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Evaluation of the suitability to European conditions of the WNTE 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**

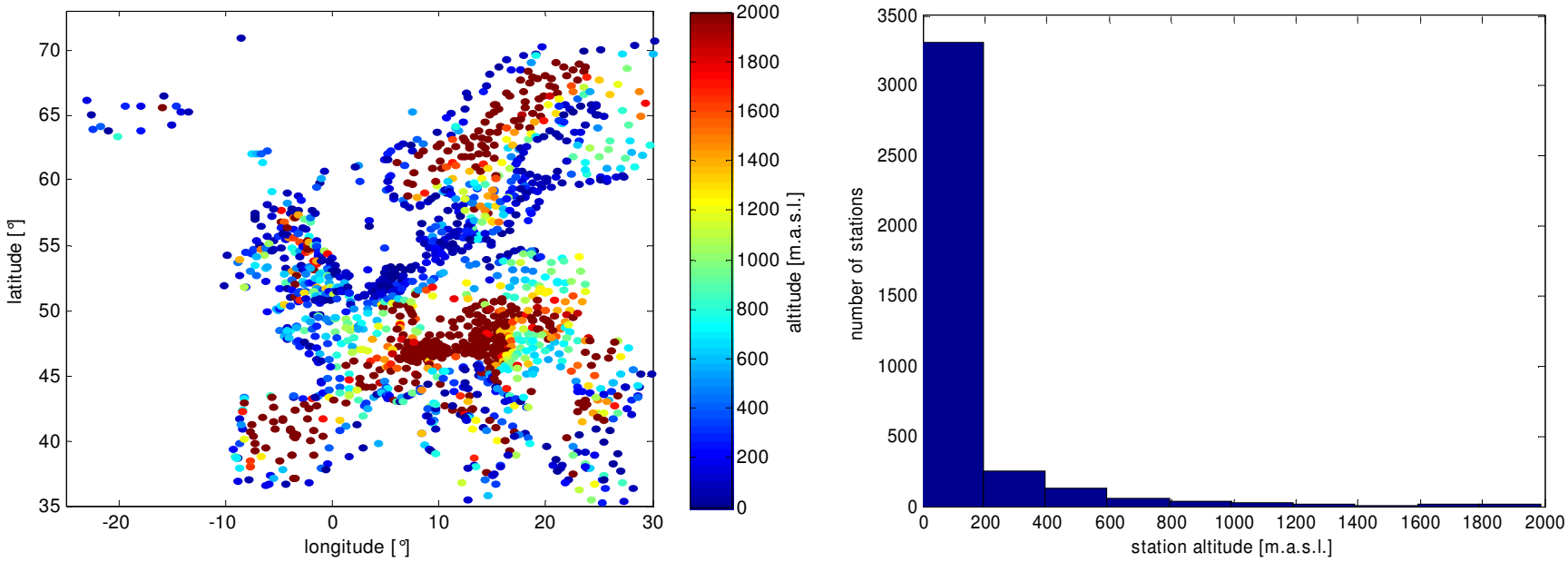
WNTE Ambient Conditions Proposal

- **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

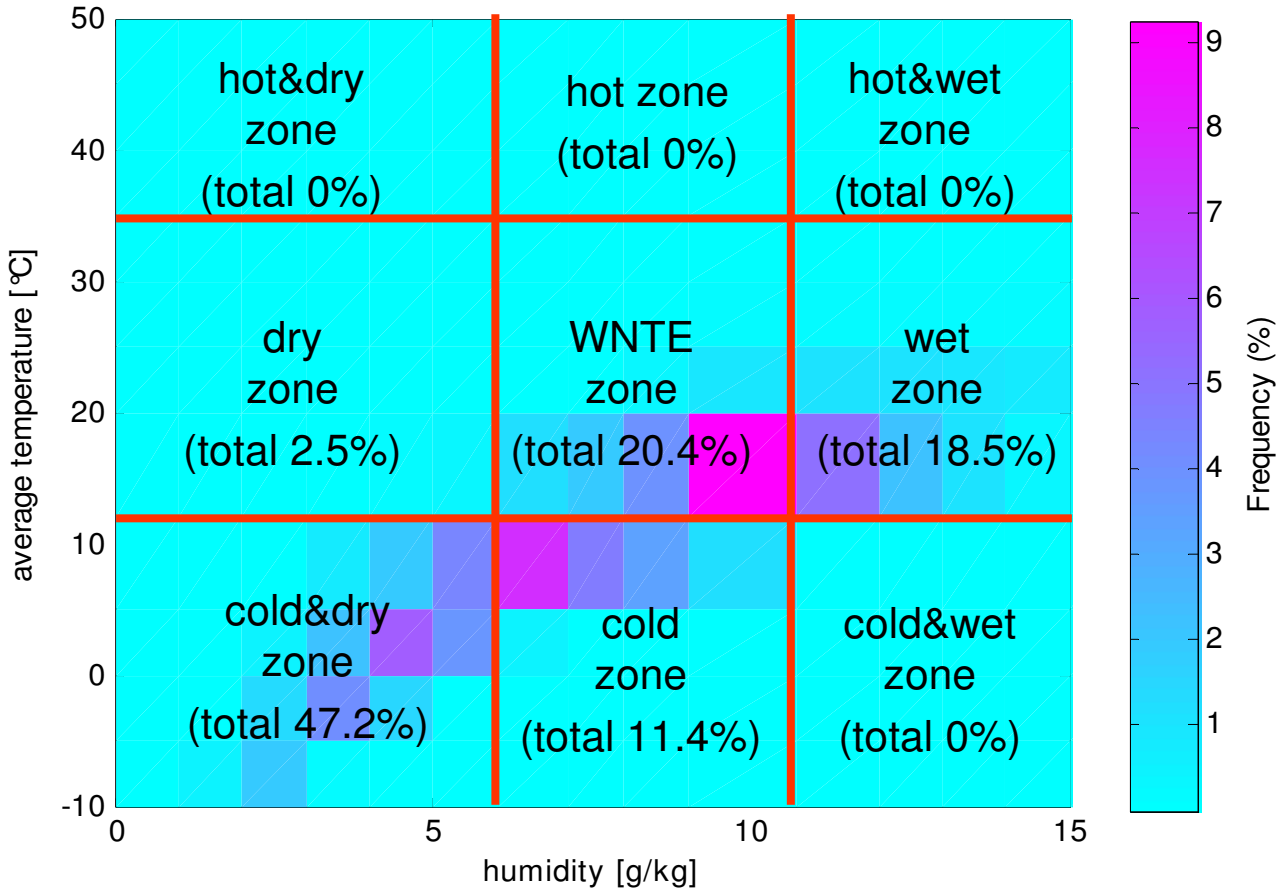
- **Main alp-crossing transitions Brenner (1375 m), Frejus (1312 m) and Gotthard (1175 m) lie below the proposed 1680 m**

- **Weather: Analysis of daily European weather stations data of the year 2005 (source: NOAA)**



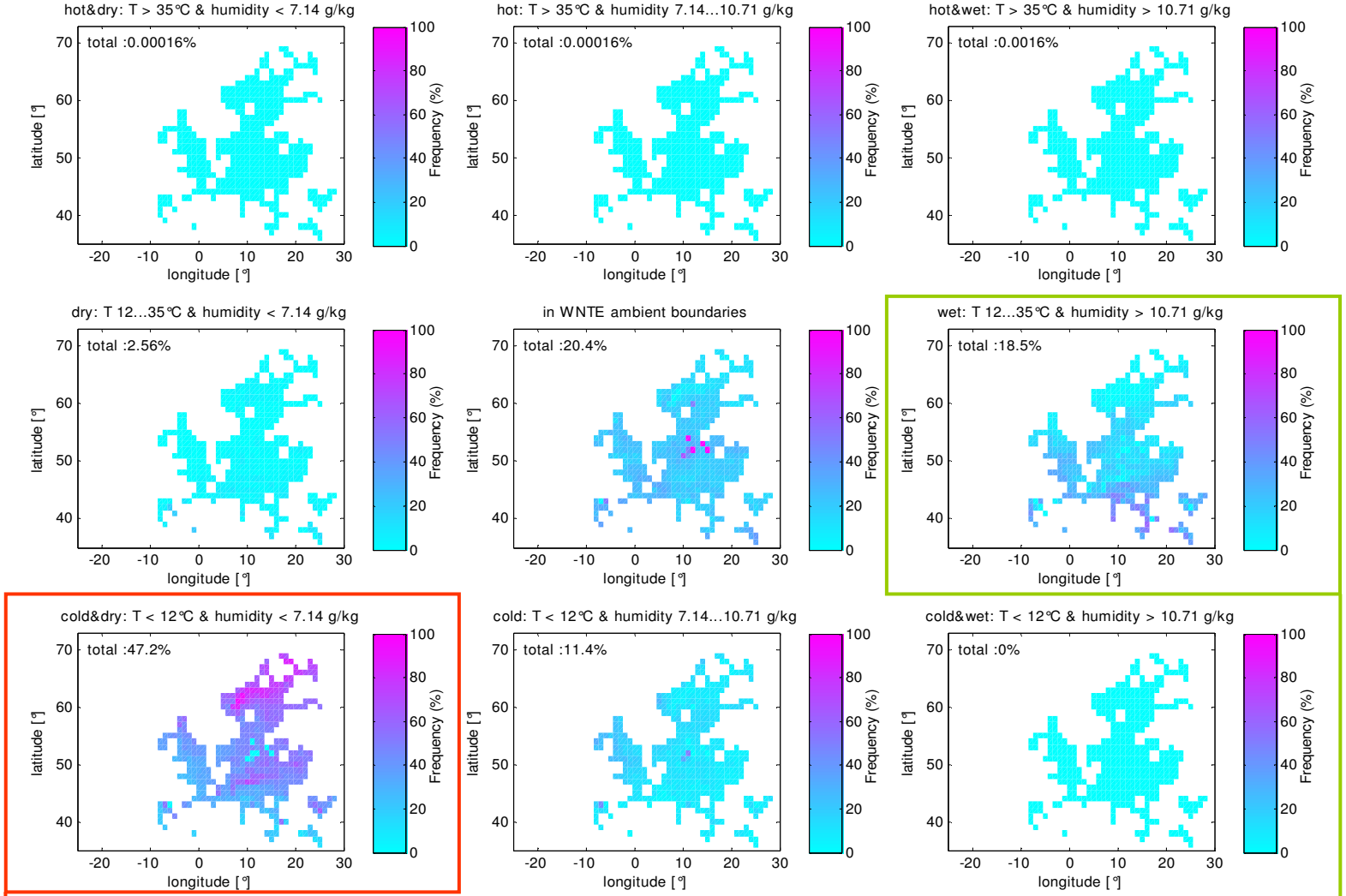
- **Average daily temperature of all stations: 9.6 °C**

Frequency Distribution of Temperature and Humidity



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

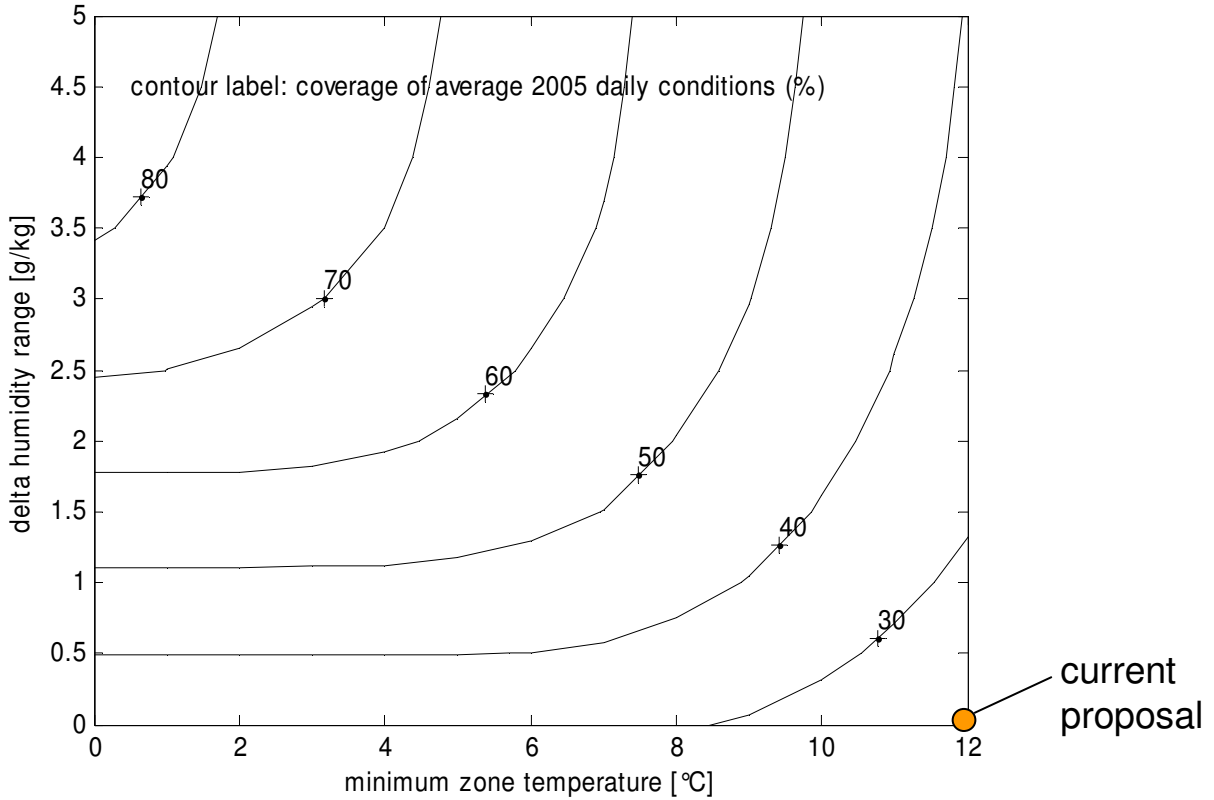
Geographical Distribution of the Weather Conditions



