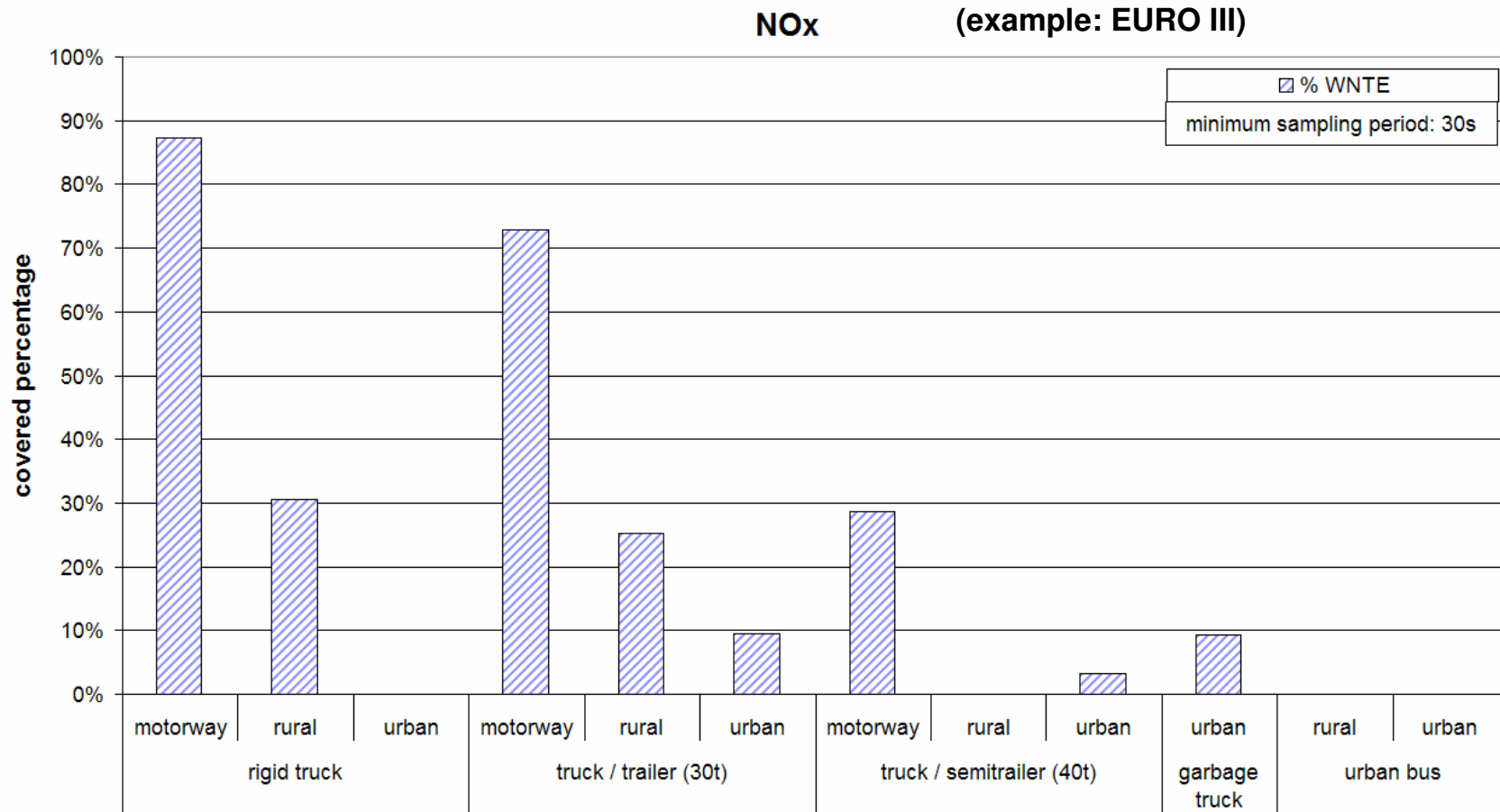
urban bus / urban

total

WNTE



Coverage of the draft WNTE (all HDV)



Coverage total HDV driving in Europe:

~22% time

~33% NOx

~28% PM

Modified control area based concepts

- **Basic WNTE version:**

Coverage total HDV fleet (example EURO III):

~22% time ~33% NOx ~28% PM

- **Alternative WNTE version #1:**

- unchanged control area
- minimum sampling period reduced to 10s

~33% time ~53% NOx ~46% PM

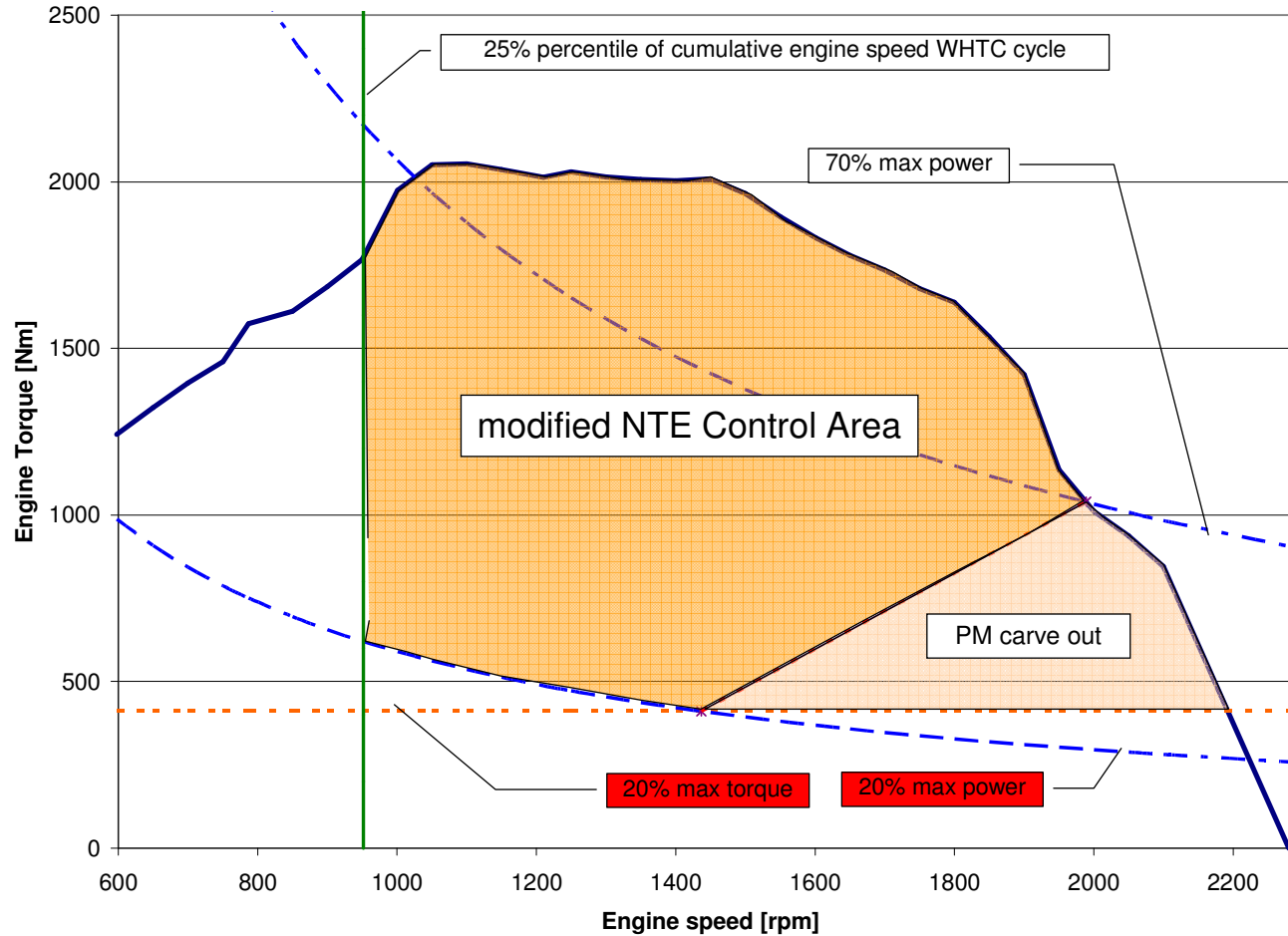
- **Alternative WNTE version #2:**

- enlarged control area
- minimum sampling period reduced to 10s

~41% time ~63% NOx ~57% PM

- Problems:
- highly transient operation not covered
 - interpretability of short emission peaks
 - PM mass measurement with filter not applicable

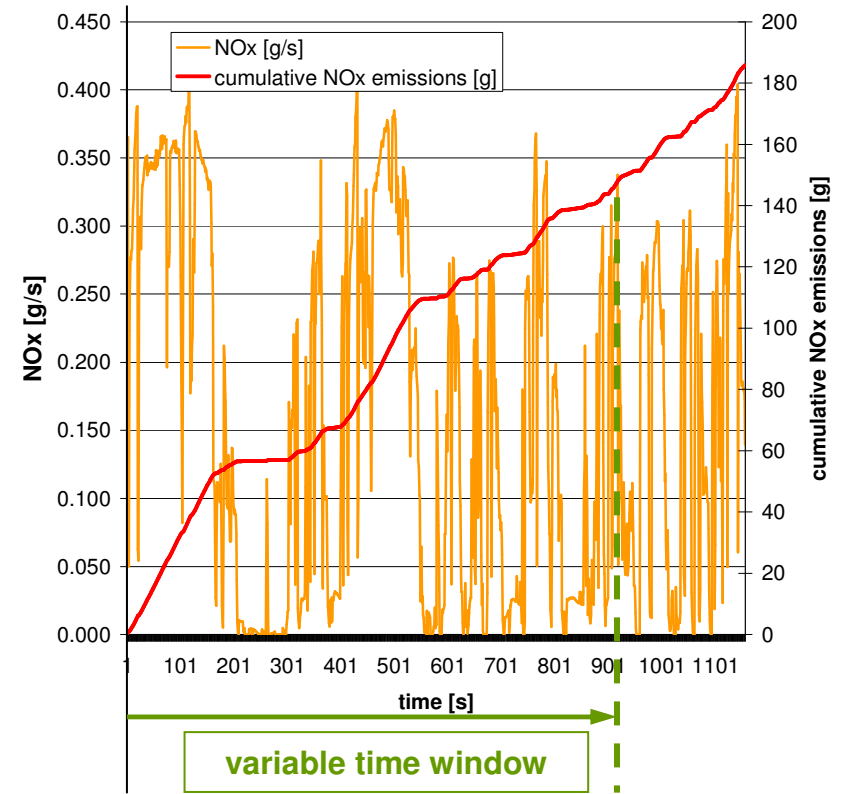
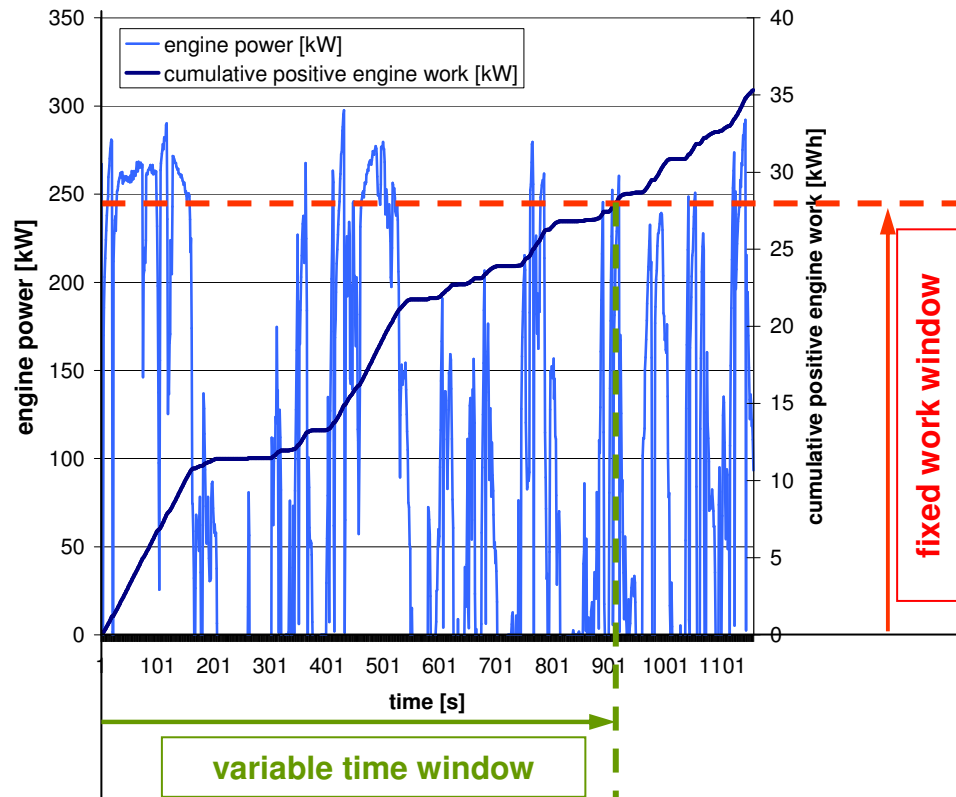
Enlarged WNTe control zone