northern European and alpine countries are often cold and dry

southern European countries are often wet

Influence of Widening the Zone



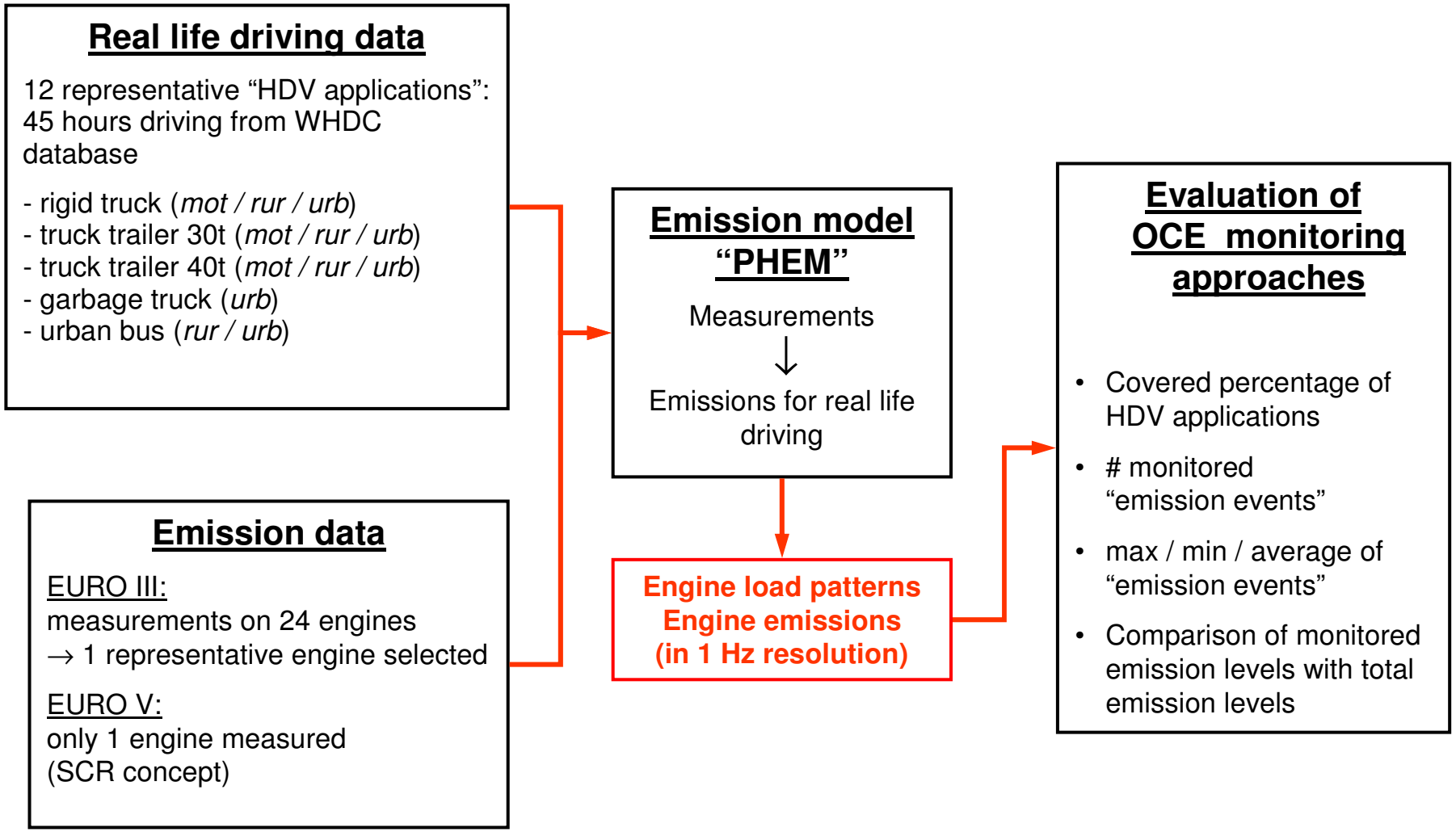
→ **If the minimum zone temperature would be lowered to 5°C and the humidity range would be widened by 3 g/kg, about 65 % of the average European conditions could be covered (instead of ~ 20% with the current proposal) without the use of correction factors.**

Evaluation OCE monitoring approaches

Requirements OCE monitoring approach:

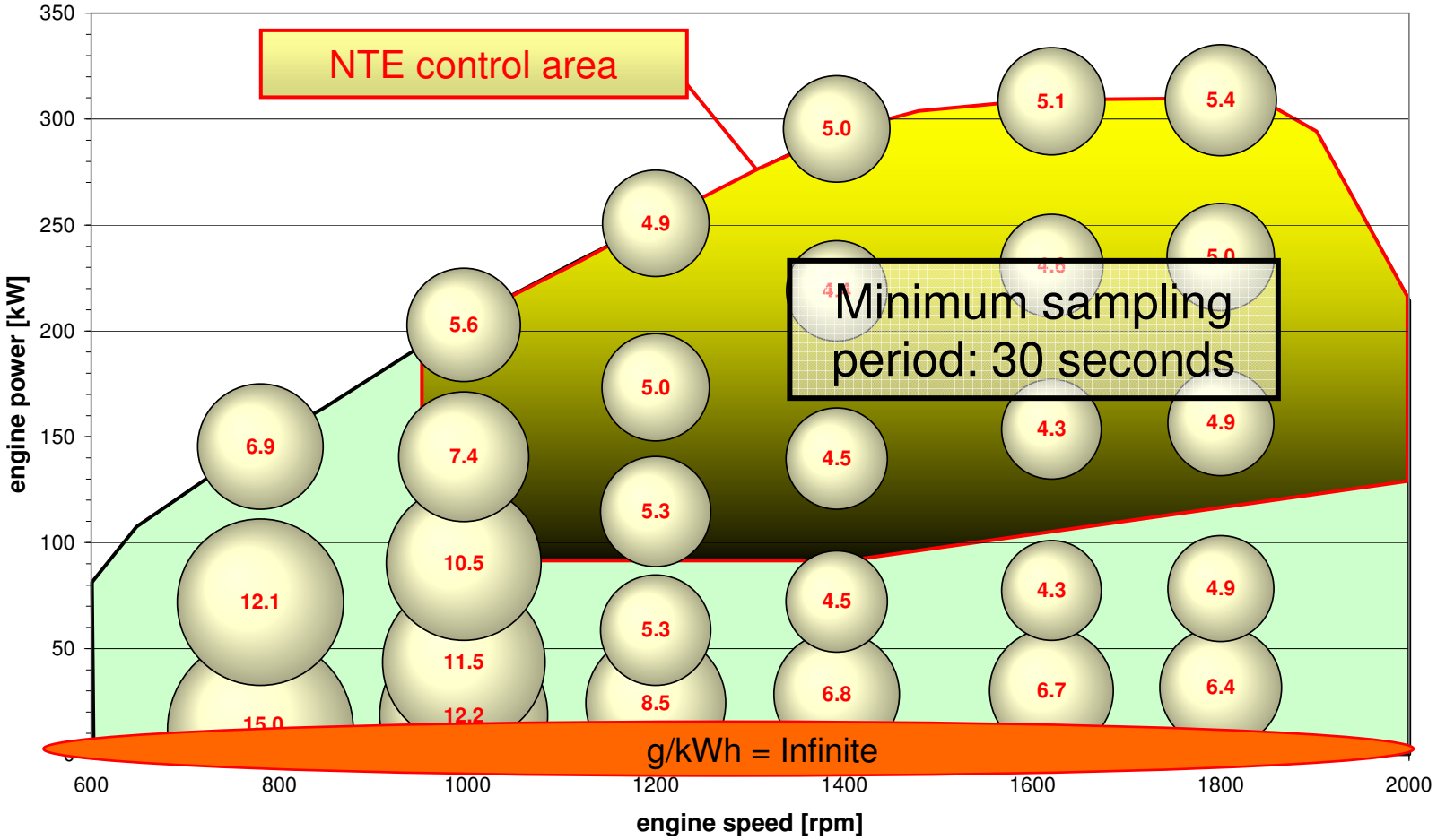
- **include all relevant operating conditions**
- **shall be able to detect defeat strategies**
- **compliant with PEMS**

Methodology



WNTE current draft

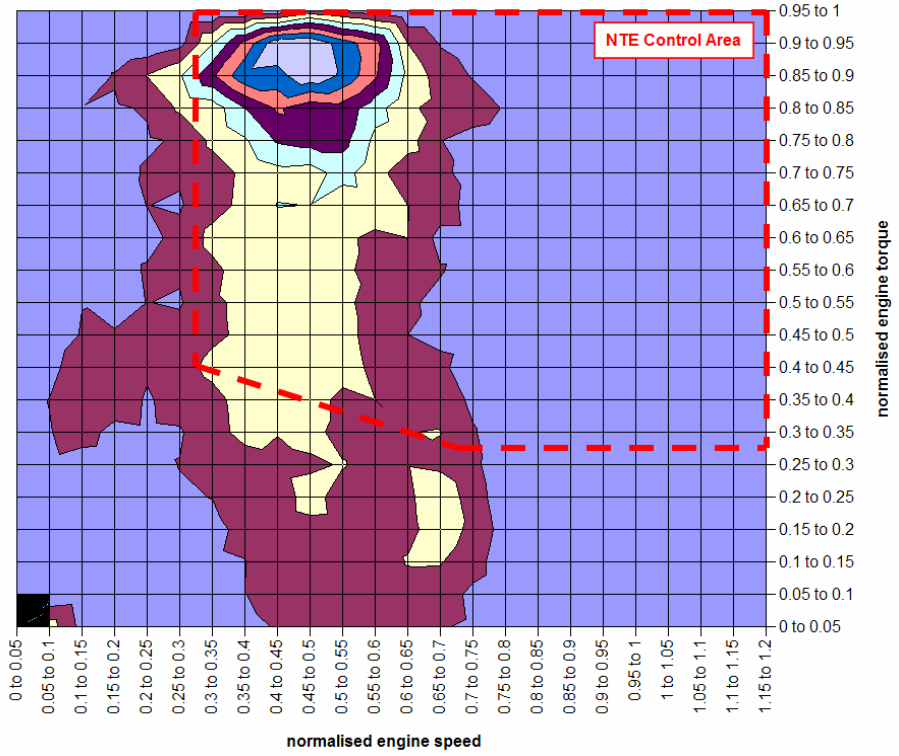
Brake specific NOx emissions [g/kWh] / EURO III



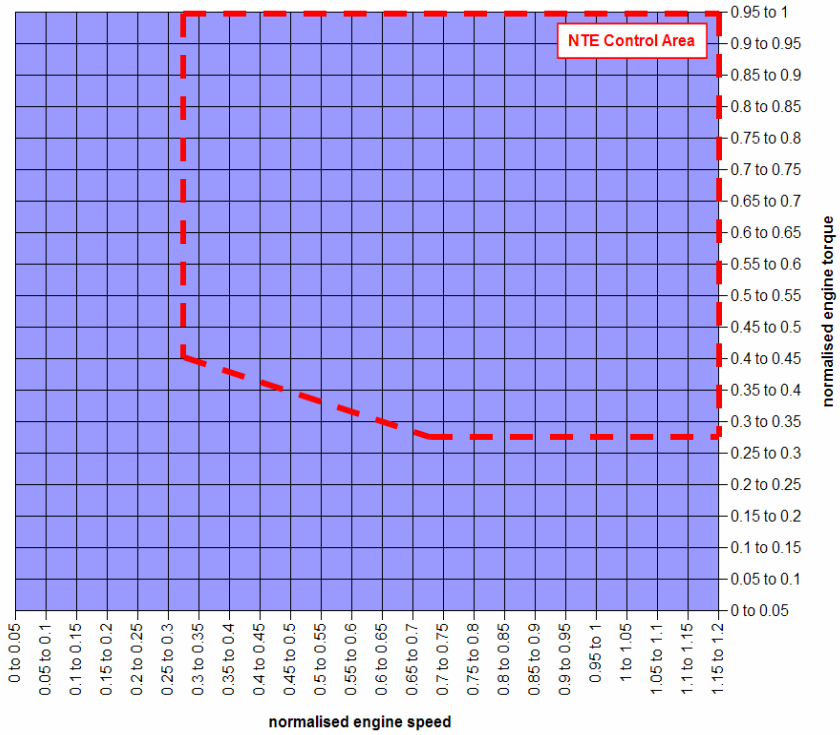
Distribution of NOx emissions

urban bus / urban

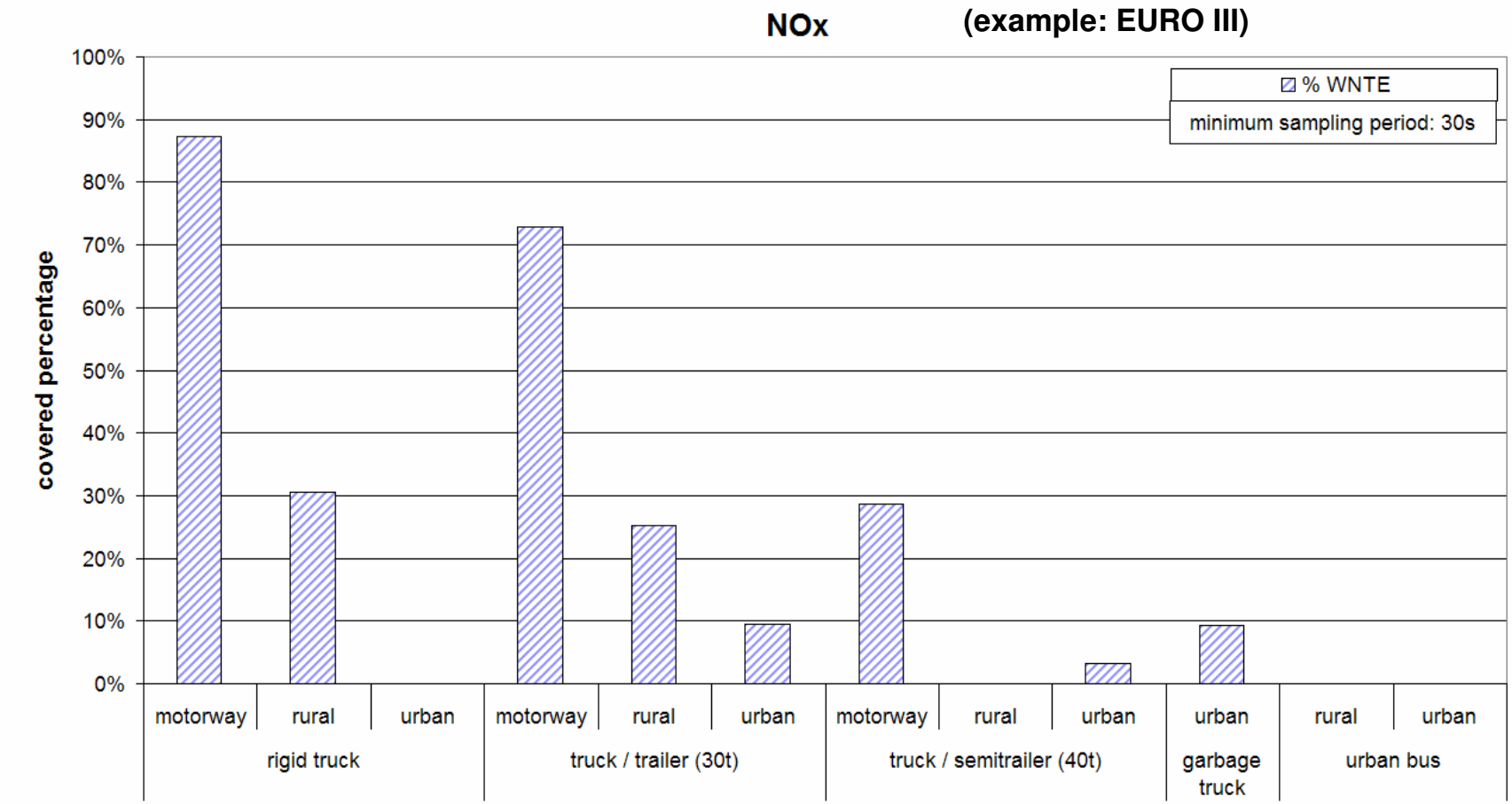
total



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

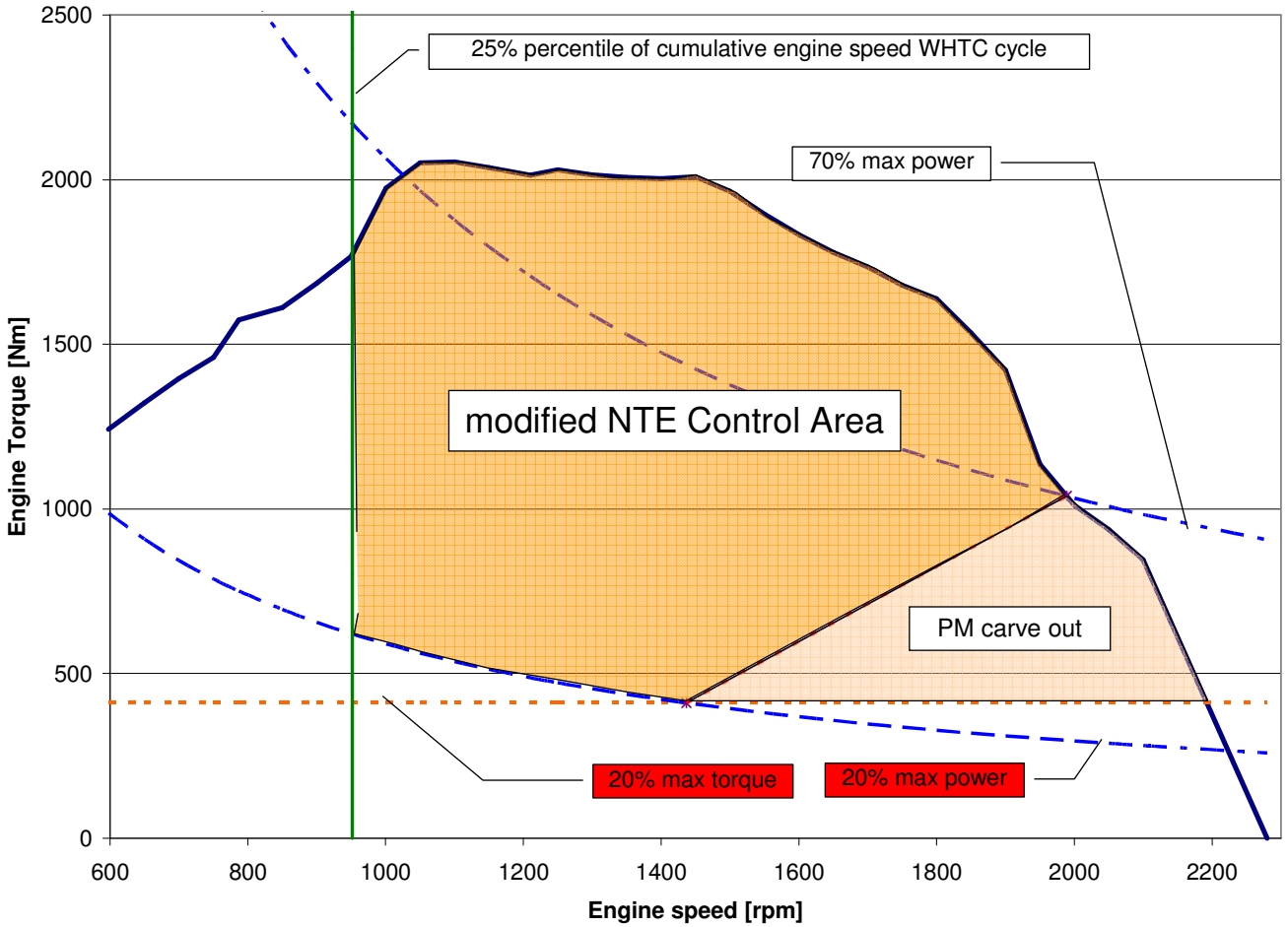
- **Alternative WNTE version #2:**

  - 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

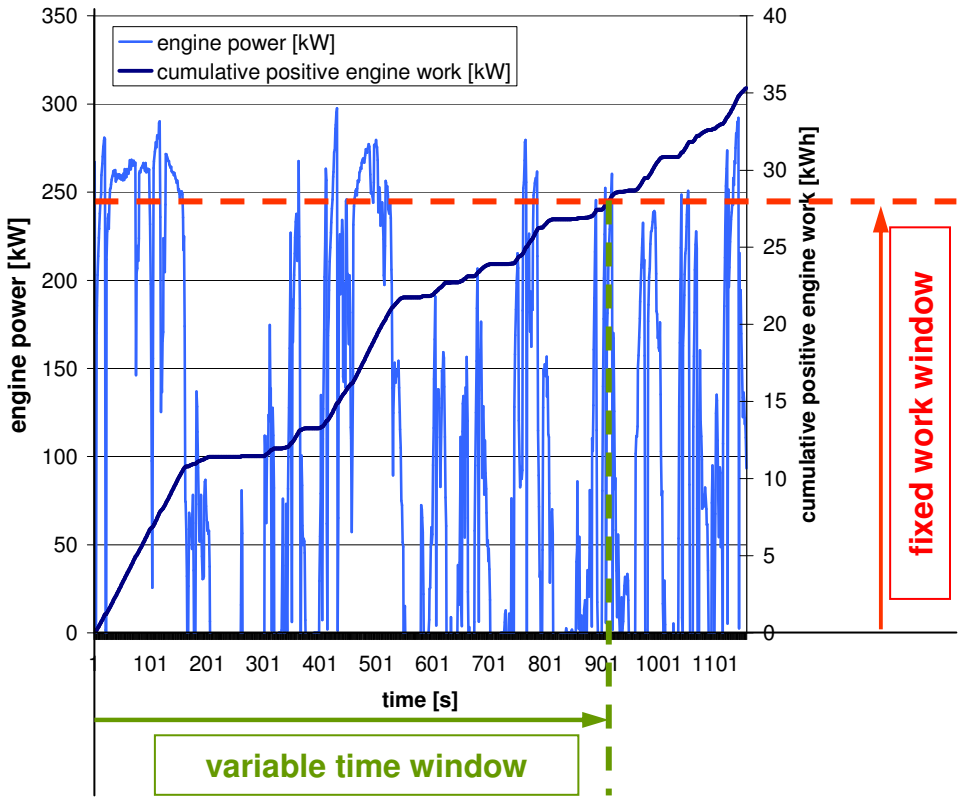
Enlarged WNTE control zone

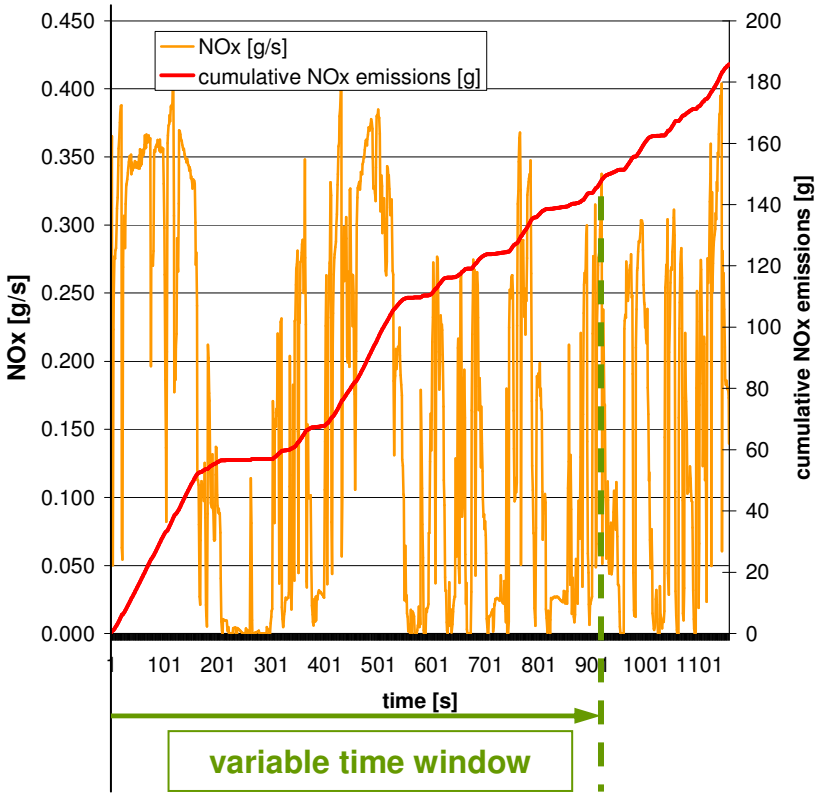


Alternative approach: „Work window“

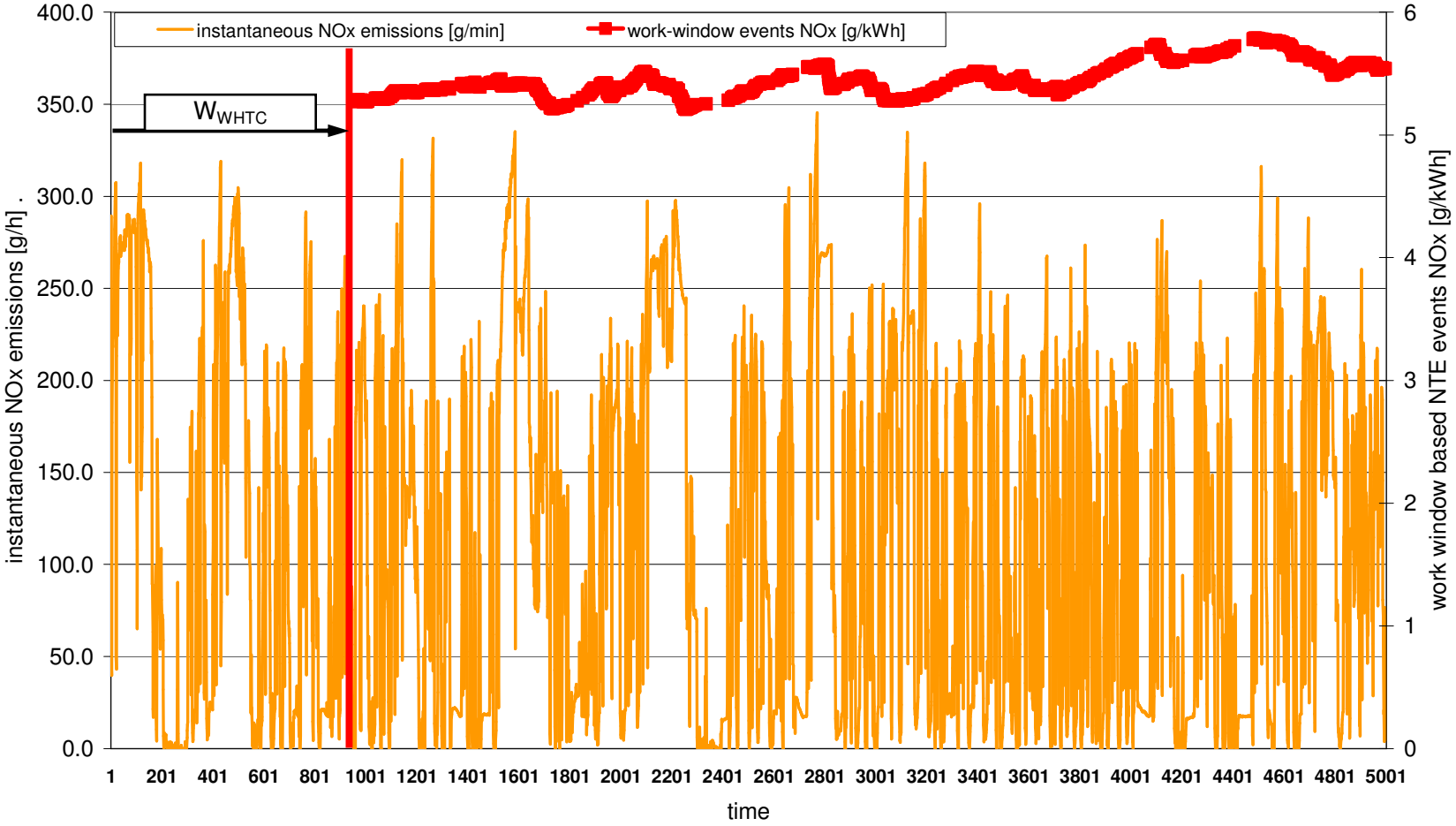
Method:

- 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: CO_2 specific

Method:

- **Total driving time is measured and evaluated**
- **Calculation of [g/kg CO_2] averaged over a fixed amount of emitted CO_2 („CO_2 window“)**

Coverage total HDV fleet (example EURO III):

~99% time ~99% NOx ~99% PM

Features of work window and CO_2 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

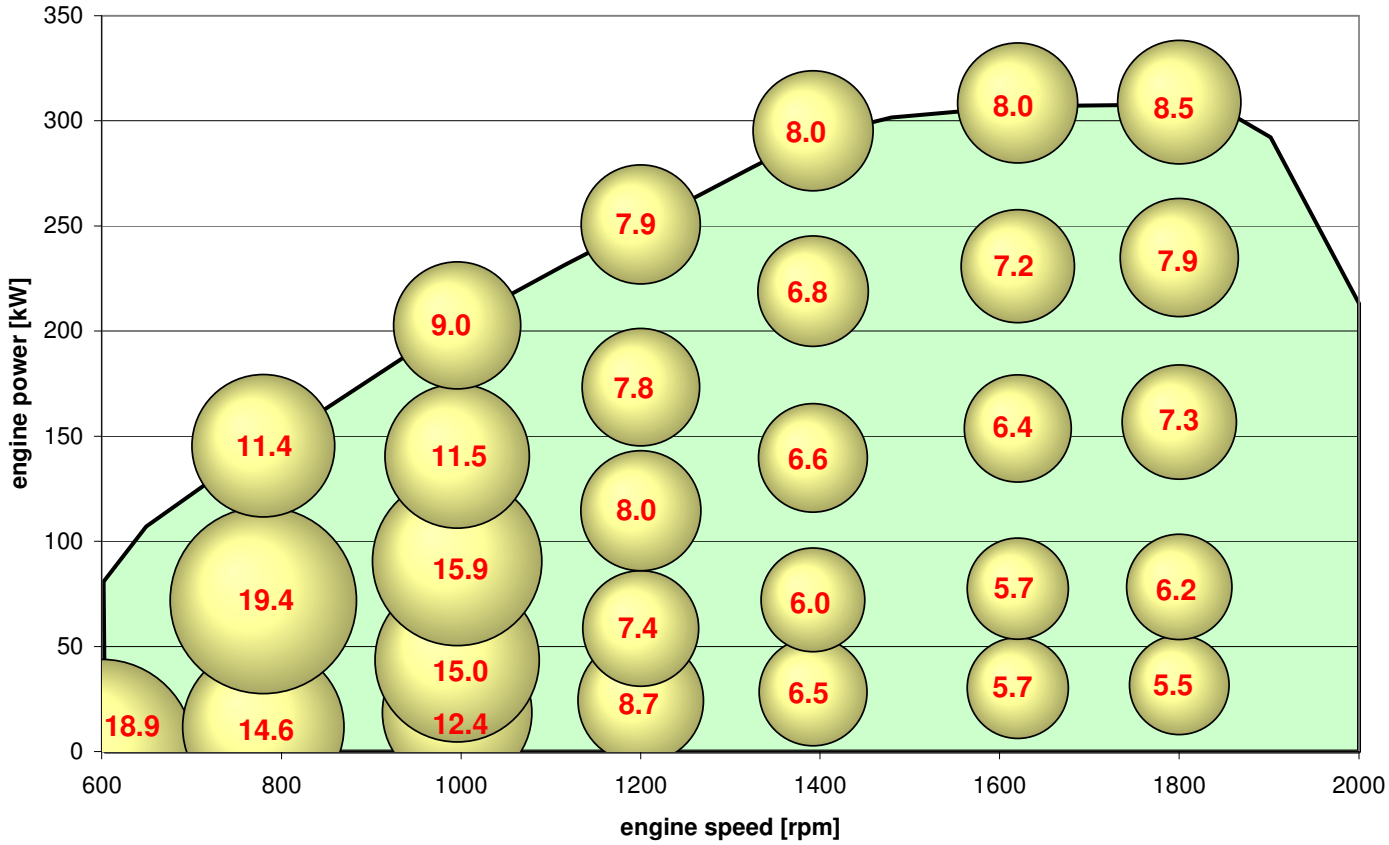
Alternative approach: CO_2 specific

Extra advantages CO_2 specific method:

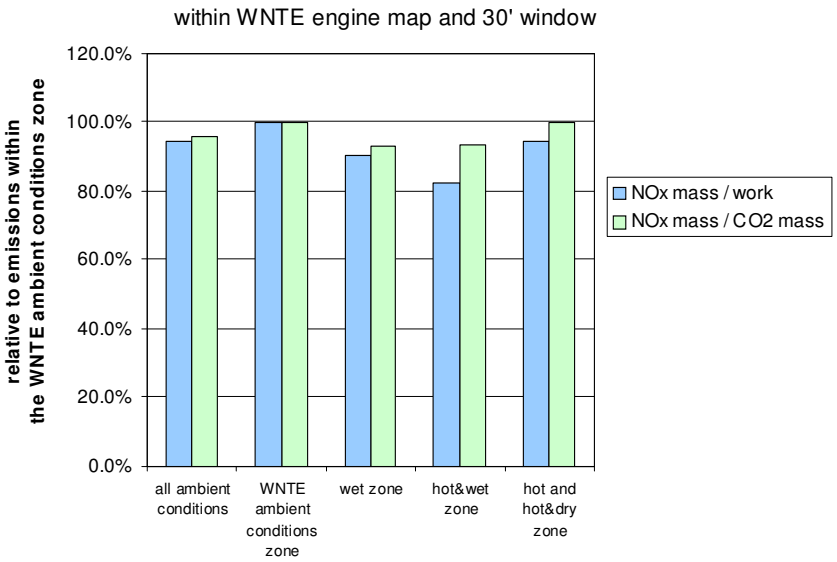
- No „tricks“ needed to prevent excessive emissions in [g/kWh] at low loads
- Less sensitive to ambient conditions
- No ECM, kW or engine speed data necessary
- Less sensitive for possible PEMS flow measurement errors

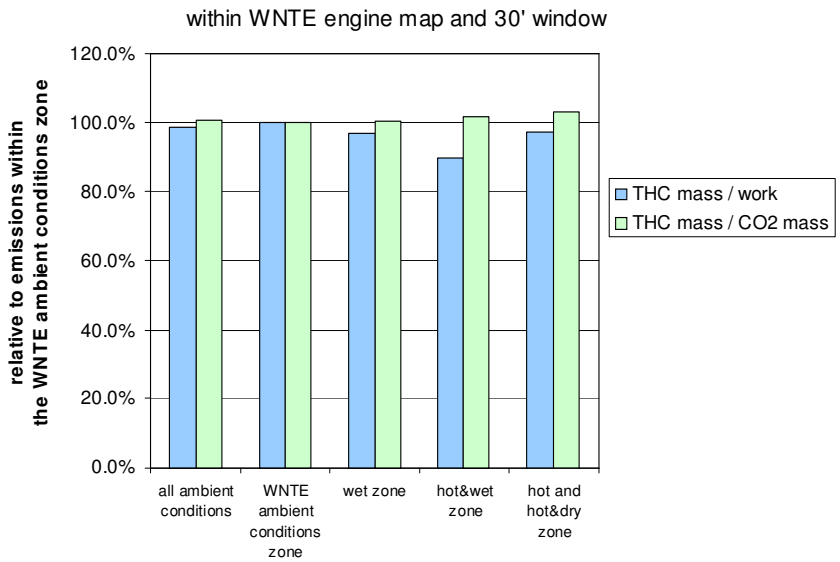
Alternative approaches: CO2 specific methods

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	"unavoid-able" high emissions excluded	feasibility with PEMS (*)	ECU data necessary
WNTE	draft WNTE	- -	+ +	- -	yes
	+ 10s minimum sampling period	-	-	- -	yes
	10s + enlarged control area	o	-	- -	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	o	+	- -	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 CO_2 specific approach cover all relevant driving situations
  –> large additional value to existing type approval
- The CO_2 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 CO_2 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