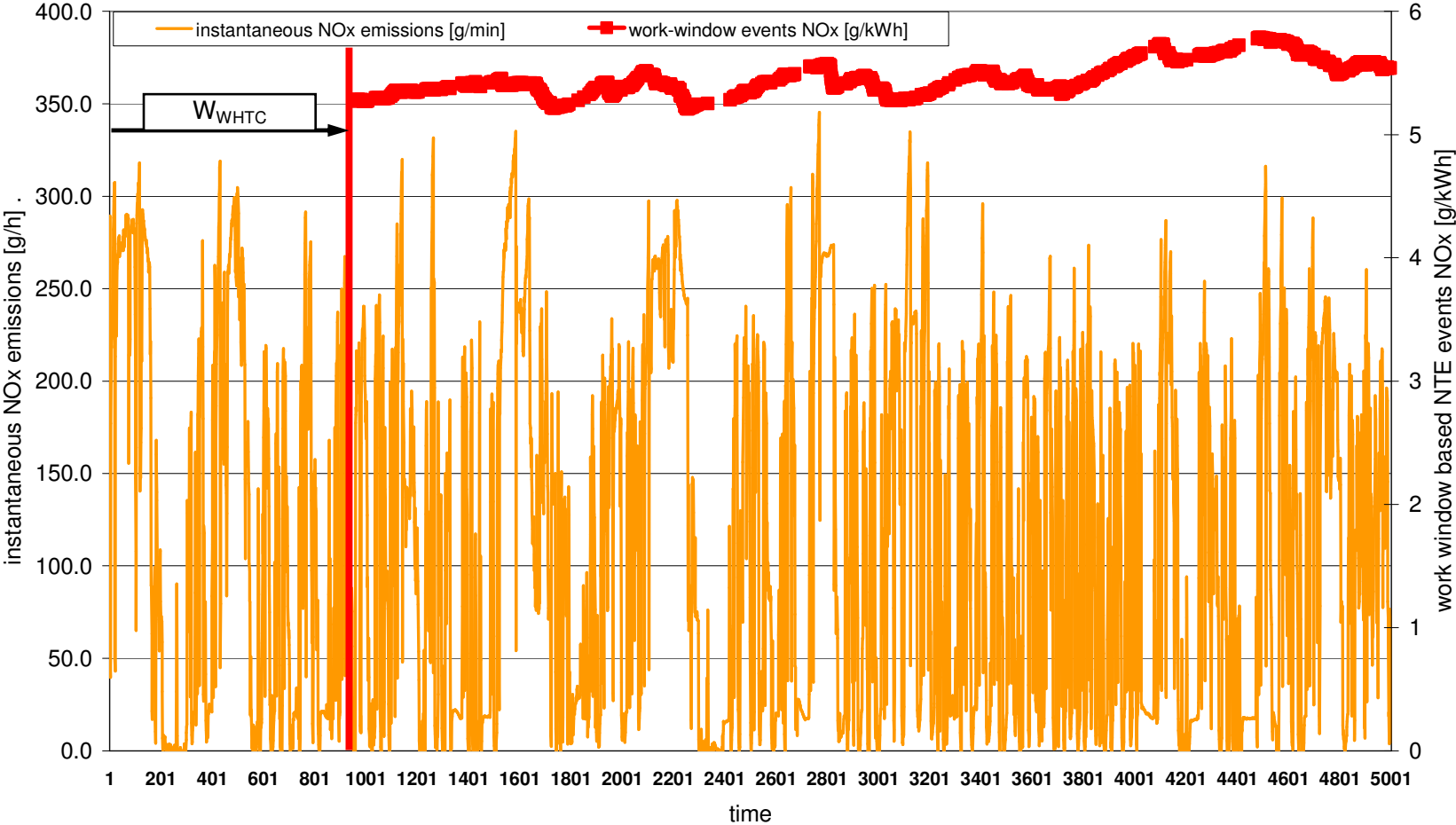
Alternative approach: „Work window“

Method:

- Total driving time is measured and evaluated
- Calculation of [g/kWh] averaged over a fixed amount of engine work („work window“)



Work window based emission events



Alternative approach: CO₂ specific

Method:

- Total driving time is measured and evaluated
- Calculation of [g/kg CO₂] averaged over a fixed amount of emitted CO₂ („CO₂ window“)

Coverage total HDV fleet (example EURO III):

~99% time

~99% NO_x

~99% PM

Features of work window and CO₂ specific method:

- all relevant operation conditions covered
- classification of emission events possible (unavoidable high or „defeat strategy“) if boundary conditions for test trip are well defined
- PM mass measurement with filter is applicable

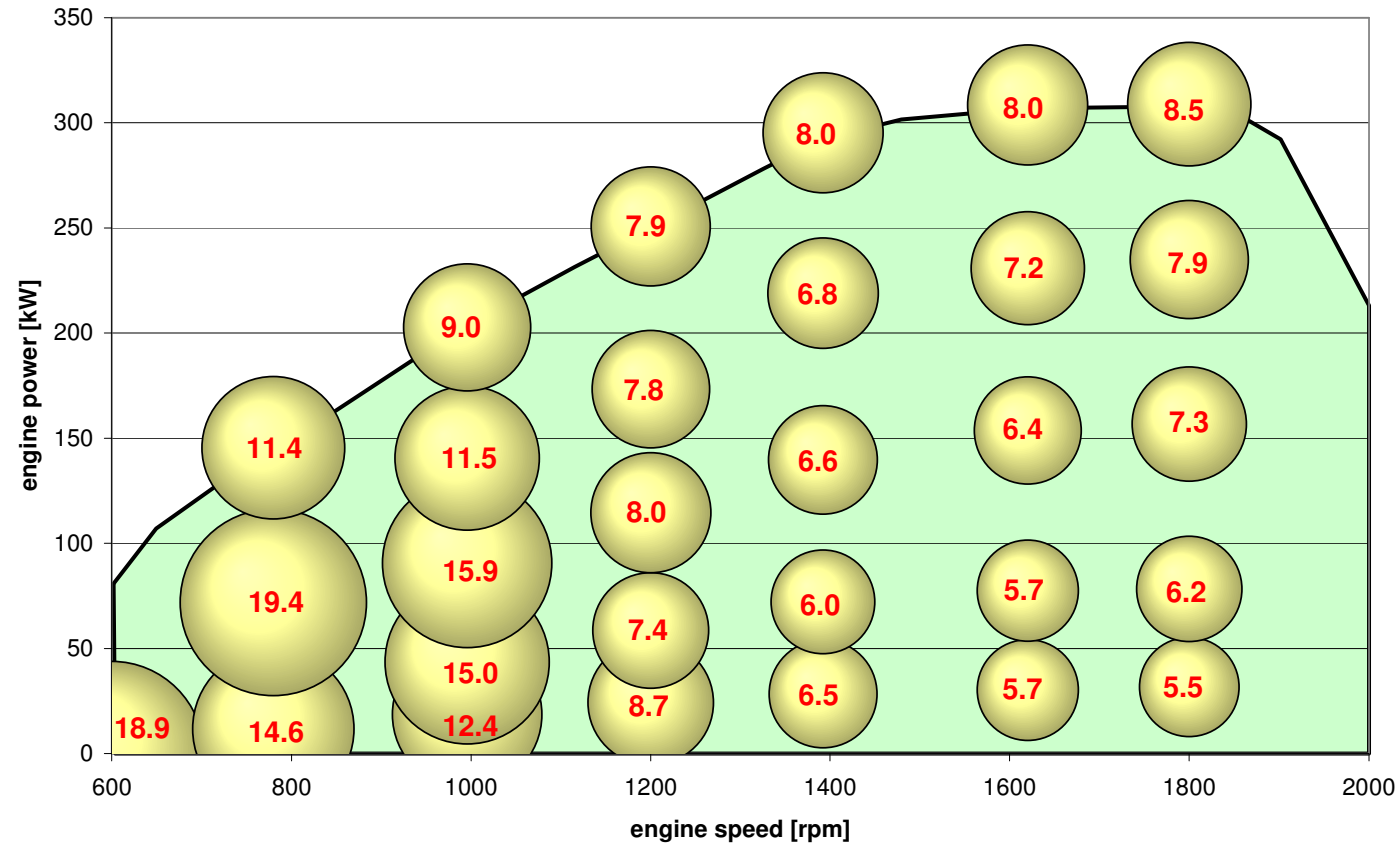
Alternative approach: CO₂ specific

Extra advantages CO₂ specific method:

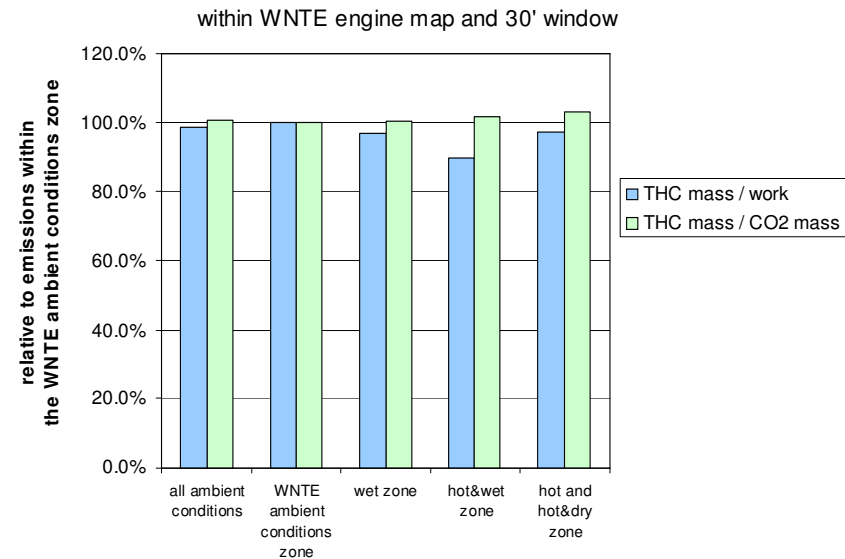
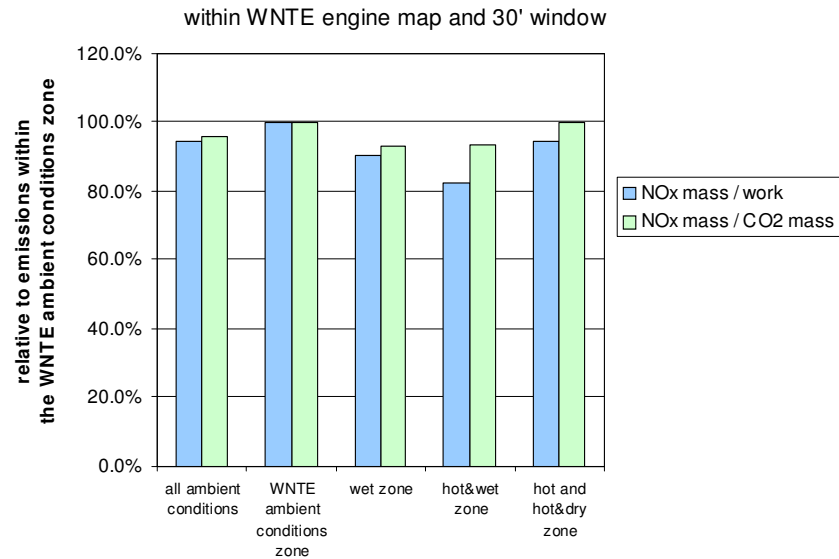
- No „tricks“ needed to prevent excessive emissions in [g/kWh] at low loads
- Less sensitive to ambient conditions
- No ECM, kW or engine speed data necessary
- Less sensitive for possible PEMS flow measurement errors

Alternative approaches: CO2 specific methods

CO2 specific NOx emissions [g/kg] / EURO III



Alternative approaches: CO2 specific methods



Comparison OCE monitoring approaches

	OCE monitoring approach	coverage of relevant operating conditions	“unavoidable” high emissions excluded	feasibility with PEMS (*)	ECU data necessary
WNTE	draft WNTE	--	++	--	yes
	+ 10s minimum sampling period	-	-	--	yes
	10s + enlarged control area	0	-	--	yes
Alternatives	“Work window”	+	+	++	yes
	“Compliance factor” based on CO ₂ specific emissions	+	++	++	no
	WNTE + minimum sampling period & work window for averaging of emission events	0	+	--	yes

(*) incl. filter-based measurement of PM emissions

Summary I

- **Findings are based on a large set of driving conditions from the WHDC database & emission data from ARTEMIS + COST 346 + D.A.CH.-NL (only one EURO V HDV):**
- **All approaches have specific advantages and disadvantages**
- **The actual proposal with a 30 second sampling period covers ~30% of European HDV emissions (large gaps especially in urban and rural driving)**
→ no large additional value to existing type approval
- **Only ~20% of the European weather conditions are covered without the use of correction factors**
- **Reducing the minimum temperature from 12°C to 5°C & widening the humidity range by 3 g/kg, leads to a much better coverage of weather conditions (65% instead of 20%)**

Summary II

- **PM mass measurement with filter is not applicable for control area based approaches**
- **An alternative with 10 second sampling and enlarged control area covers ~55% of European HDV emissions, but transient and low load urban driving is still not covered**
 - reasonable additional value to existing type approval
- **The work window based approach and the CO₂ specific approach cover all relevant driving situations**
 - large additional value to existing type approval
- **The CO₂ based approach showed lower sensitivity to operating + ambient conditions and does not need measurement of engine work**
- **PM mass measurement with filter would be applicable**

Summary III

- **At least for work window and the CO₂ specific approach further boundary conditions for the test trip would have to be defined**
- **The test trips and the evaluation should be divided at least into urban driving and highway driving**
- **The measured EURO V vehicle would have failed all OCE approaches due to increased emission levels after highly transient load changes and with inactive SCR in low loads; although the overall emission level was low (on average < 2g/kWh but scattering from 0.5 to 8 g/kWh)**
- **Without introducing OCE approaches EURO V and VI may have high NOx emission levels in several urban driving conditions which frequently occur**

Open questions

Policy questions to define the boundary conditions:

- Shall OCE monitoring cover the thermal management of the engine and the exhaust gas after treatment too (e.g. cool down of SCR in stop&go)?
If yes, low load driving has to be included in the trips
- Shall future HDV have low NOx emissions also in very unfavourable traffic situations (e.g. highly transient conditions)?
If yes, the control area based approach is not suitable
- Feasibility and costs for manufacturers should be considered too

Technological question:

- How can particulate mass be measured comparable to the type approval with filter method?

Thank you for your attention!