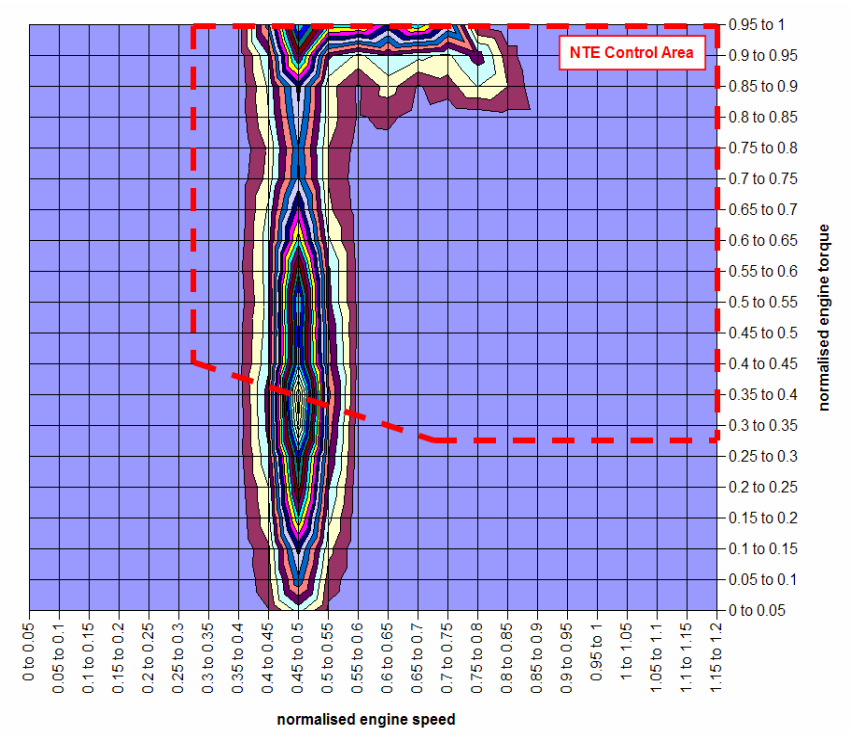
HDV mileage distribution

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%**

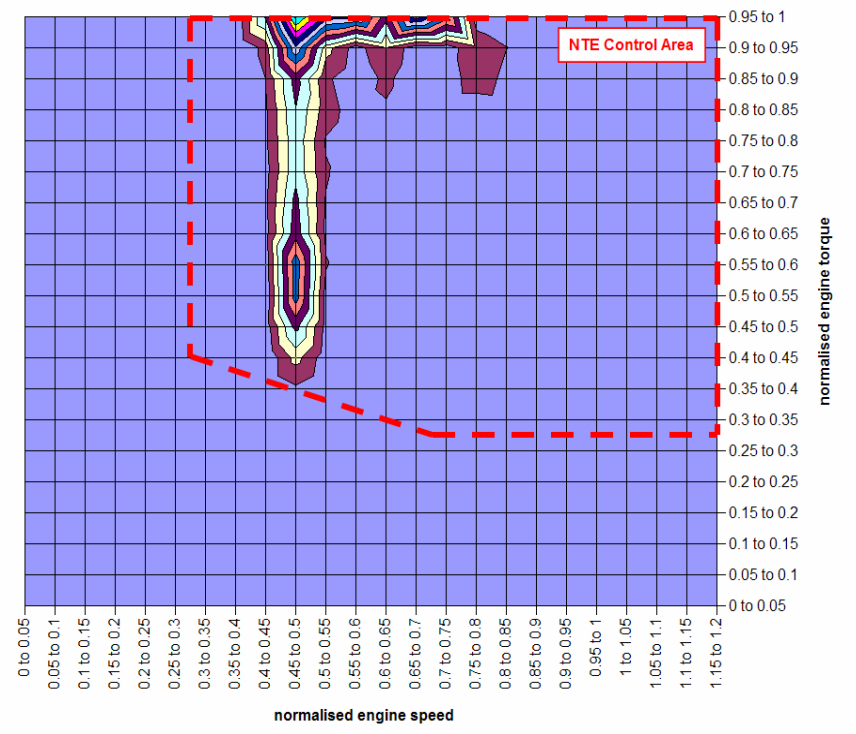
Cumulative NOx emissions

truck + semitrailer 40t / motorway

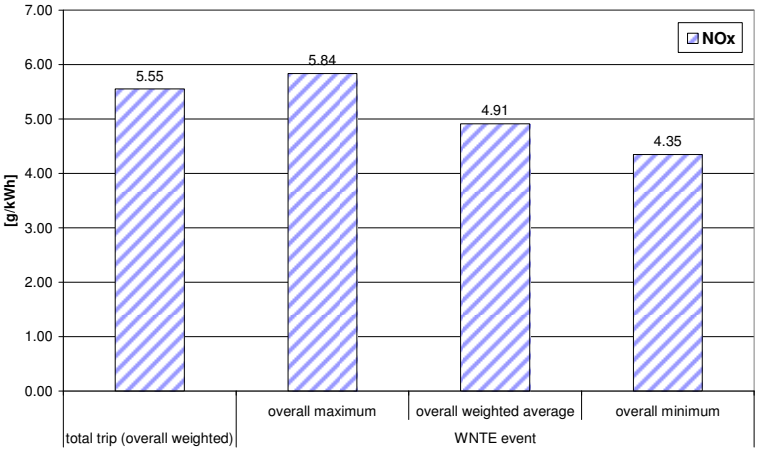
total

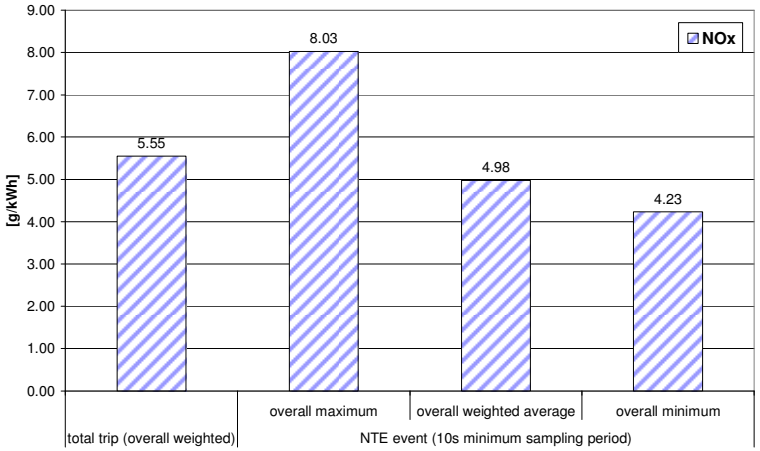


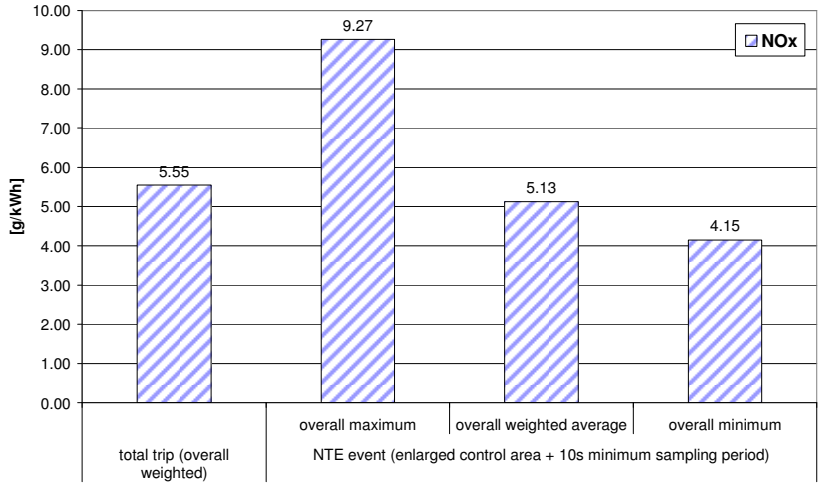
WNTE



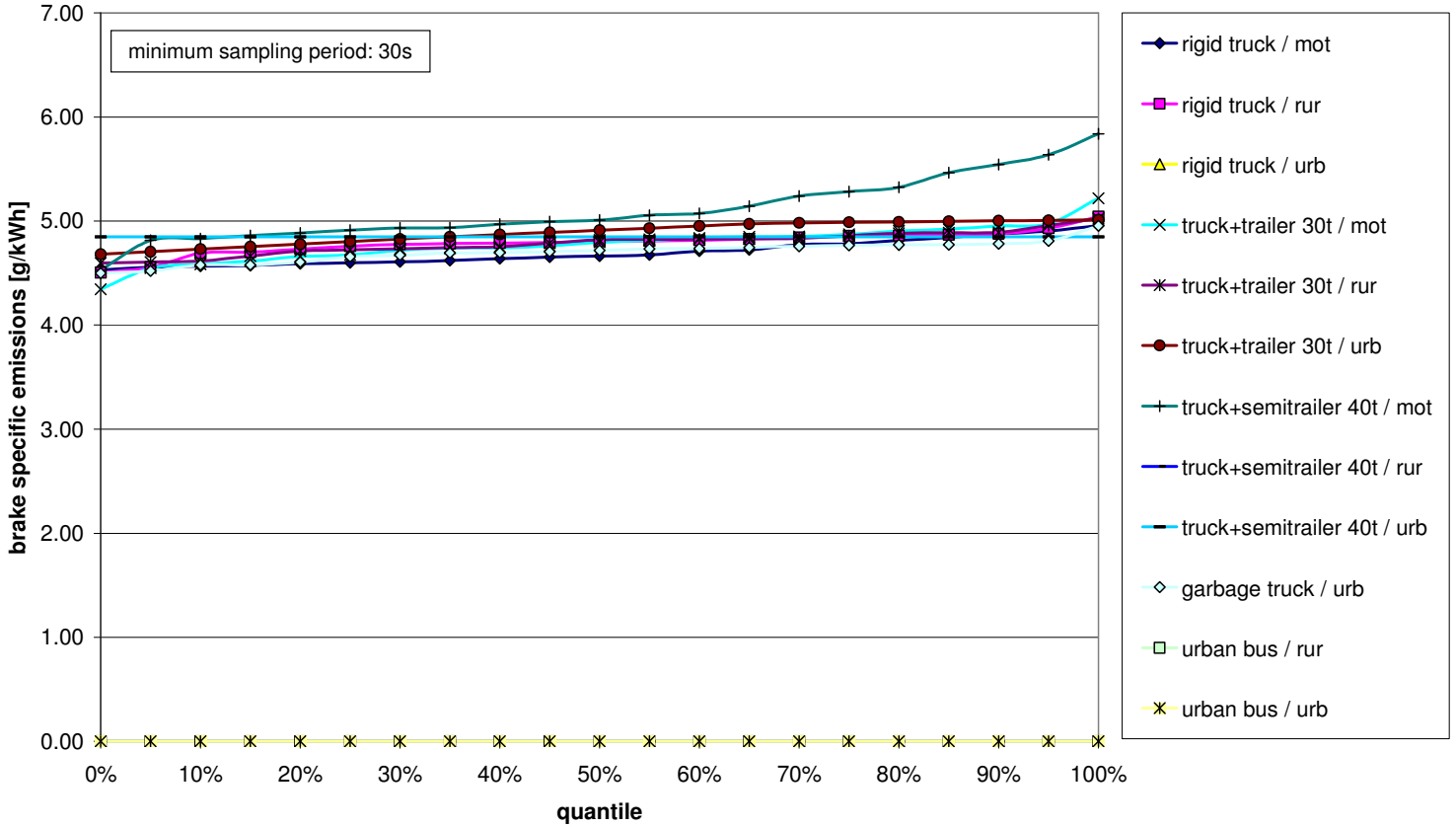
WNTE control area + variants – Euro III



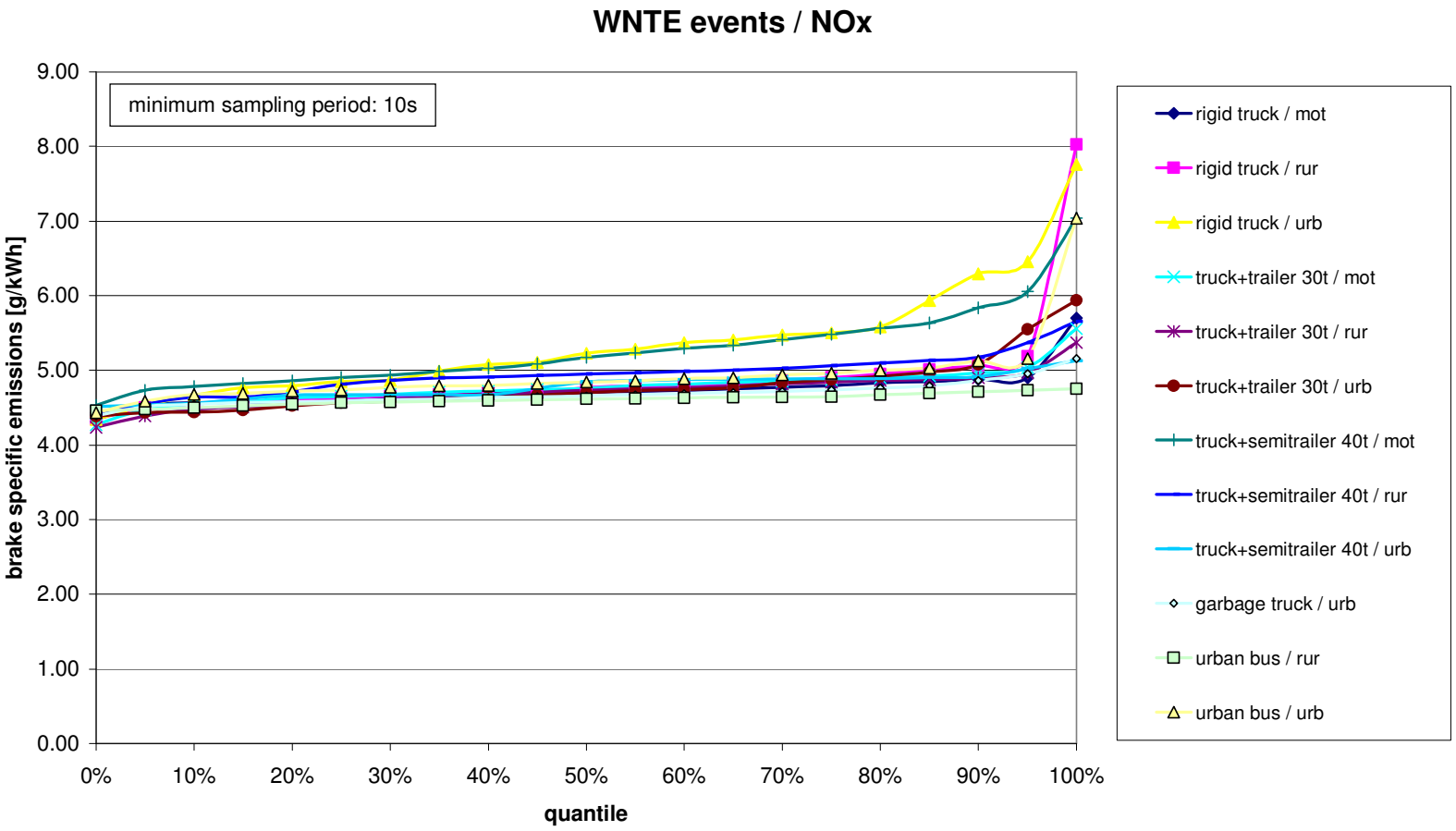