Backup Slides

HDV mileage distribution

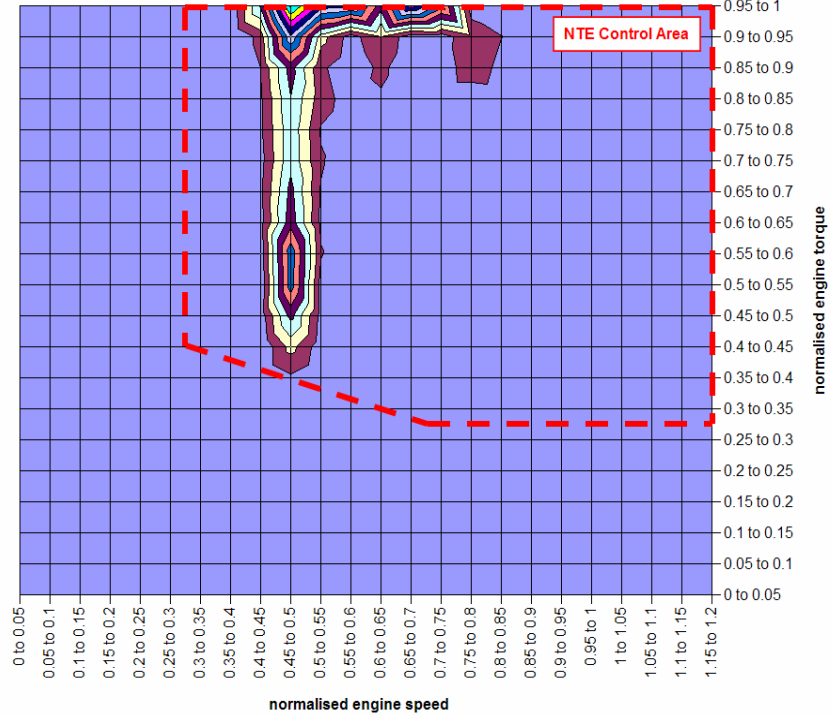
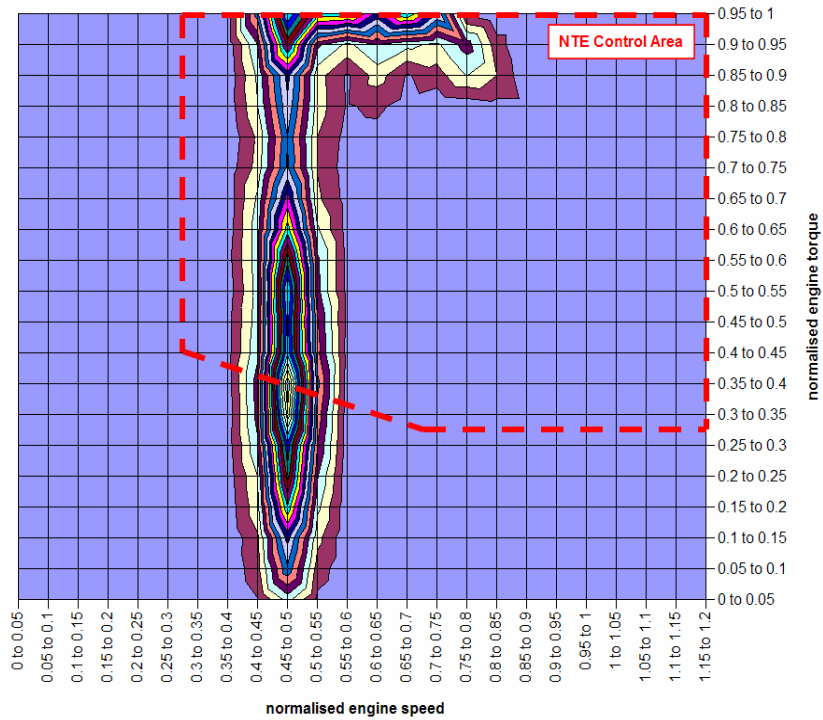
share on total HDV mileage		country / weighting factor			
		mix	GER	NL	A
		100.0%	82.3%	10.6%	7.1%
rigid truck	motorway	10.9%	9.2%	22.1%	13.5%
	rural	11.0%	10.9%	12.1%	10.4%
	urban	7.7%	8.1%	5.2%	7.2%
truck&trailer (GVM: 30t)	motorway	13.9%	14.2%	9.9%	15.7%
	rural	5.2%	5.4%	3.4%	4.4%
	urban	2.8%	2.8%	4.0%	2.0%
truck&(semi)trailer (GVM: 40t)	motorway	31.4%	32.5%	22.9%	31.4%
	rural	10.9%	11.5%	8.2%	8.8%
	urban	3.2%	2.2%	10.3%	4.0%
garbage truck	urban	0.4%	0.4%	0.3%	0.4%
urban bus	rural	1.1%	1.2%	0.7%	0.2%
	urban	1.5%	1.6%	1.1%	2.0%
TOTAL		100.0%	100.0%	100.0%	100.0%

Cumulative NOx emissions

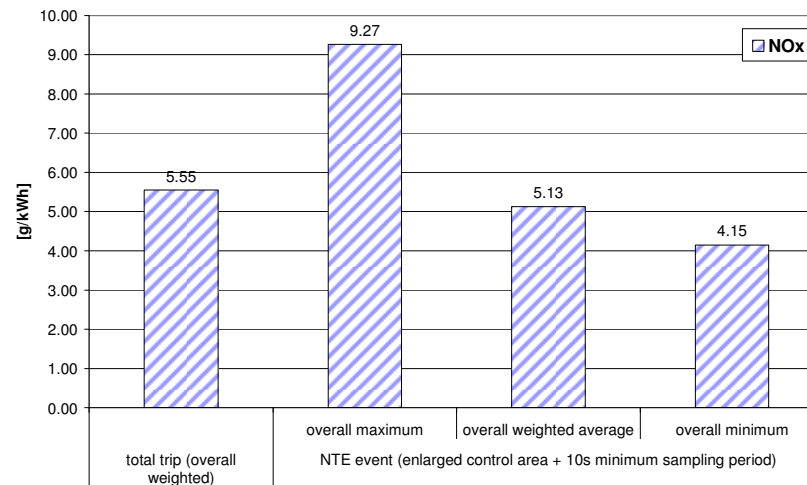
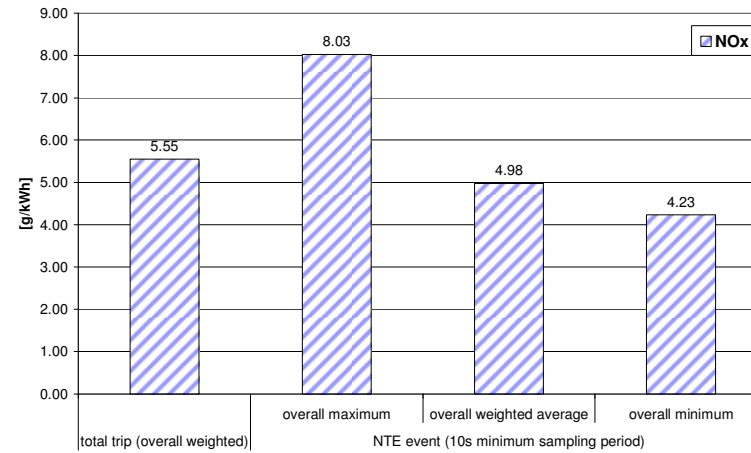
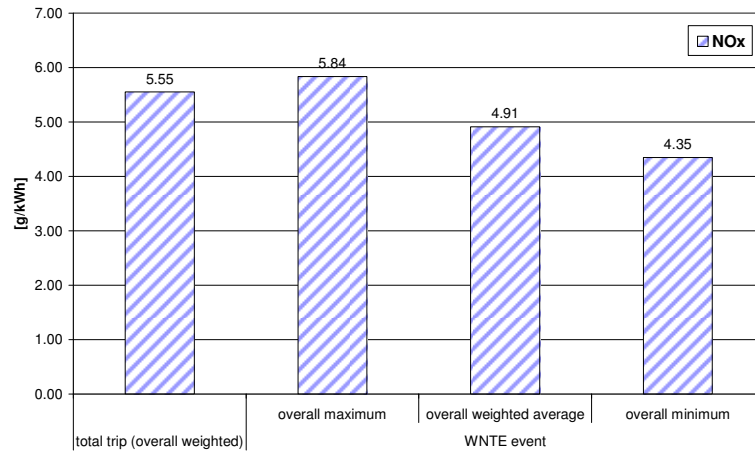
truck + semitrailer 40t / motorway

total

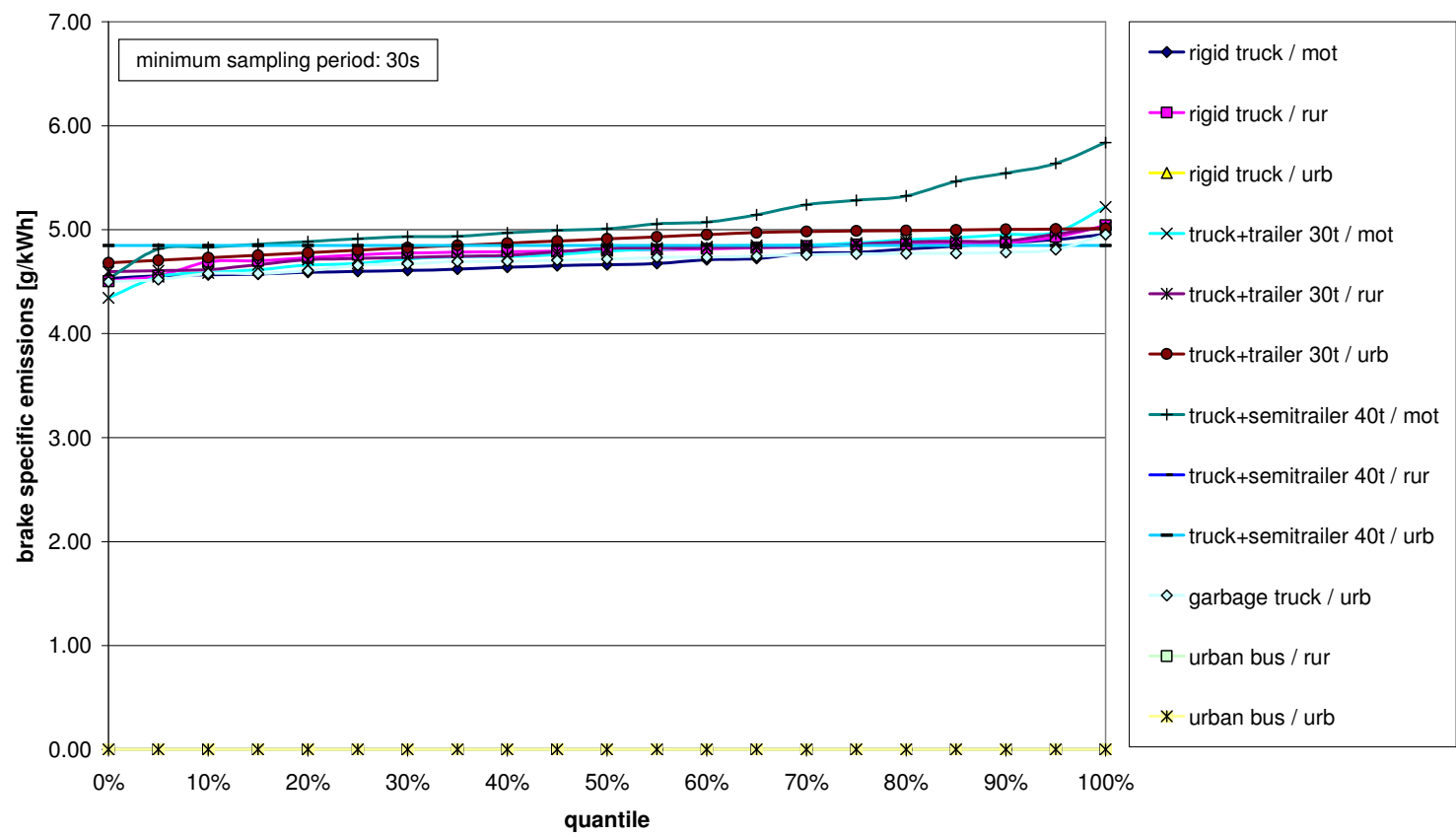
WNTE



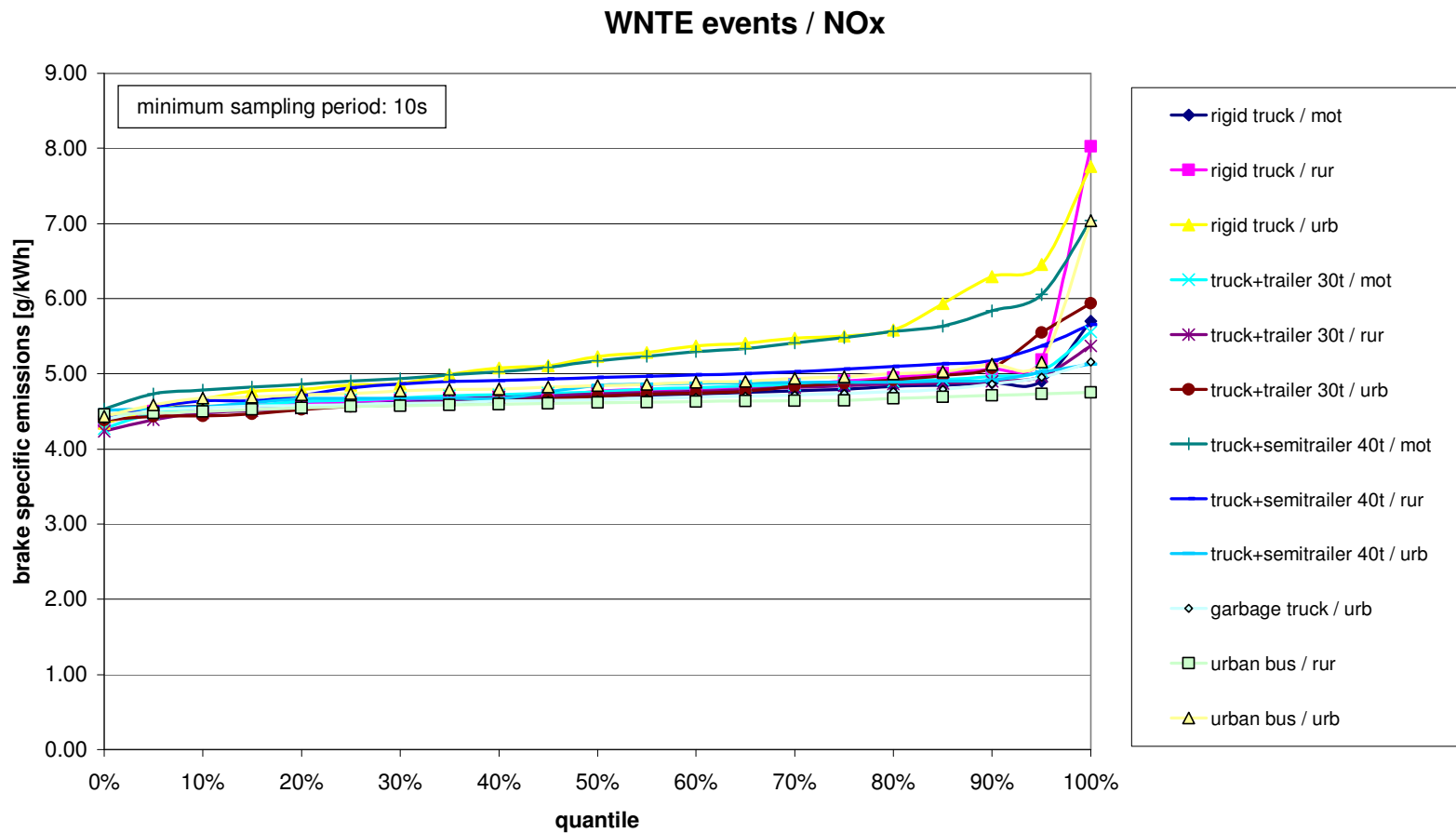
WNTE control area + variants – Euro III



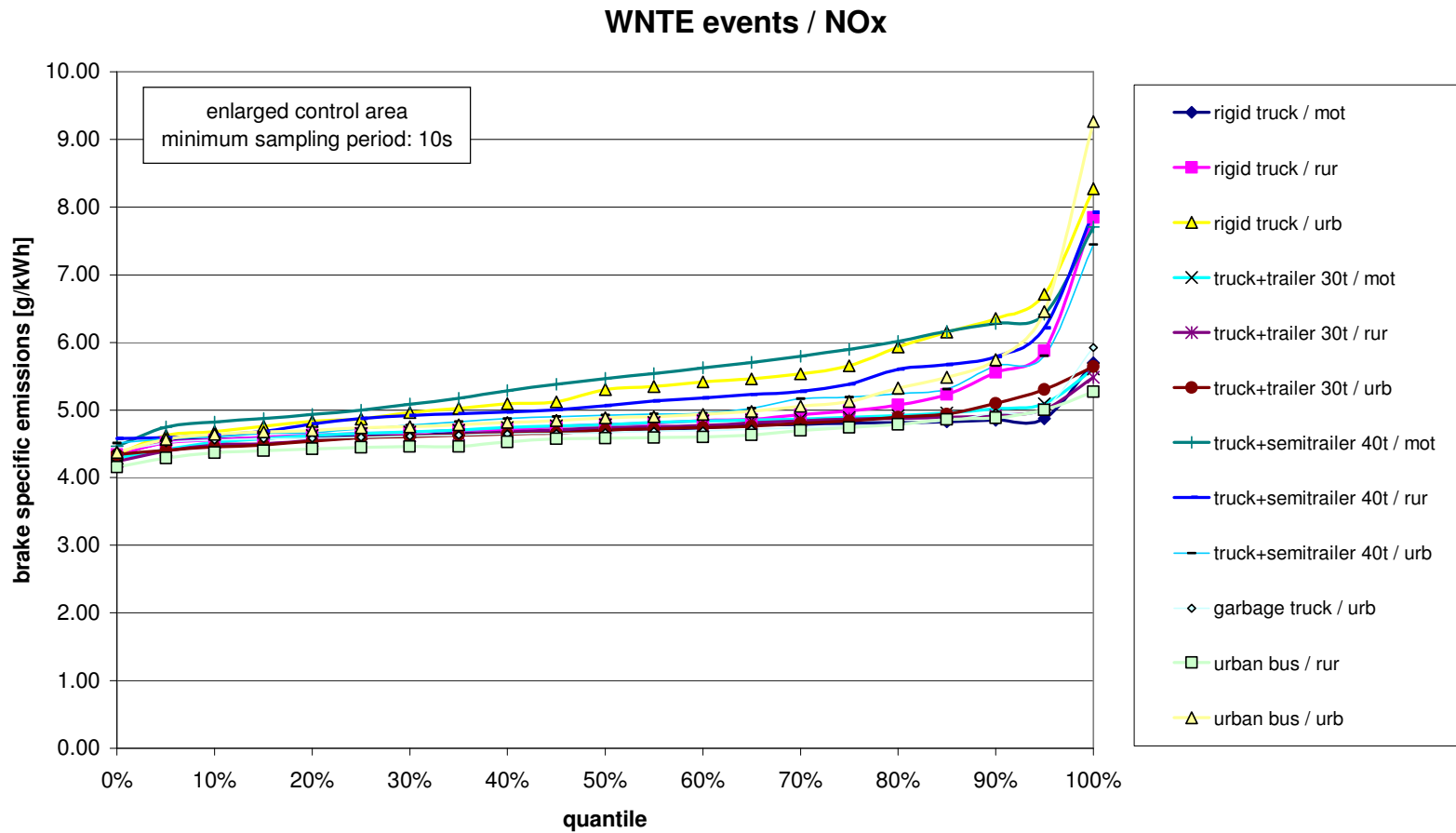
WNTE control area – Euro III



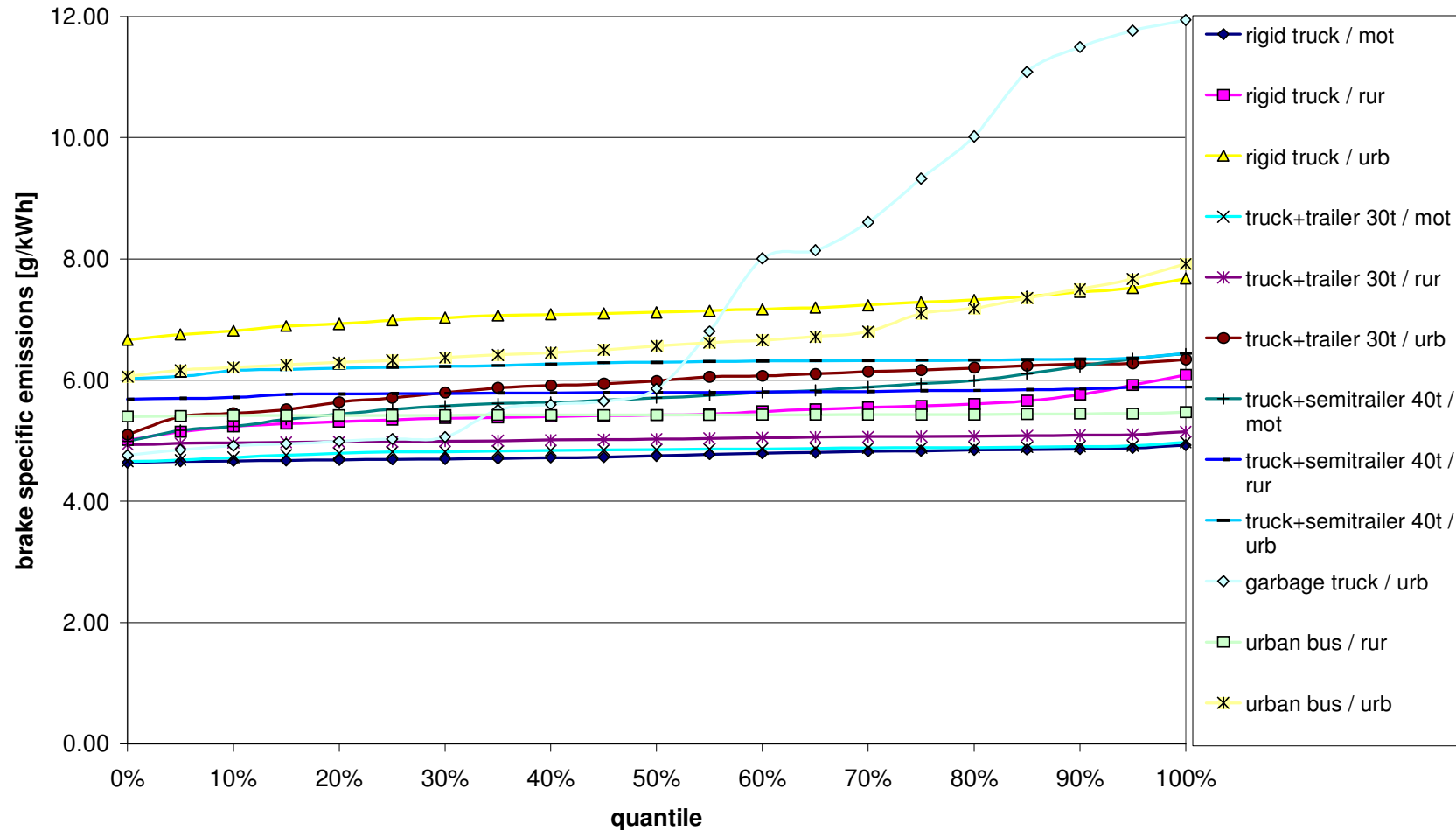
WNTE control area variants – Euro III



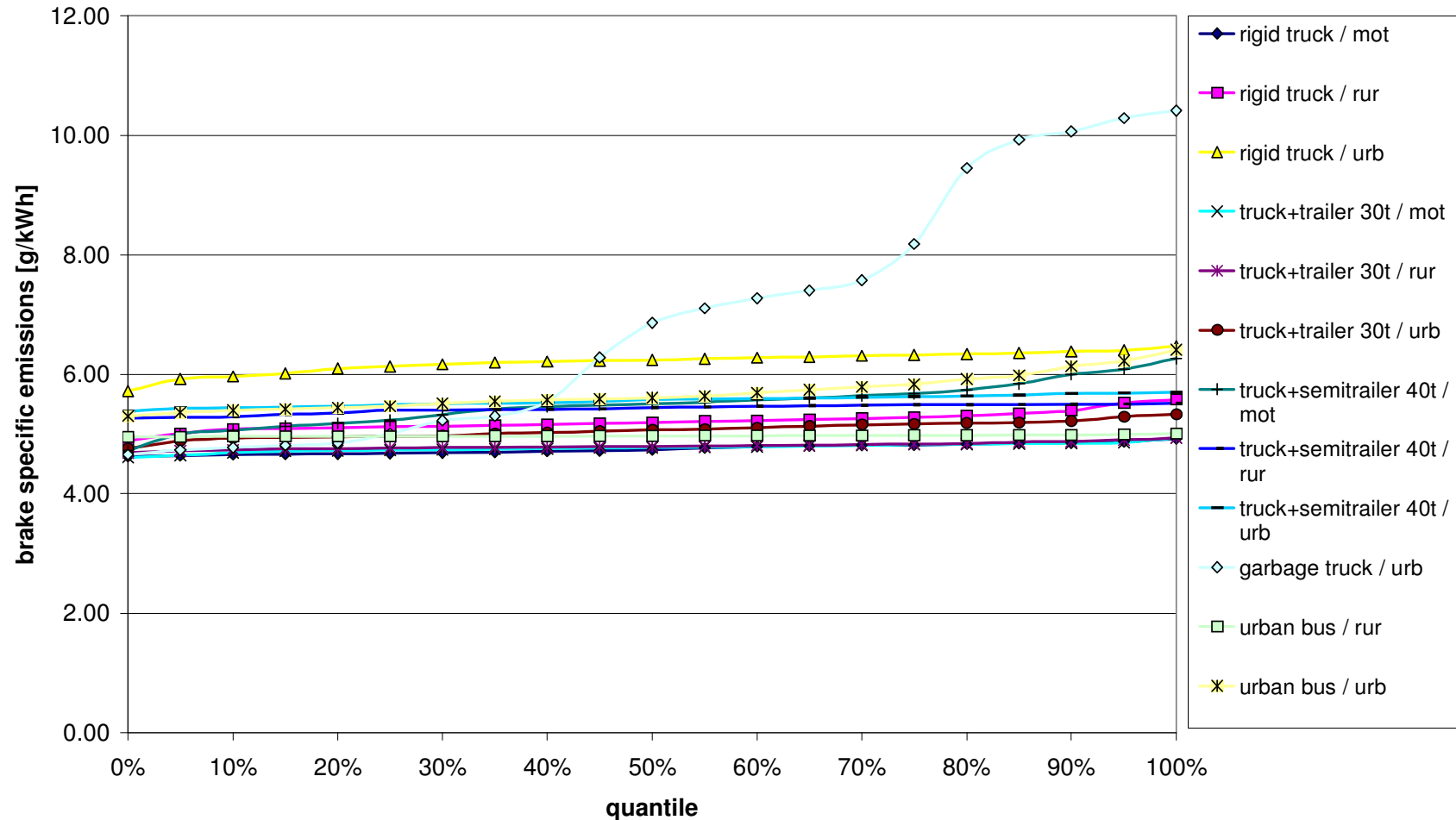
WNTE control area variants – Euro III



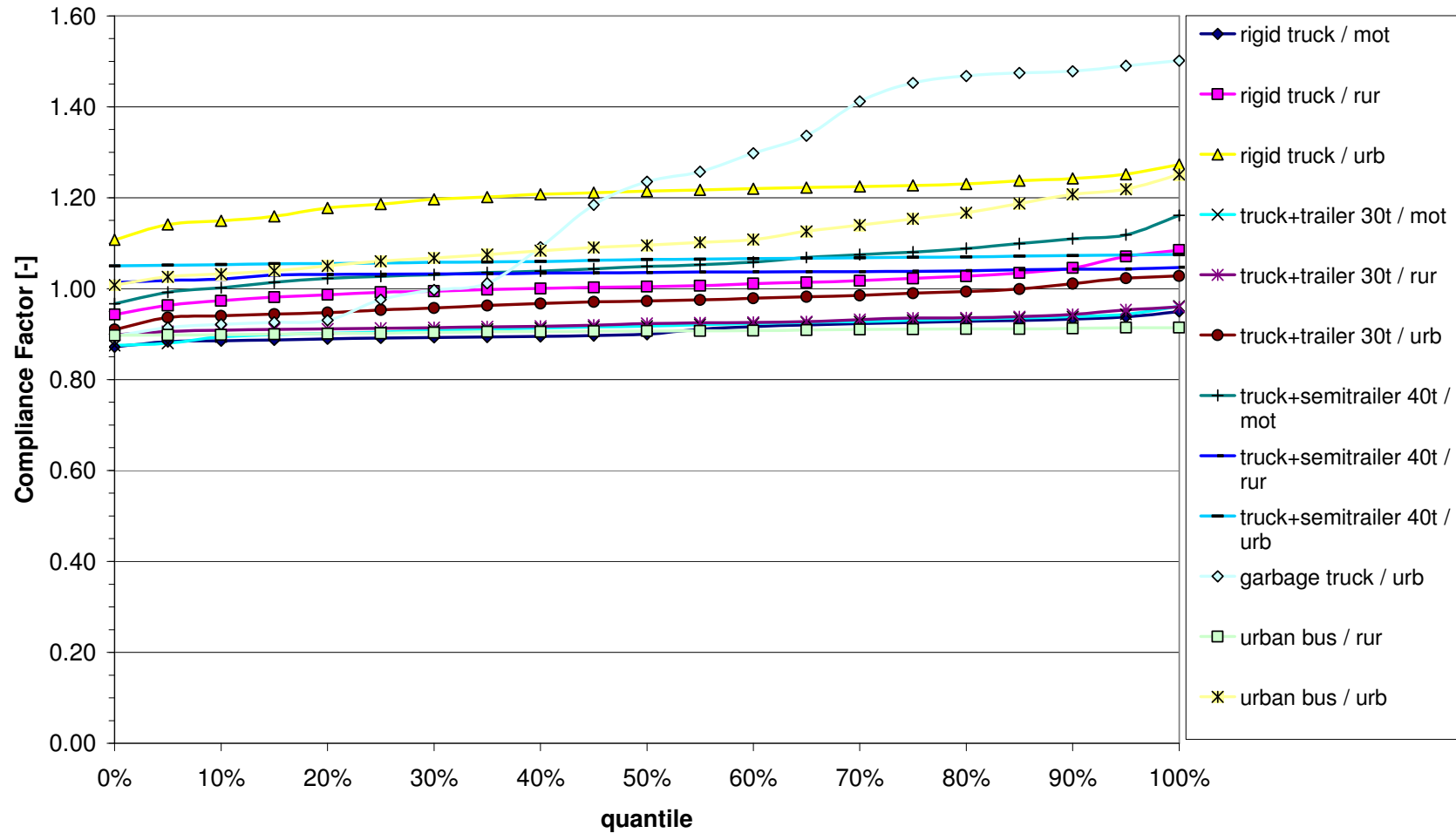
Work Window approach #1 Euro III