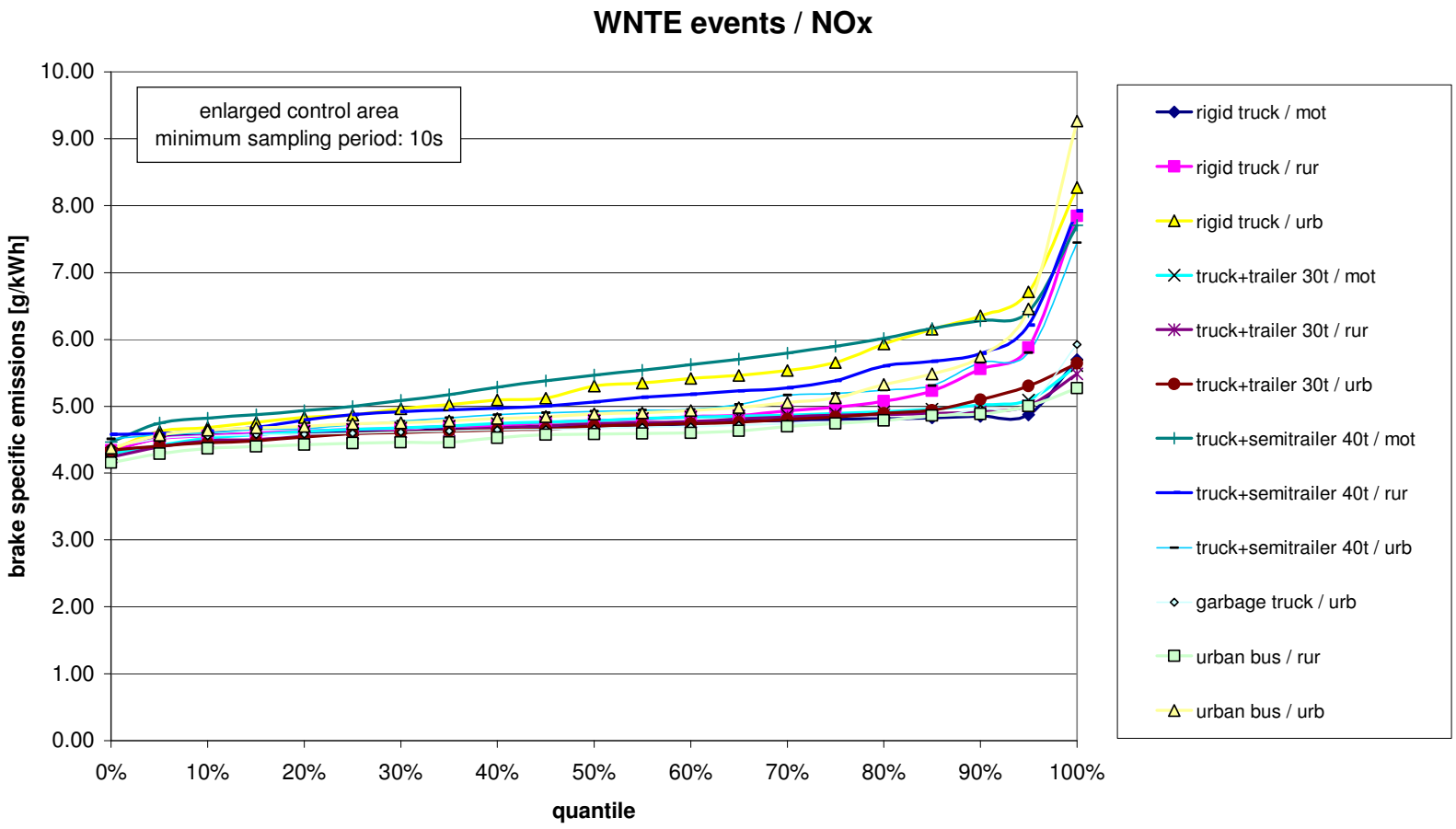
WNTE control area – Euro III



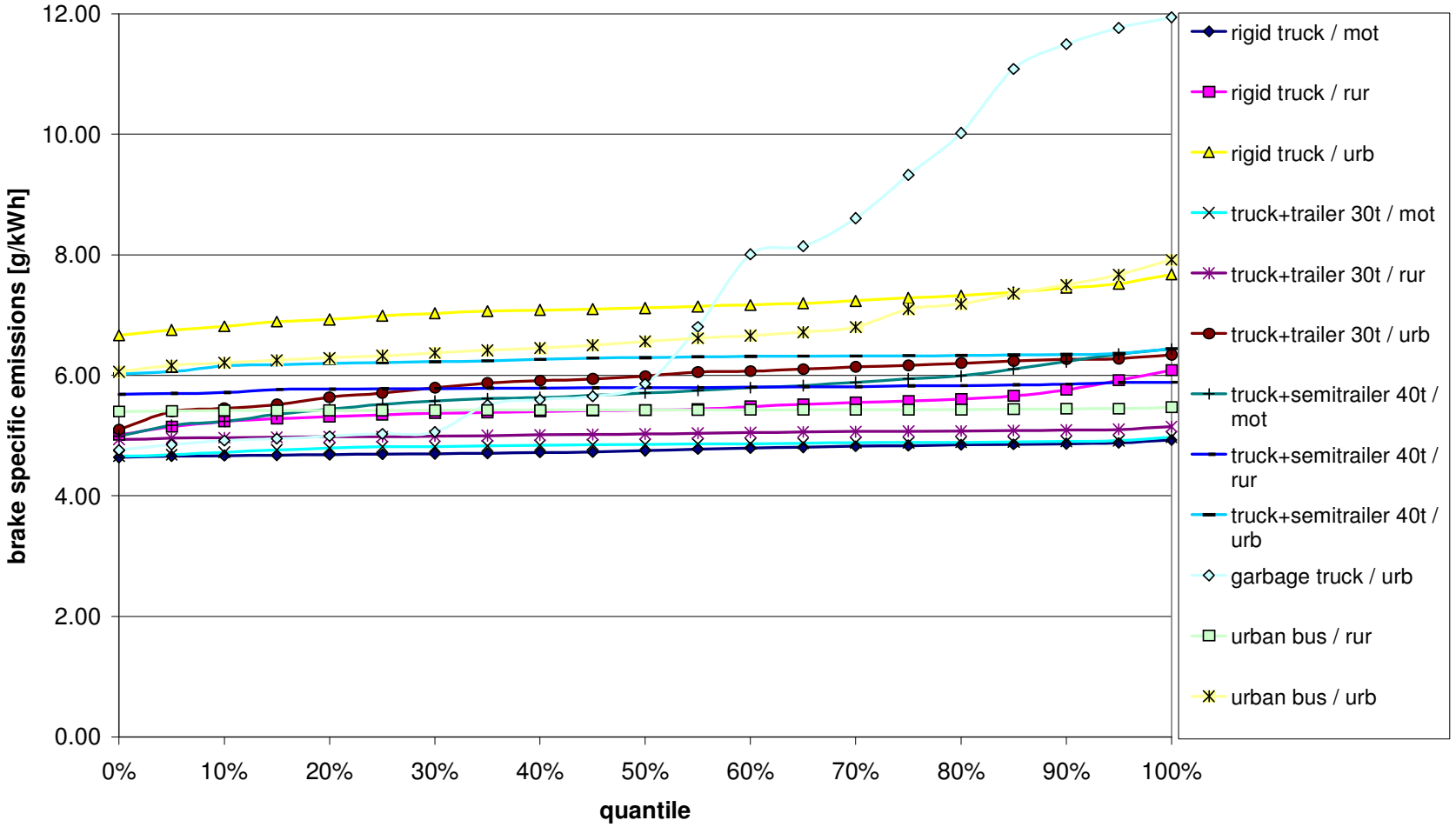
WNTE control area variants – Euro III



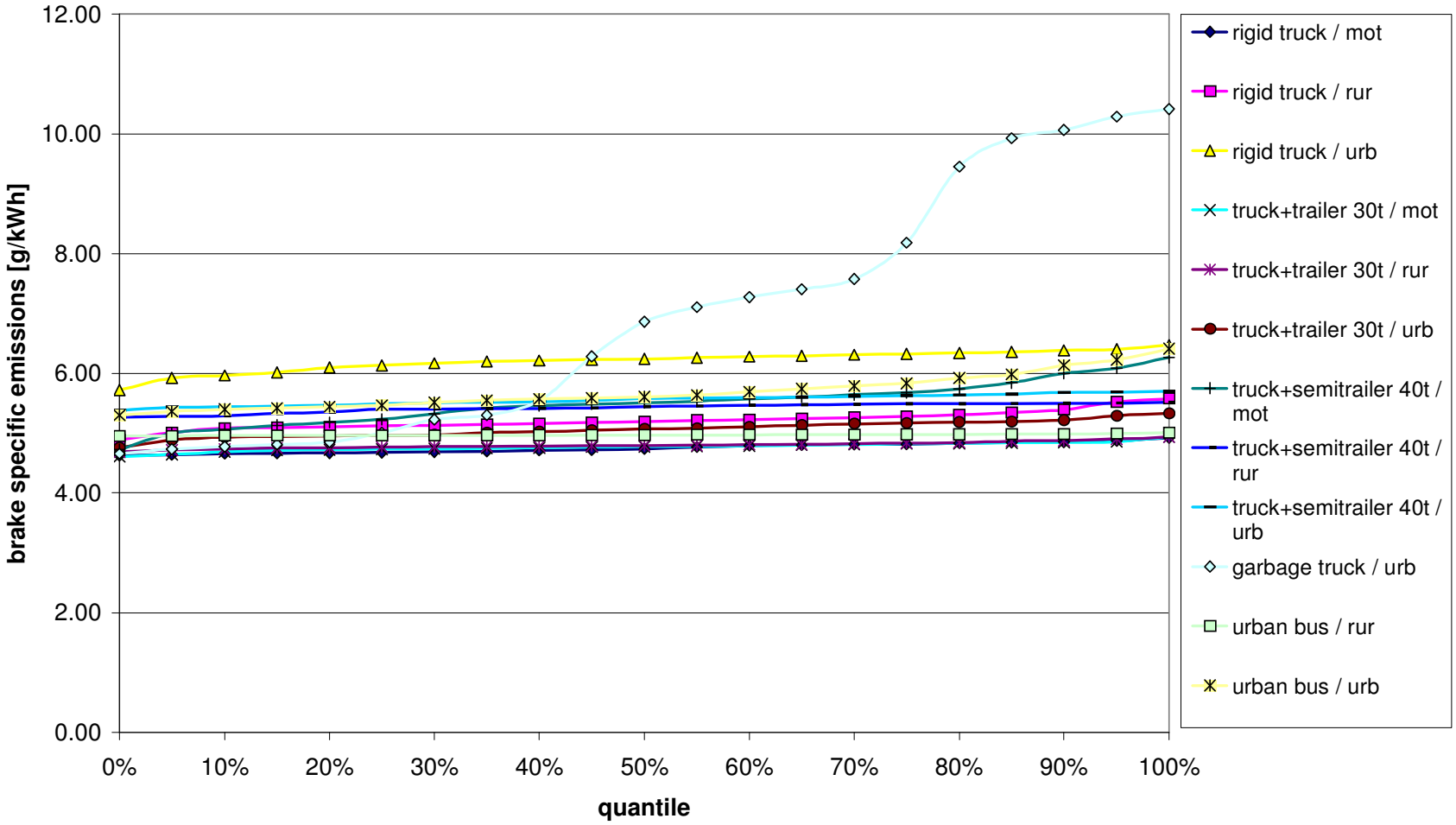
WNTE control area variants – Euro III



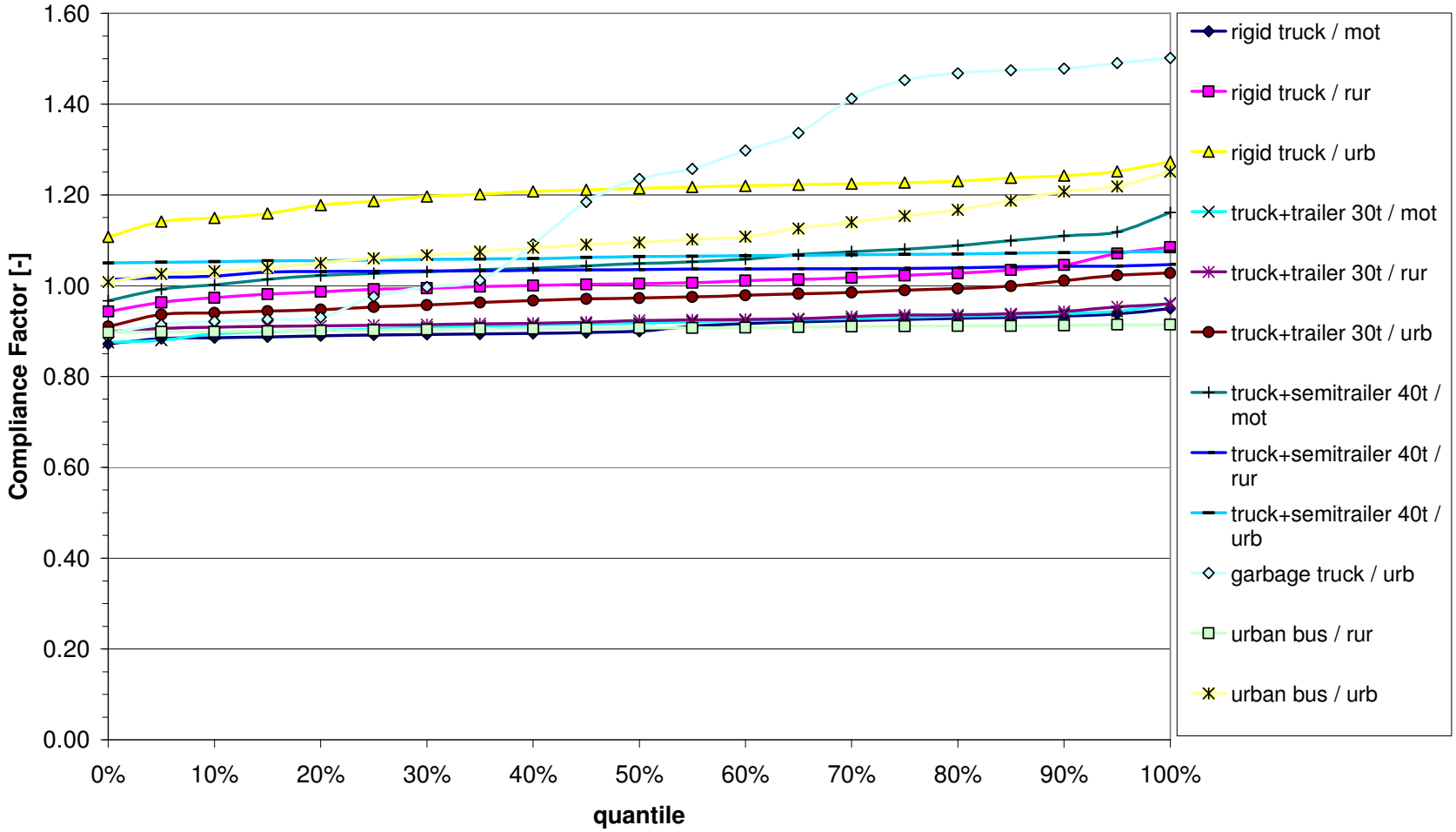
Work Window approach #1 Euro III



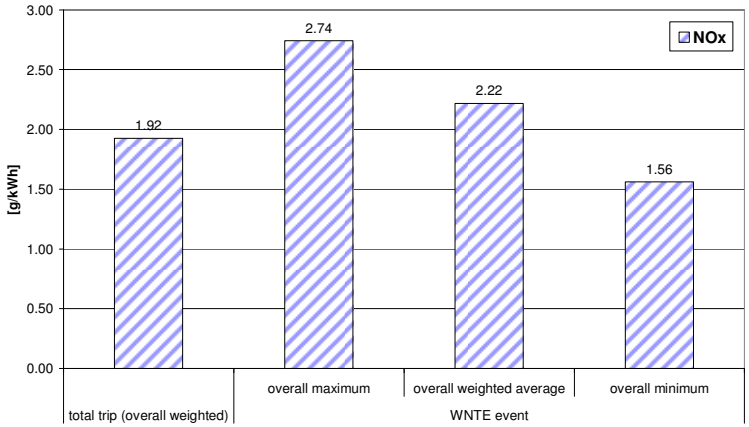
Work Window approach #3 Euro III

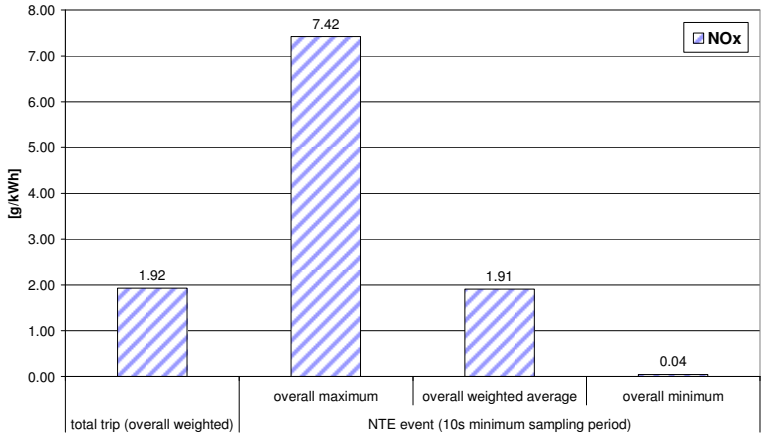


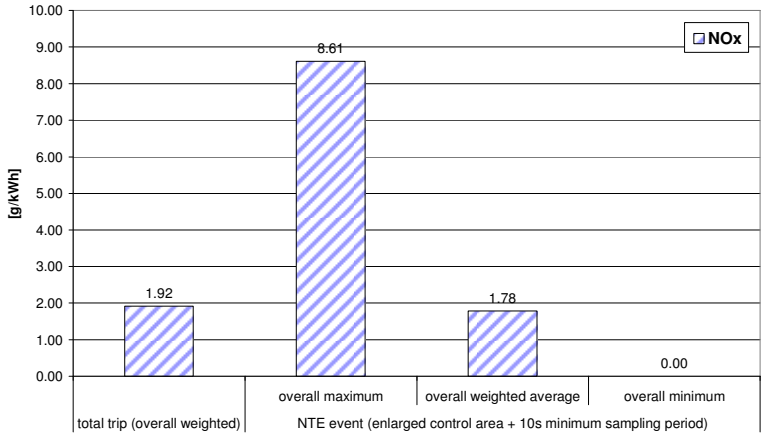
CO_2 based compliance factor Euro III



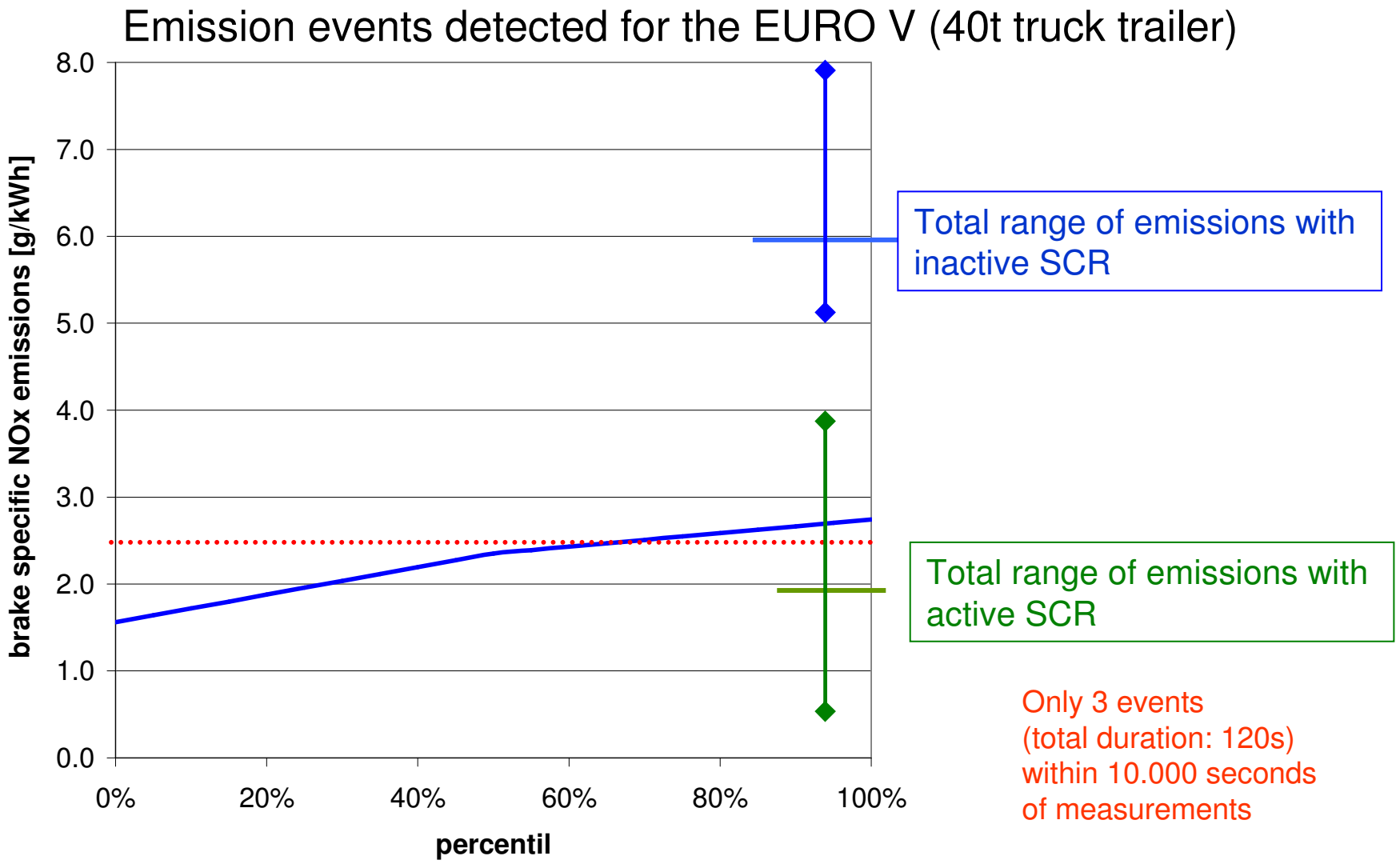
WNTE control area + variants - Euro V



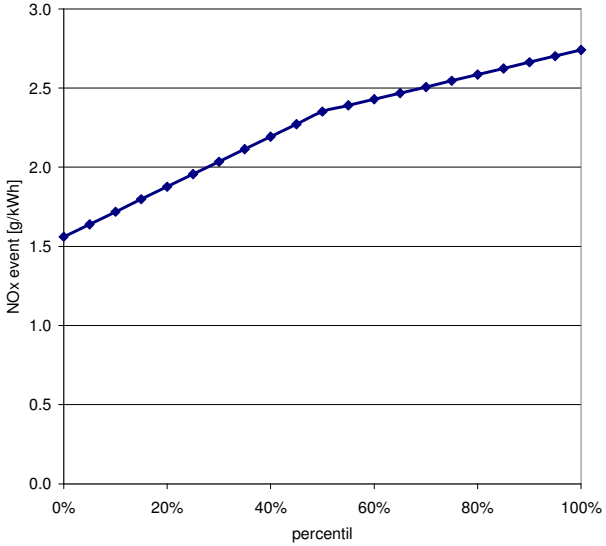


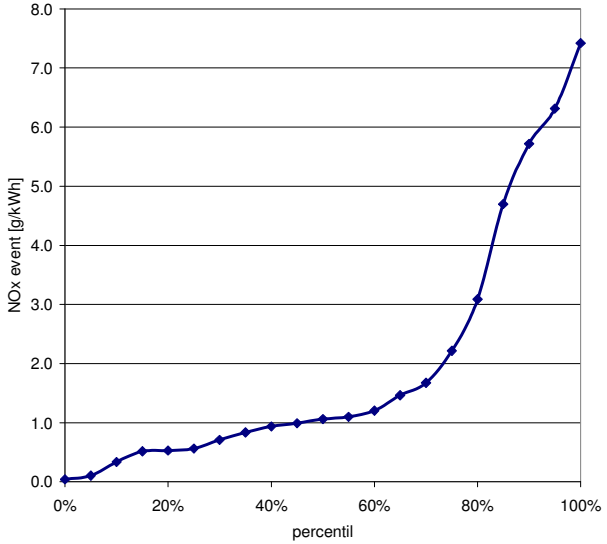


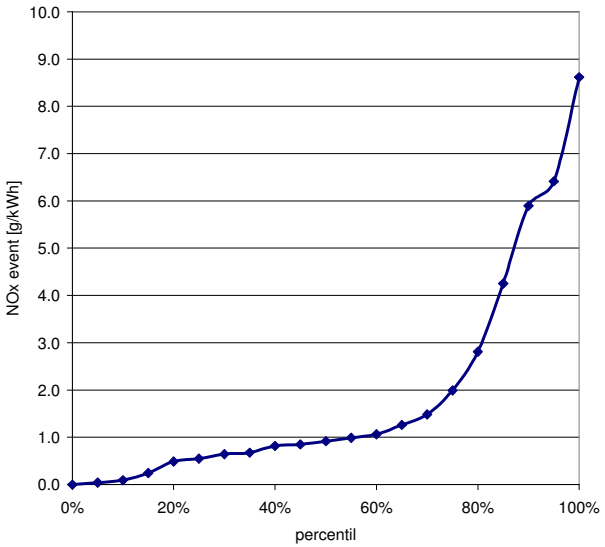
WNTE current draft

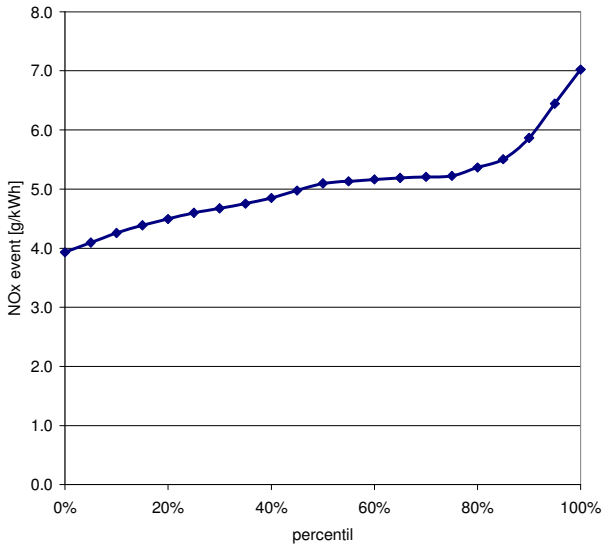


WNTE control area variants - Euro V

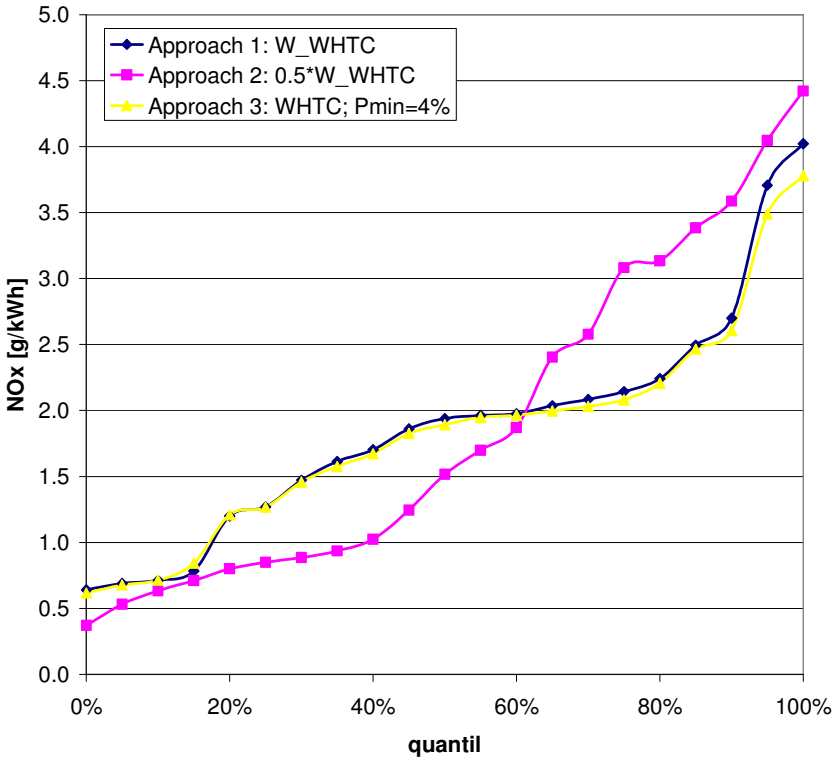


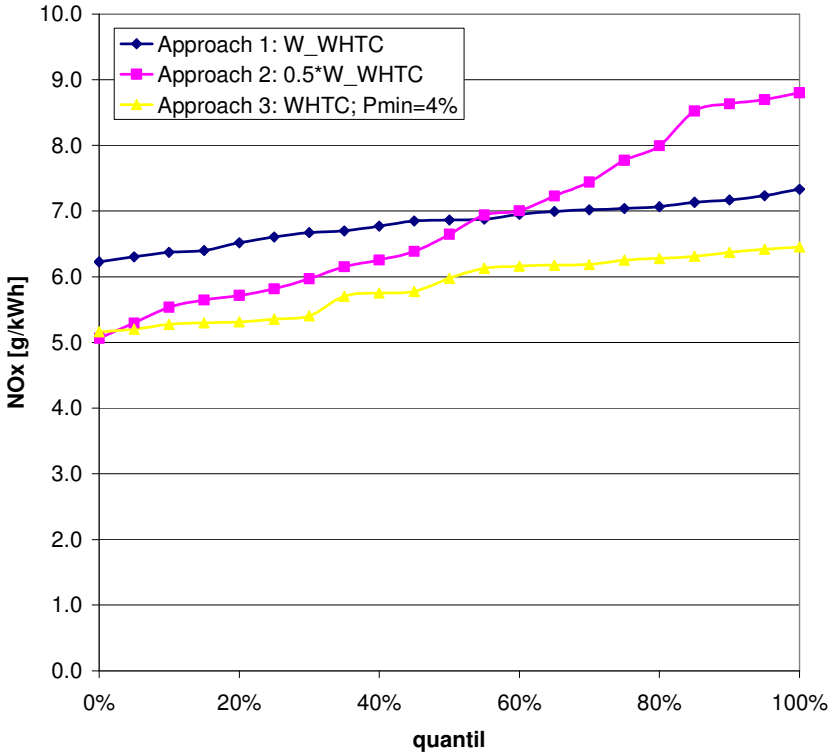




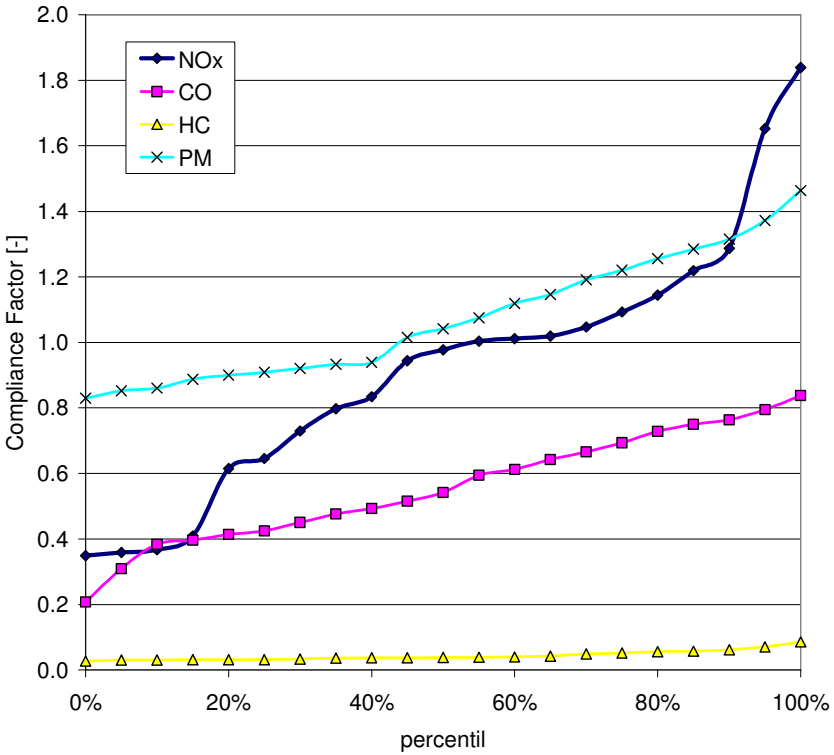


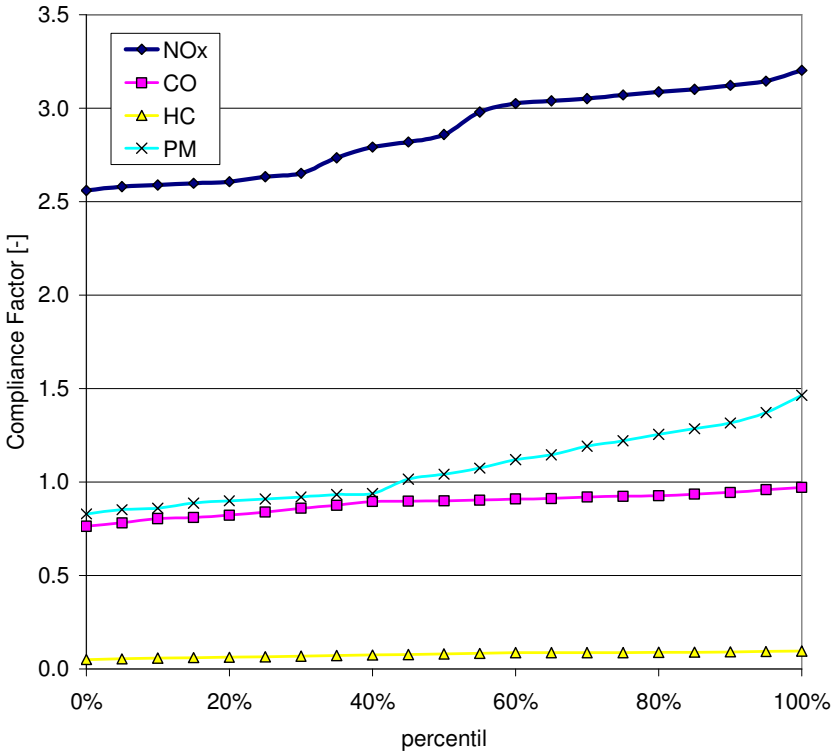
Alternative approach: Work Window Euro V