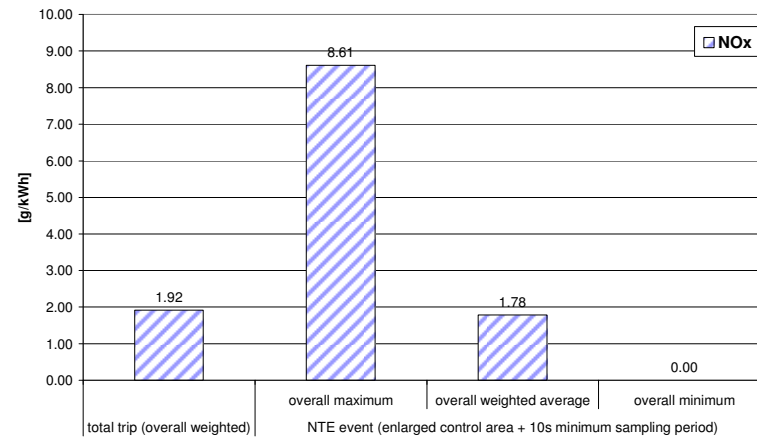
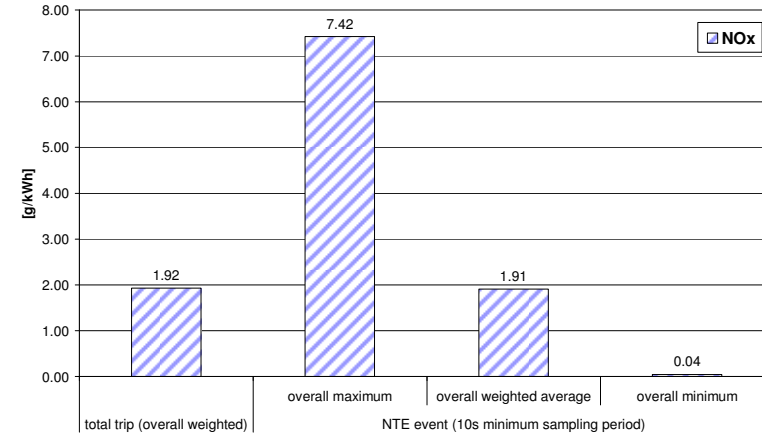
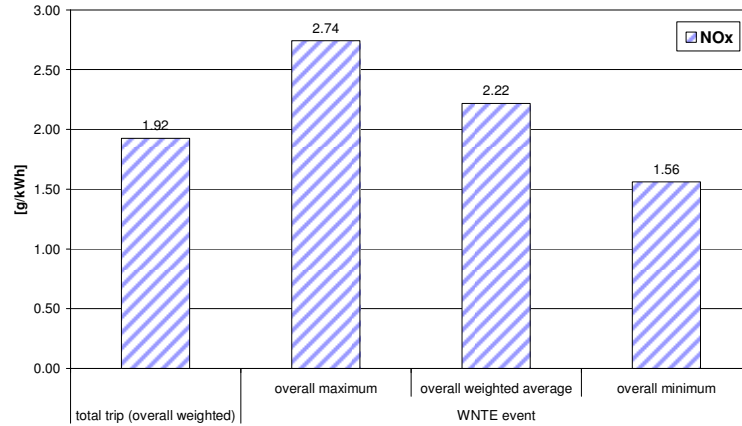
Work Window approach #3 Euro III



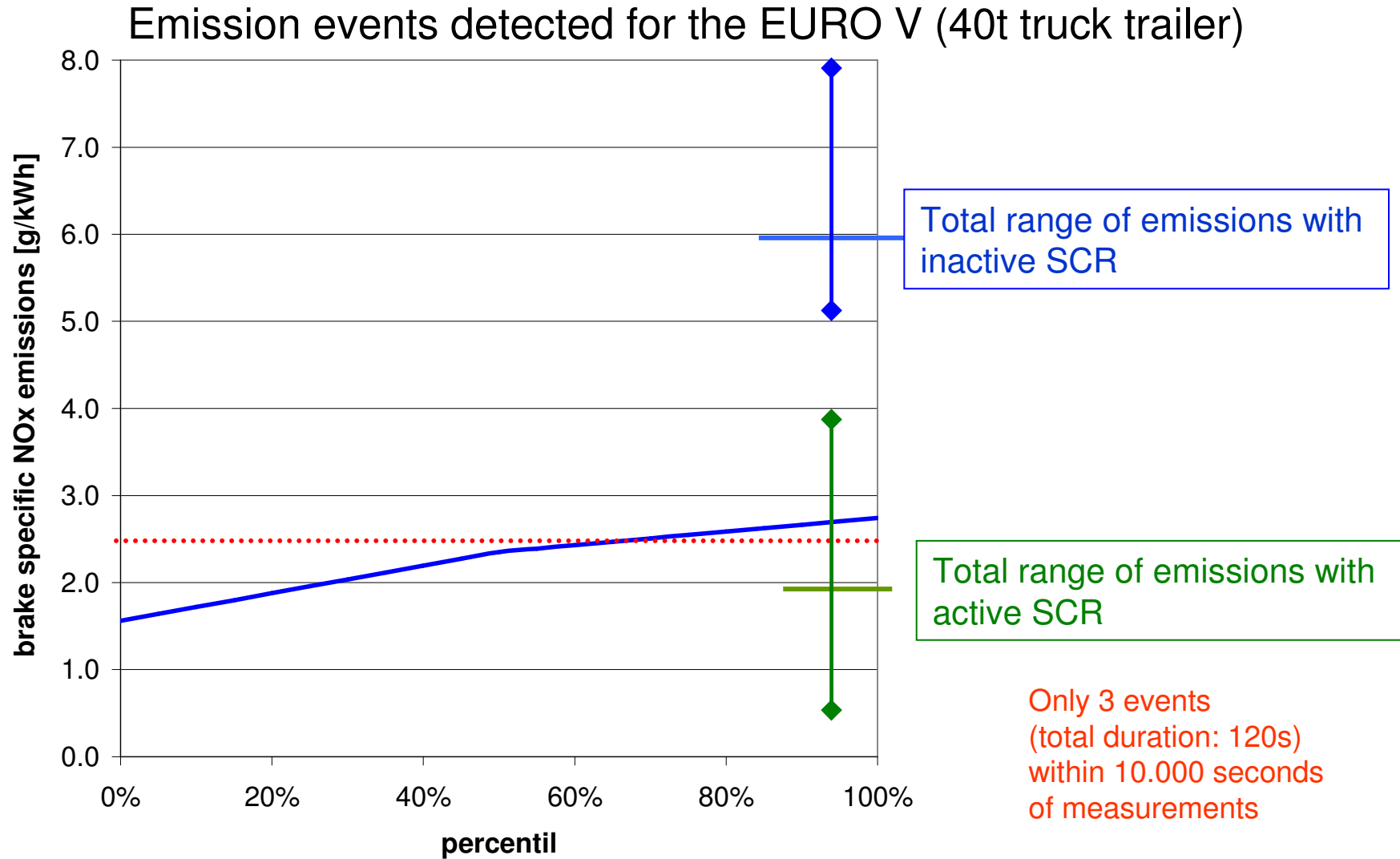
CO₂ based compliance factor Euro III



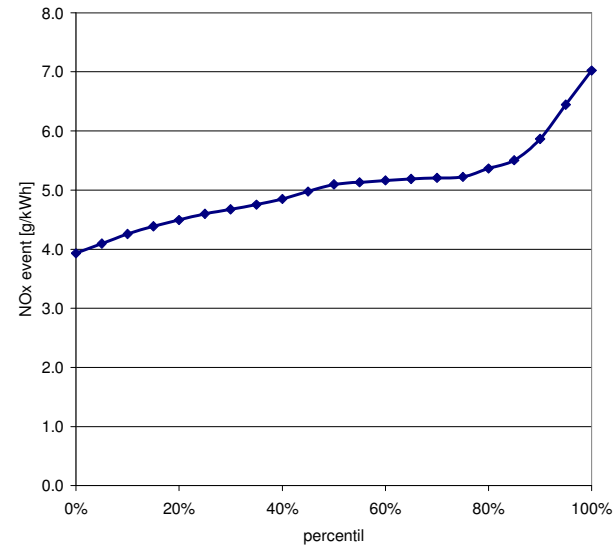
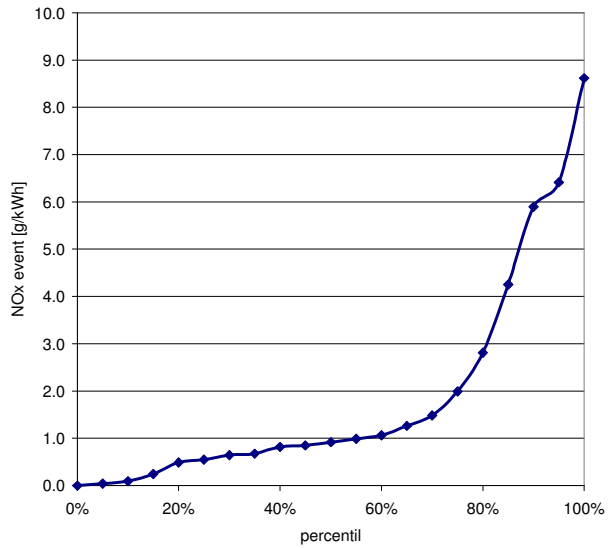
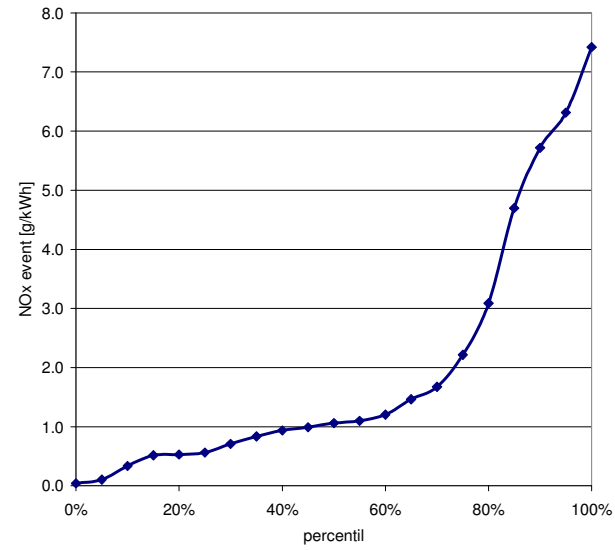
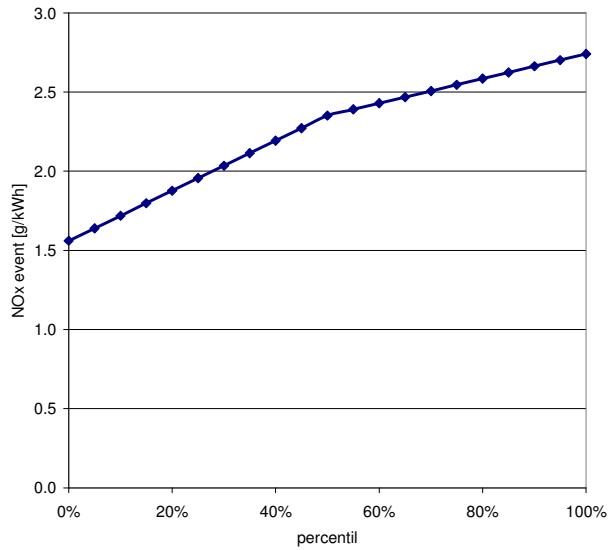
WNTE control area + variants - Euro V



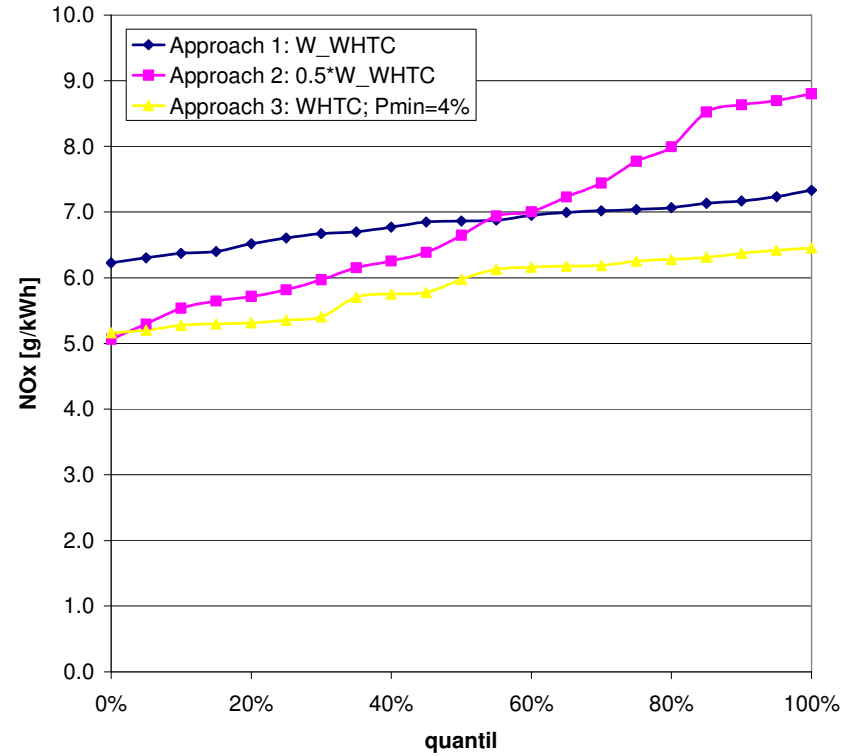
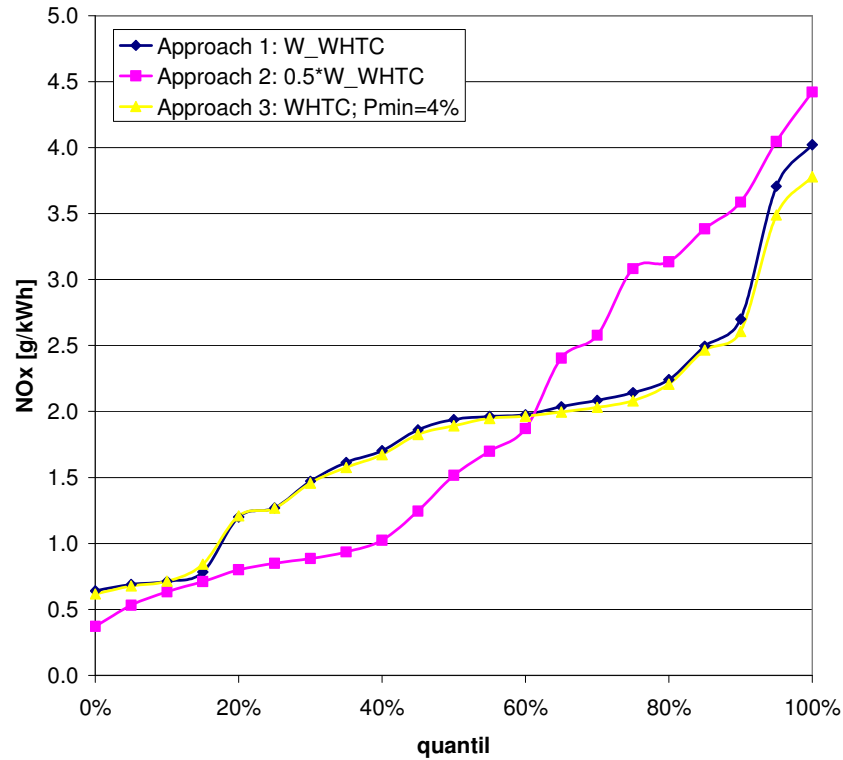
WNTE current draft



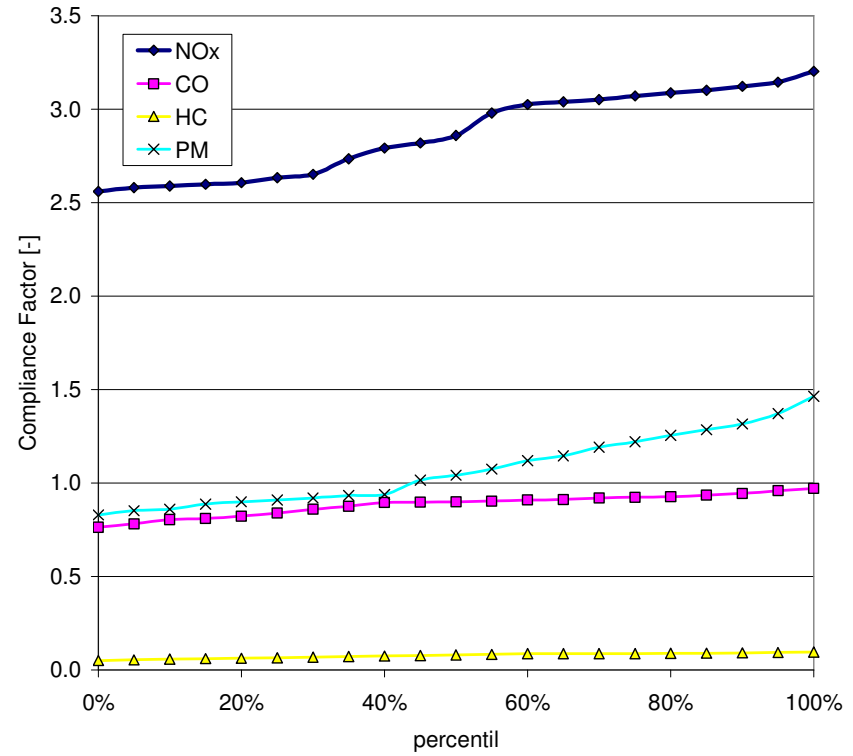
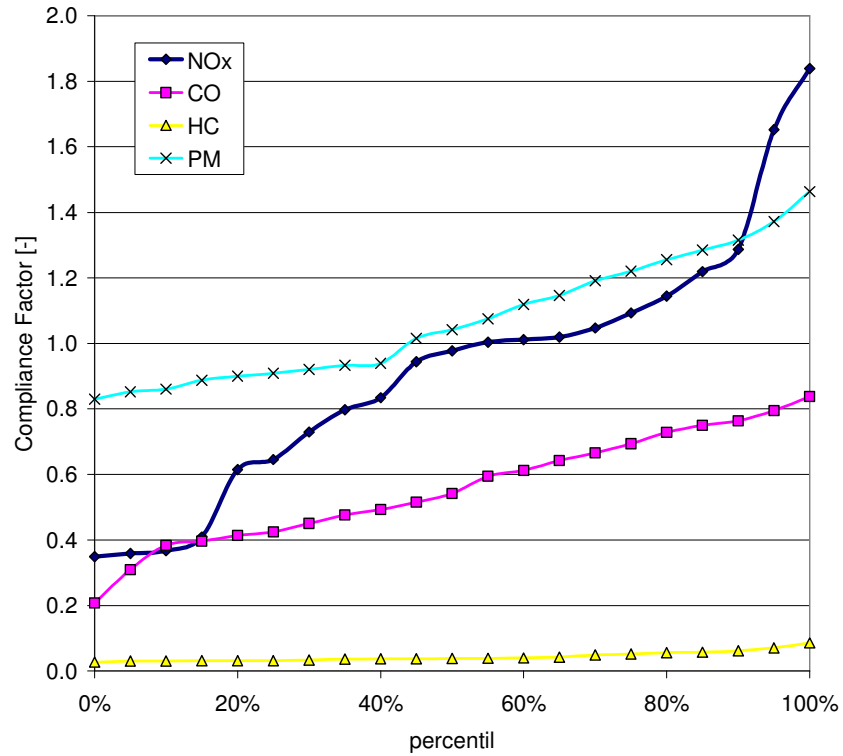
WNTE control area variants - Euro V



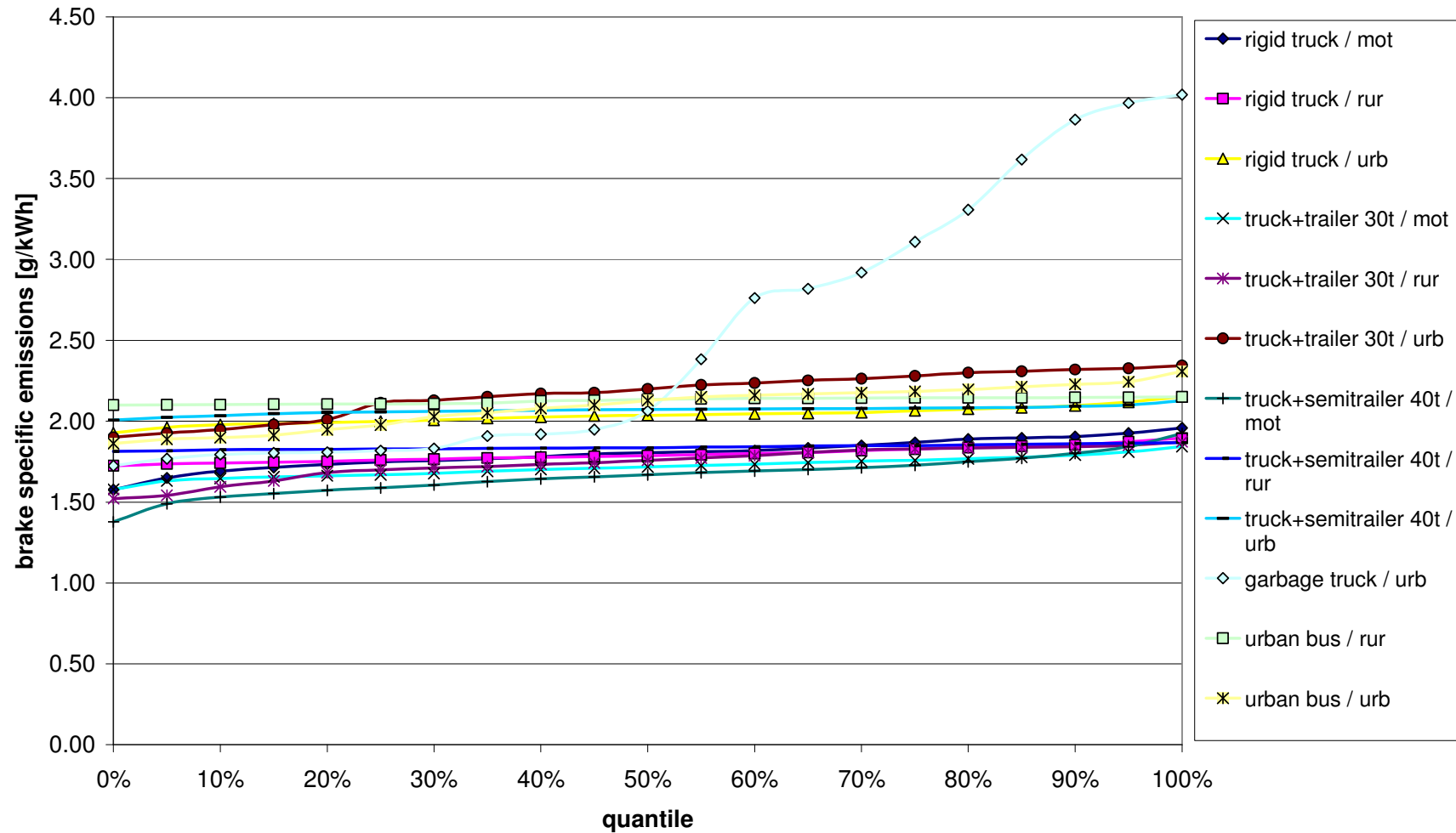
Alternative approach: Work Window Euro V



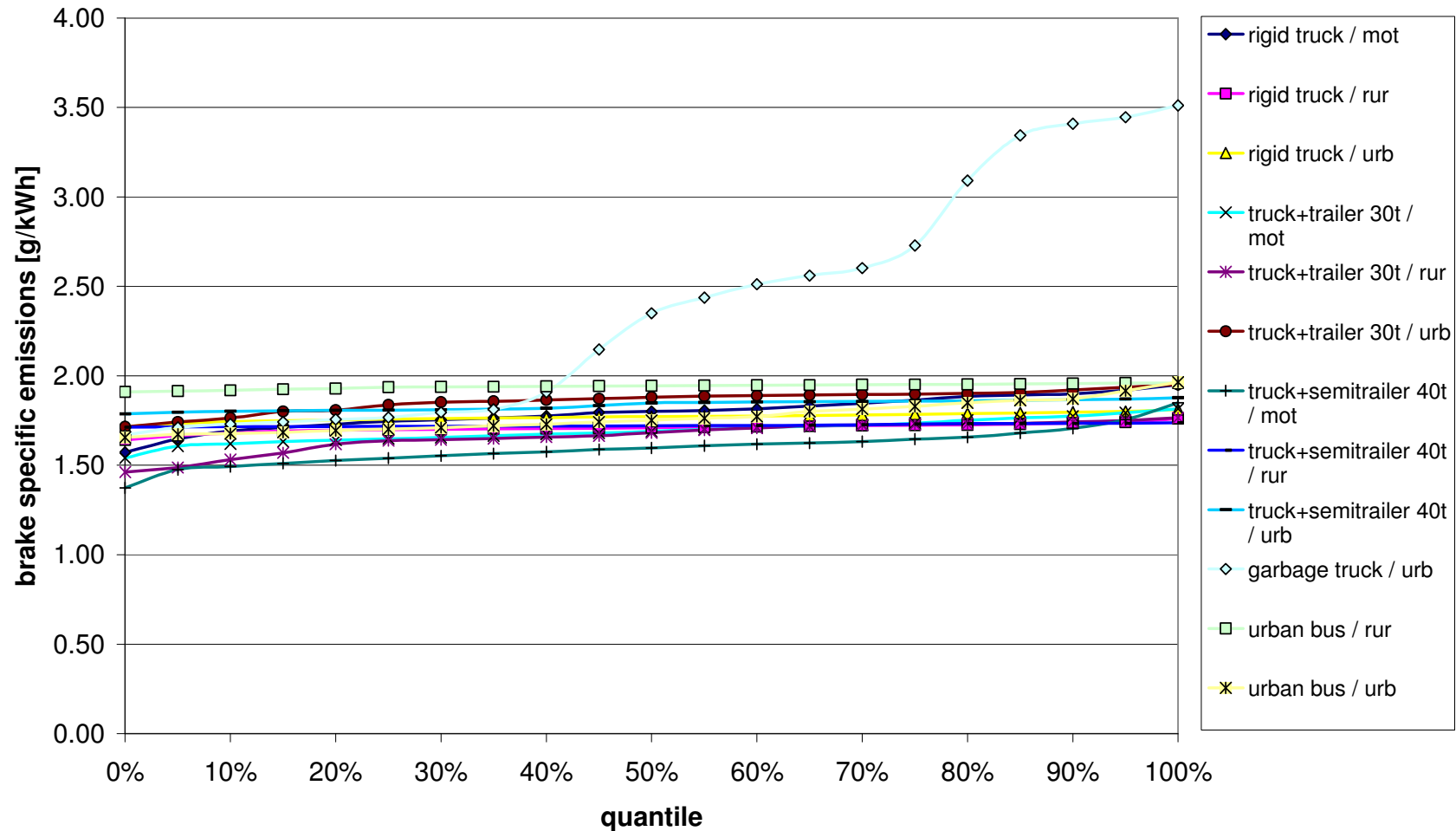
Alternative approach: CO₂ Euro V



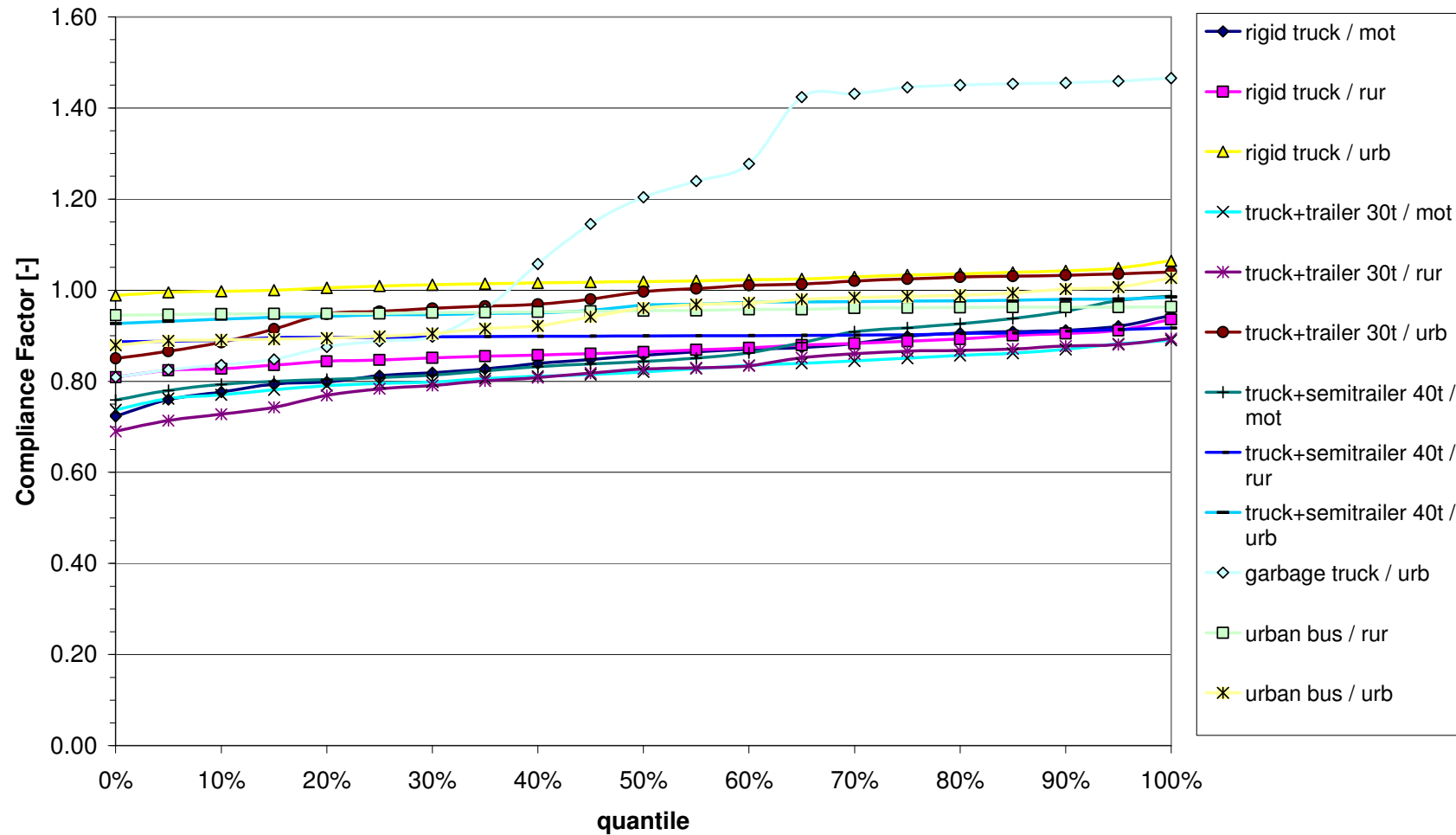
Work Window approach #1 Euro V sim



Work Window approach #3 Euro V sim



CO₂ based Euro V (simulated engine)



WNTE limits

WNTE limits for EURO III engines

EURO III		ETC limit [g/kWh]	WNTE limit [g/kWh]
NOx	OICA proposal 04/2006	5.00	6.25
	OICA proposal 06/2006		6.36
PM	OICA proposal 04/2006	0.16	0.200
	OICA proposal 06/2006		0.211
HC		0.78	0.98
CO		5.45	6.81

WNTE limits for EURO V engines

EURO V		ETC limit [g/kWh]	WNTE limit [g/kWh]
NOx	OICA proposal 04/2006	2.00	3.00
	OICA proposal 06/2006		2.50
PM	OICA proposal 04/2006	0.03	0.045
	OICA proposal 06/2006		0.039
HC		0.55	0.83
CO		4.00	5.00

Alternative approach: CO₂ specific

1. Assessment of the CO₂-specific emission behaviour in the type approval cycle “TA” based on the according emission limits:

$$\text{TA} [\text{g}_{\text{emissions}}/\text{g}_{\text{CO}_2}] = \frac{(\text{emission limit})_{\text{transient TA cycle}} [\text{g/kWh}]}{190 [\text{g/kWh}] * \frac{(\text{carbon content})_{\text{fuel}} [-]}{0,273}}$$

2. Determination of the CO₂ specific emission events during the OCE monitoring “OCE”:
Boundary constraint:
 - a) In the OCE testing the same fuel has to be used as in type approval test
 - b) The emission events “OCE” are calculated by averaging the CO₂ specific emissions over periods fixed by the amount of CO₂ emitted in the type approval test:

$$\text{OCE} [\text{g}_{\text{emissions}}/\text{g}_{\text{CO}_2}] = \frac{\sum^{(\text{mass CO}_2)_{\text{transient TA cycle}}} (\text{mass emissions})_{\text{OCE test}} [\text{g}]}{(\text{mass CO}_2)_{\text{transient TA cycle}} [\text{g}]}$$

Alternative approach: CO₂ specific

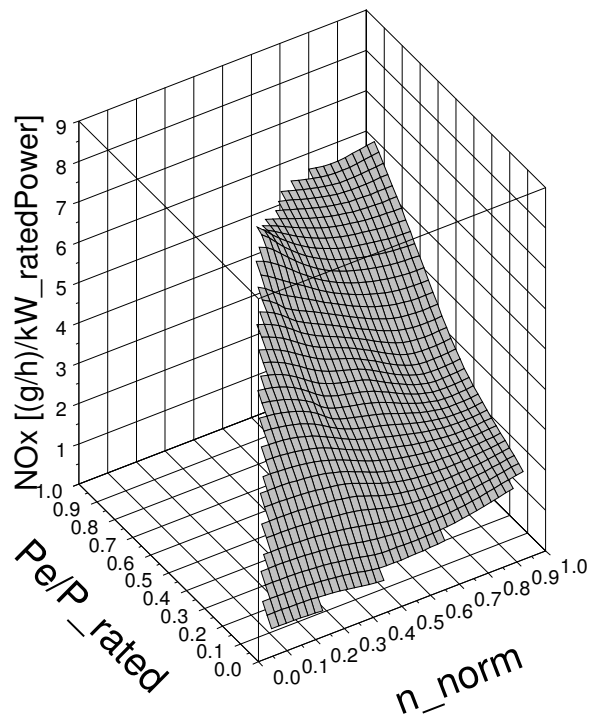
3. The considered OCE test complies with the regulations, if all compliance factor events “CF_{OCE}” (calculated by division of the CO₂ specific emission events in the OCE monitoring “OCE” by the constant CO₂-specific emission behaviour in the type approval cycle “TA”) are lower or equal the defined limit for the compliance factor for passing the OCE regulations “CF_{Fail}”:

$$CF_{OCE} = \frac{OCE}{TA} \leq CF_{Fail}$$

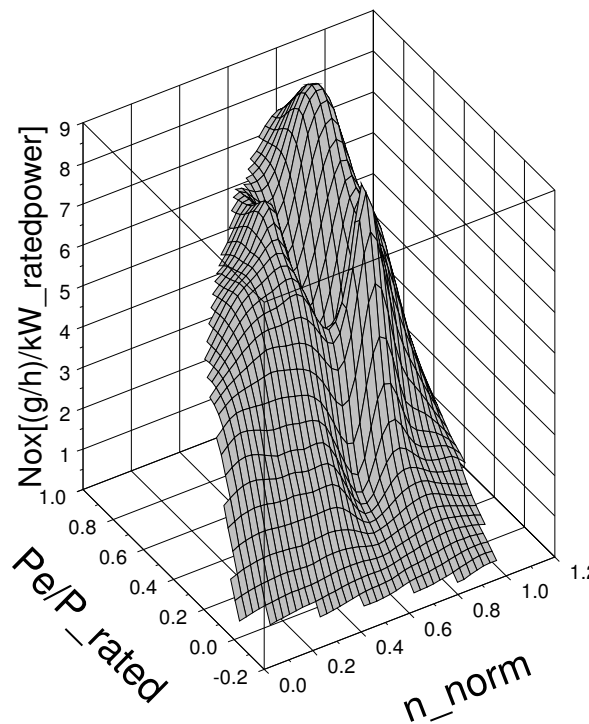
Reasons for HDV OCE monitoring

Example: 1 manufacturer, 3 emission standards

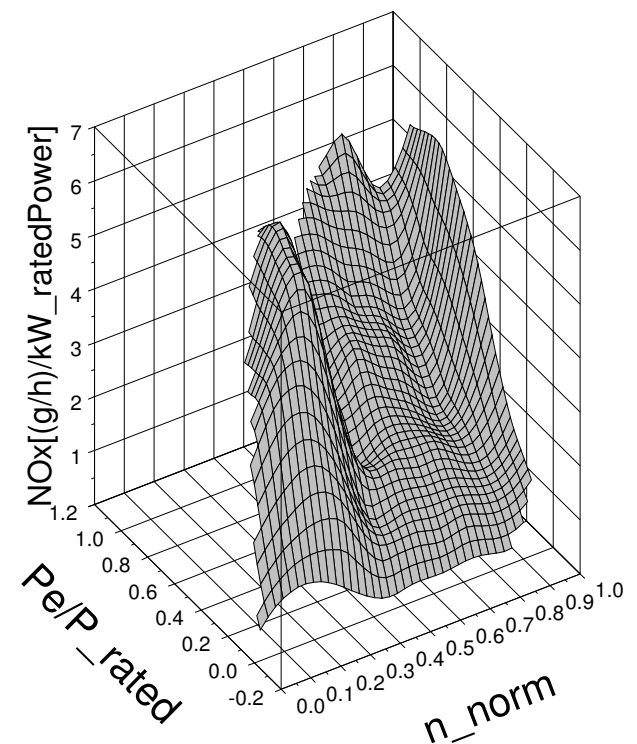
EURO I



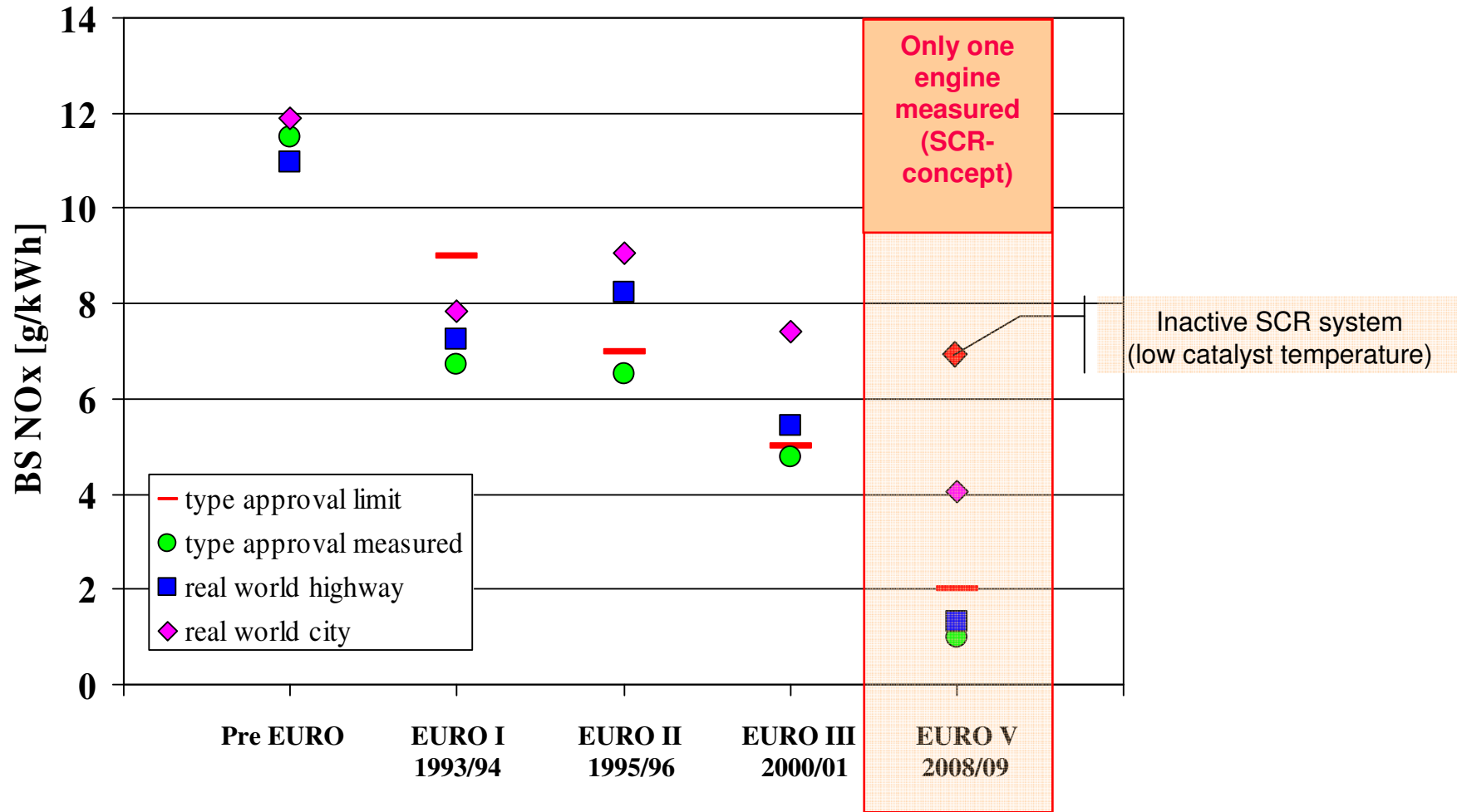
EURO II



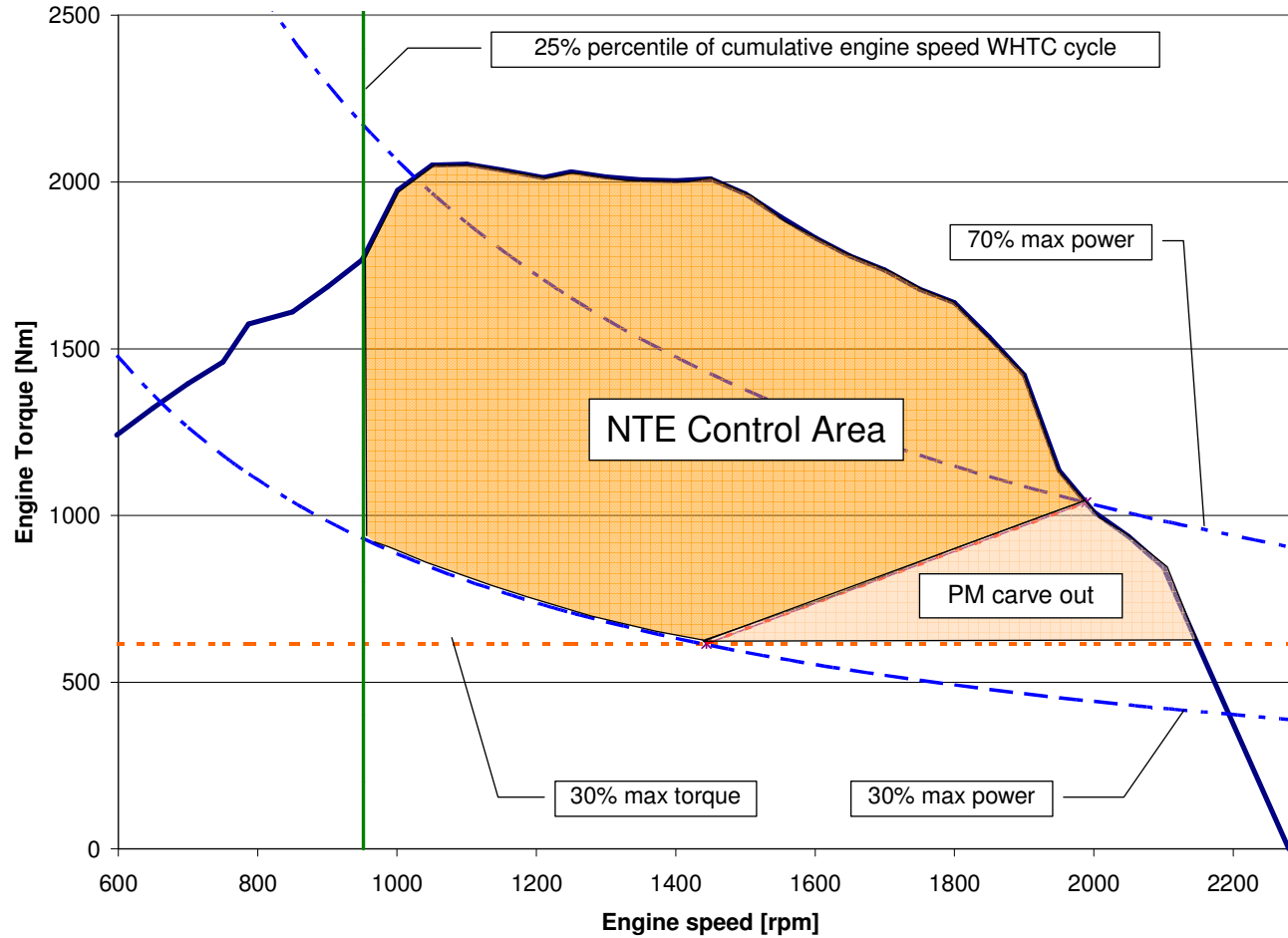
EURO III



Reasons for HDV OCE monitoring



Current WNTe control zone



European driving data

- **Basis of the analysis was the European part of the WHDC database, used for the development of a Worldwide Harmonised Heavy-Duty Engine Emissions Test Cycle**

No of vehicles	vehicle category	gross vehicle mass in kg	rated power in kW	distance driven in km			
				motorway	rural	urban	total
1	coach	16000	310	259	136	108	503
1	garbage truck	26500	180			478	478
12	rigid truck	5600 to 24000	50 to 198	1321	1865	1224	4410
16	trailer/semitrailer truck	28000 to 41380	160 to 407	39754	18960	1318	60031
5	urban bus	12300 to 27600	137 to 177		75	958	1033
			total	41334	21036	4087	66456

Percentage of driving time in WNTE zone

No time window

	percentage of time in NTE area related to driving time		
vehicle category	motorway	rural	urban
coach	51.1%	36.2%	19.1%
garbage truck			45.9%
rigid truck	62.7%	45.1%	25.8%
trailer/semitrailer truck	50.7%	44.6%	26.8%
urban bus		32.2%	25.0%

30 s time window

	percentage of time of ≥ 30 s events in NTE area related to driving time		
vehicle category	motorway	rural	urban
coach	24.2%	4.2%	0.0%
garbage truck			15.0%
rigid truck	38.6%	13.7%	1.5%
trailer/semitrailer truck	30.6%	16.5%	2.1%
urban bus		3.6%	1.1%

Percentage of driving time in WNTE zone

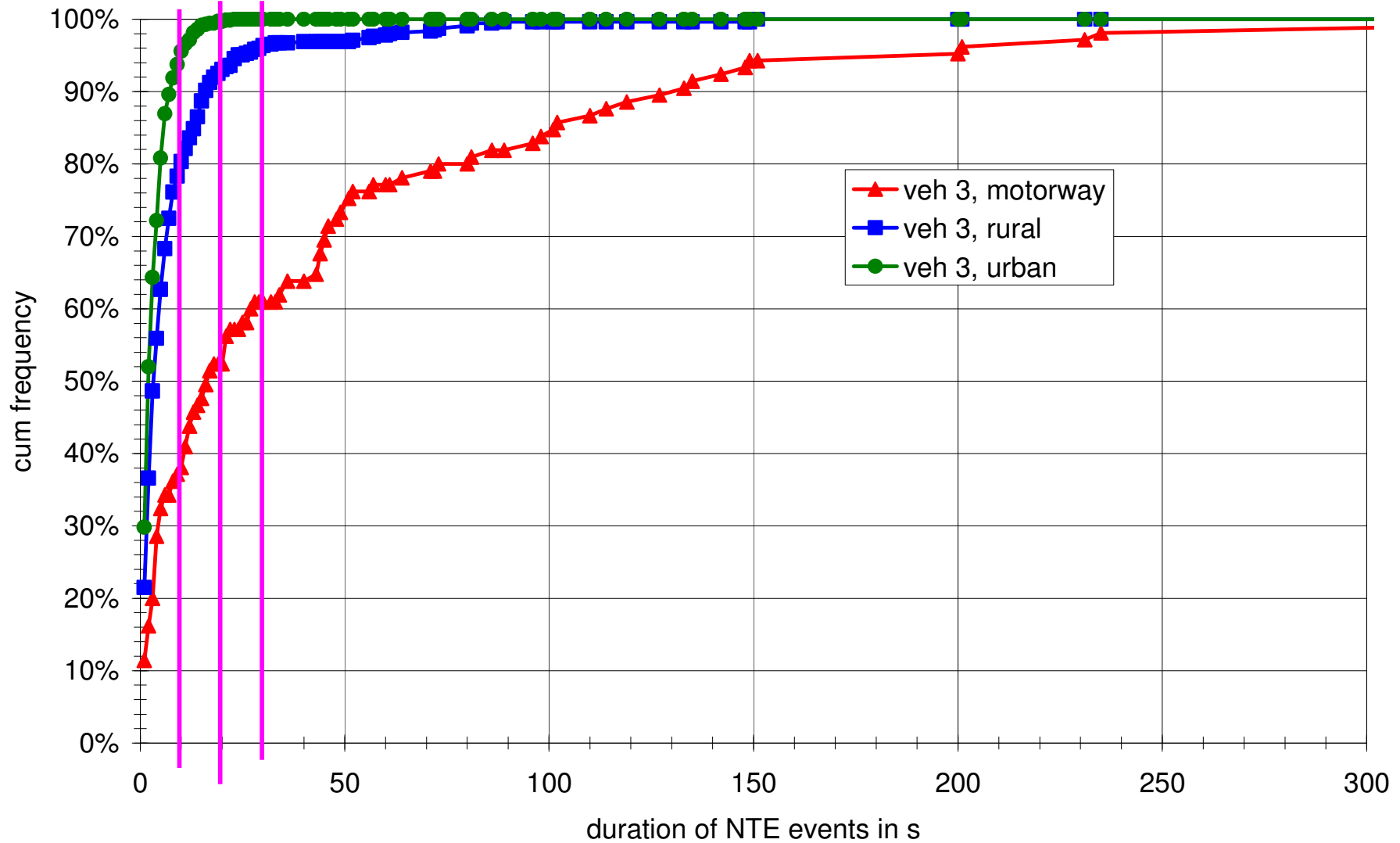
20 s time window

	percentage of time of ≥ 20 s events in NTE area related to driving time		
vehicle category	motorway	rural	urban
coach	29.8%	9.8%	0.0%
garbage truck			20.2%
rigid truck	44.1%	17.7%	3.0%
trailer/semitrailer truck	36.4%	22.5%	4.0%
urban bus		8.1%	2.9%

10 s time window

	percentage of time of ≥ 10 s events in NTE area related to driving time		
vehicle category	motorway	rural	urban
coach	37.0%	19.9%	2.2%
garbage truck			28.8%
rigid truck	52.0%	27.2%	7.8%
trailer/semitrailer truck	43.2%	32.7%	10.2%
urban bus		16.5%	8.7%

Distribution of the duration of NTE events



Distribution of the duration of NTE events