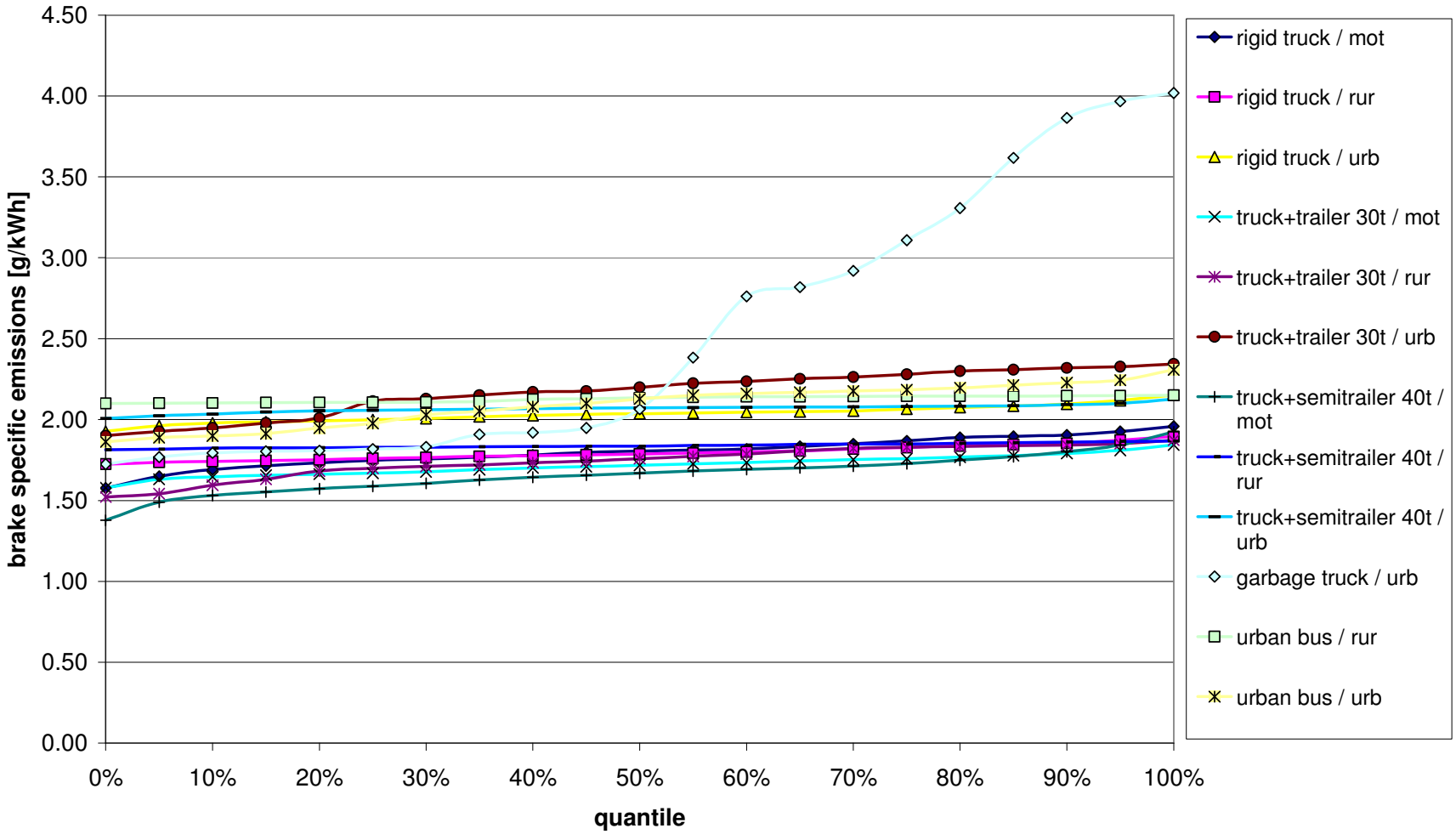


Alternative approach: CO_2 Euro V

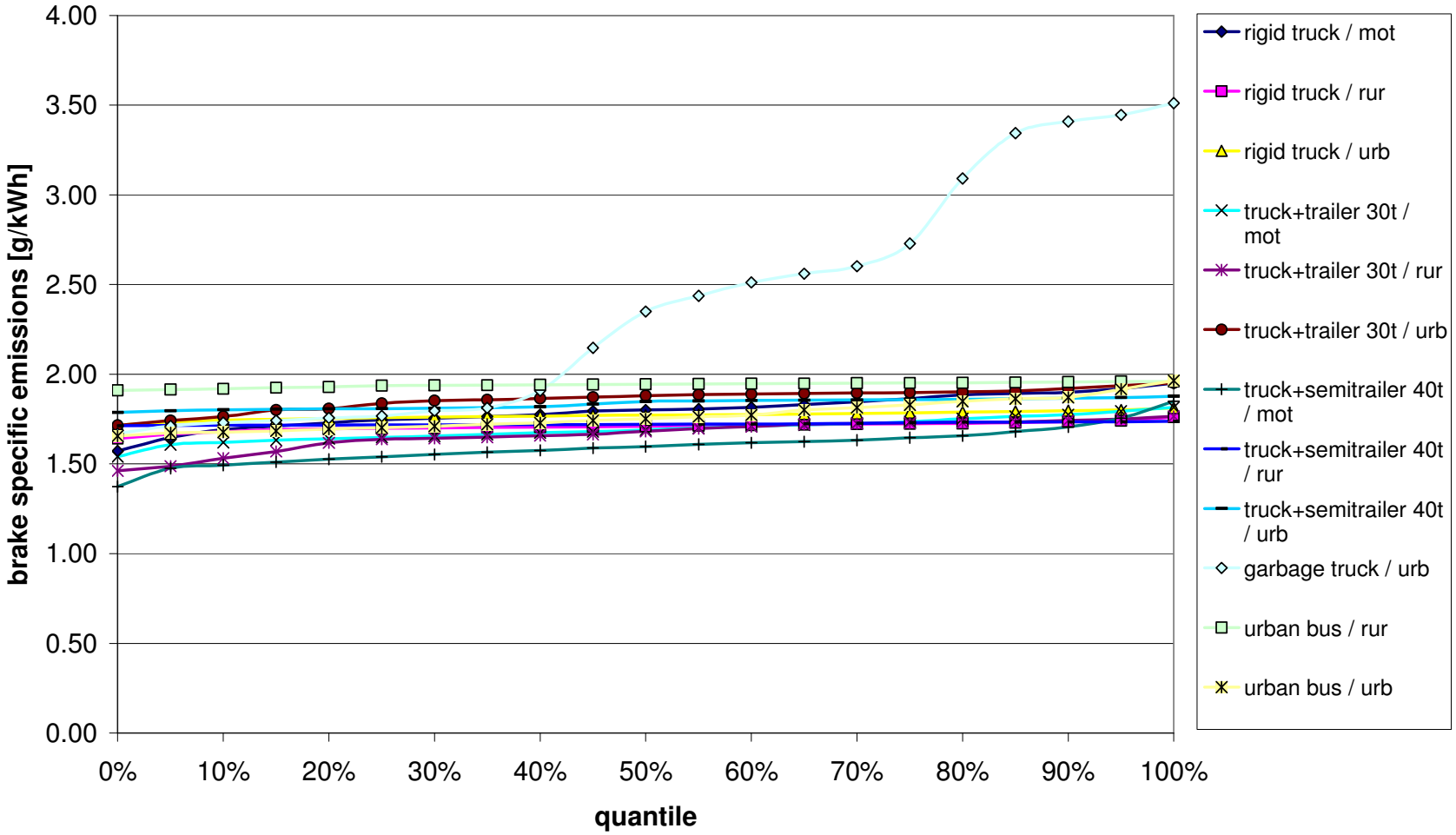




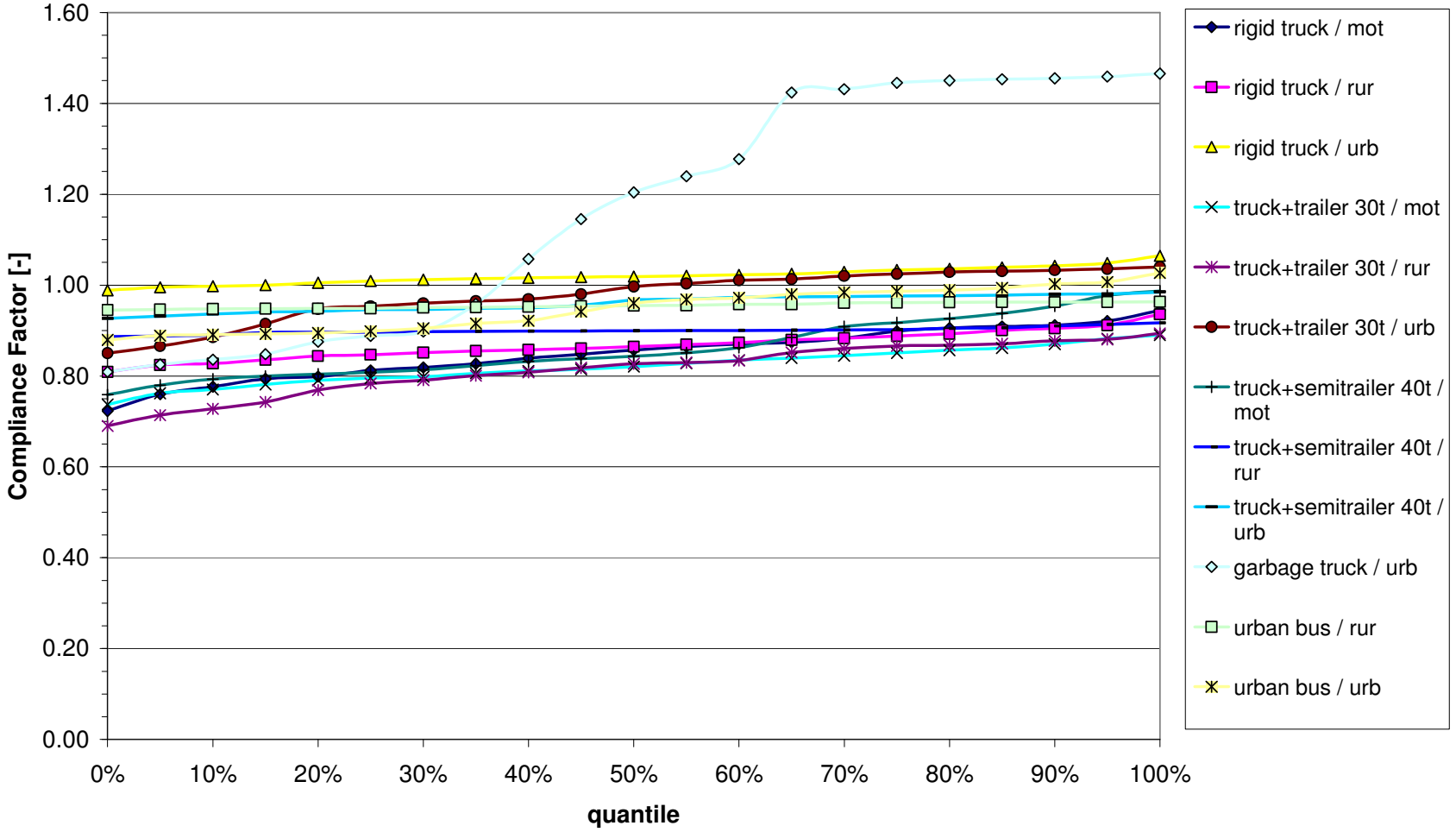
Work Window approach #1 Euro V sim



Work Window approach #3 Euro V sim



CO_2 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: CO_2 specific

1. Assessment of the CO_2-specific emission behaviour in the type approval cycle "TA" based on the according emission limits:

$$\mathrm{TA}\,[g_{\mathrm{emissions}}/g_{\mathrm{CO2}}] = \frac{(\mathrm{emission\ limit})_{\mathrm{transient\ TA\ cycle}}\,[\mathrm{g/kWh}]}{190\,[\mathrm{g/kWh}] * \frac{(\mathrm{carbon\ content})_{\mathrm{fuel}}\,[-]}{0{,}273}}$$

2. Determination of the CO_2 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 CO_2 specific emissions over periods fixed by the amount of CO_2 emitted in the type approval test:

$$\mathrm{OCE}\,[g_{\mathrm{emissions}}/g_{\mathrm{CO2}}] = \frac{\sum_{(\mathrm{mass\ CO2})_{\mathrm{transient\ TA\ cycle}}} (\mathrm{mass\ emissions})_{\mathrm{OCE\ test}}\,[\mathrm{g}]}{(\mathrm{mass\ CO_2})_{\mathrm{transient\ TA\ cycle}}\,[\mathrm{g}]}$$

Alternative approach: CO_2 specific

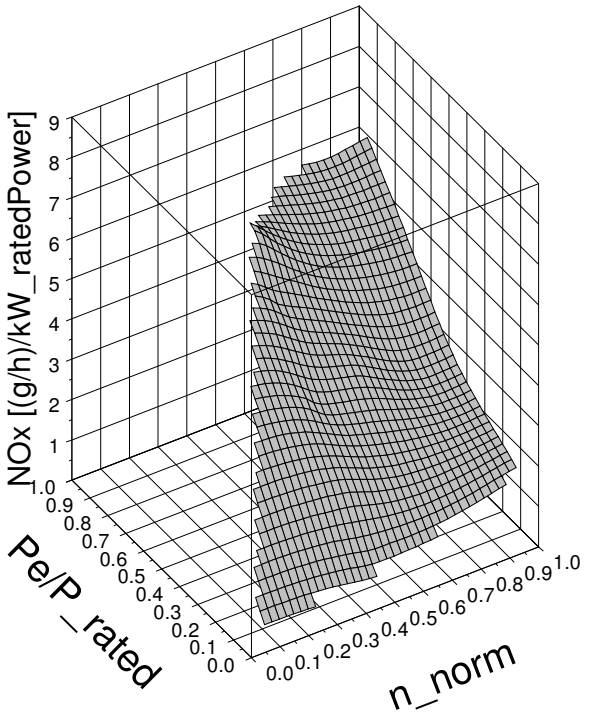
3. The considered OCE test complies with the regulations, if all compliance factor events "CF_{OCE}"(calculated by division of the CO_2 specific emission events in the OCE monitoring "OCE" by the constant CO_2-specific emission behaviour in the type approval cycle "TA") are lower or equal the defined limit for the compliance factor for passing the OCE regulations "CF_{Fail}":

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

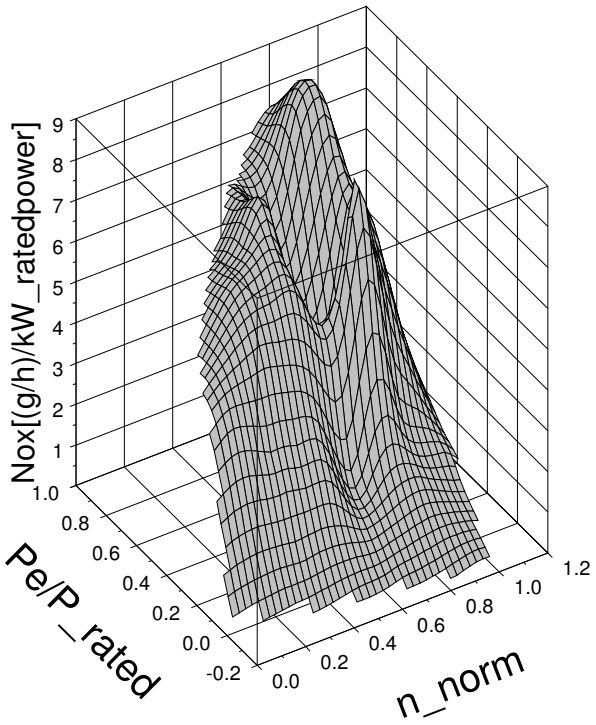
Reasons for HDV OCE monitoring

Example: 1 manufacturer, 3 emission standards

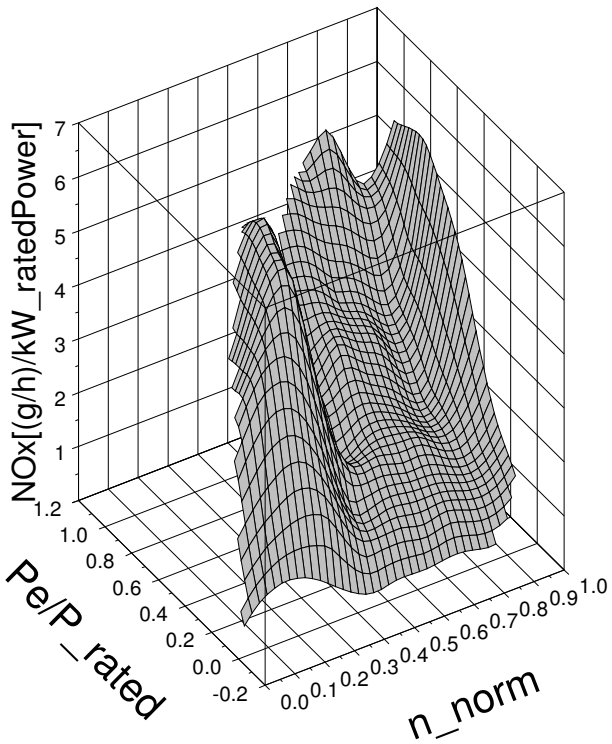
EURO I



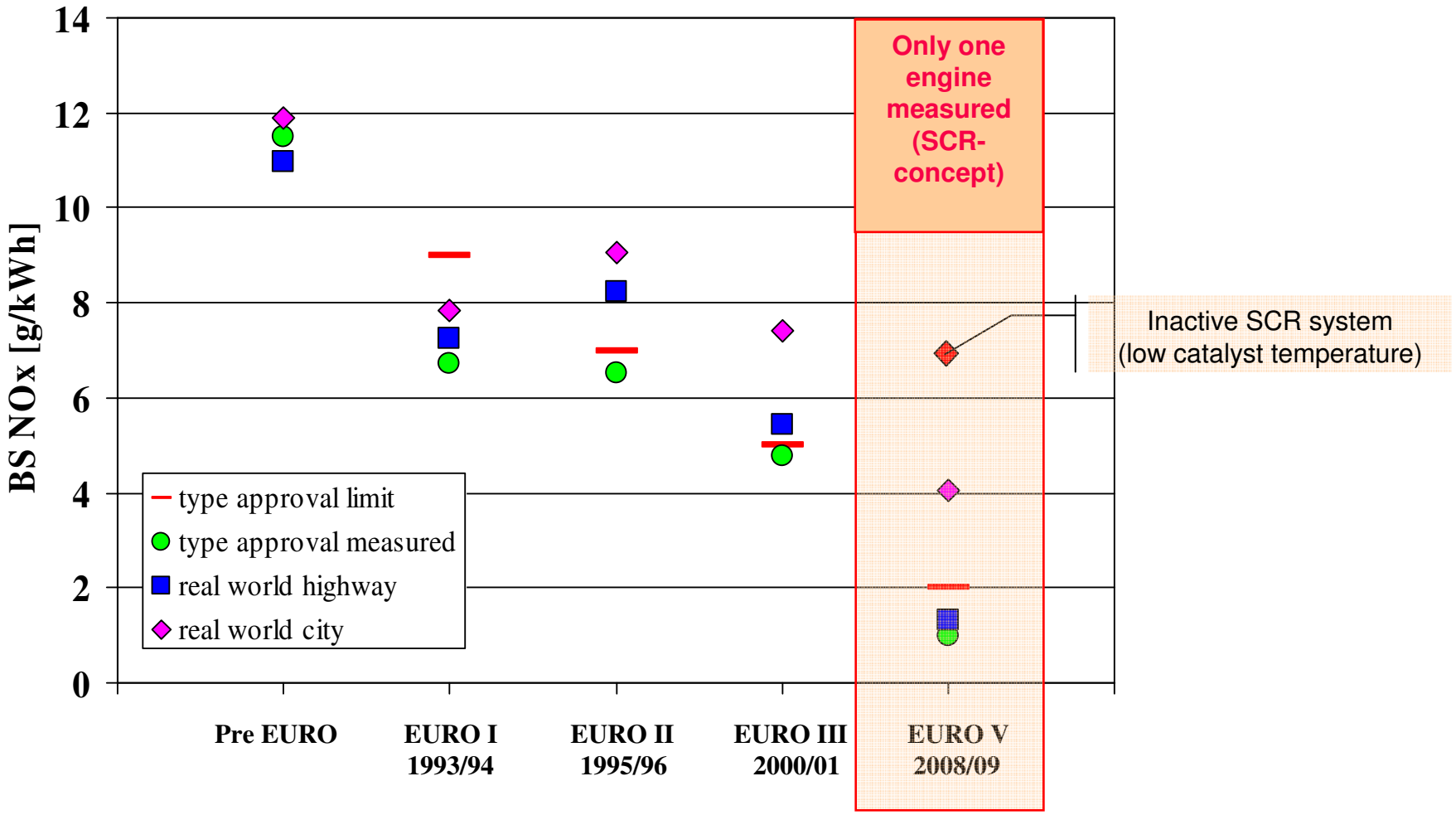
EURO II



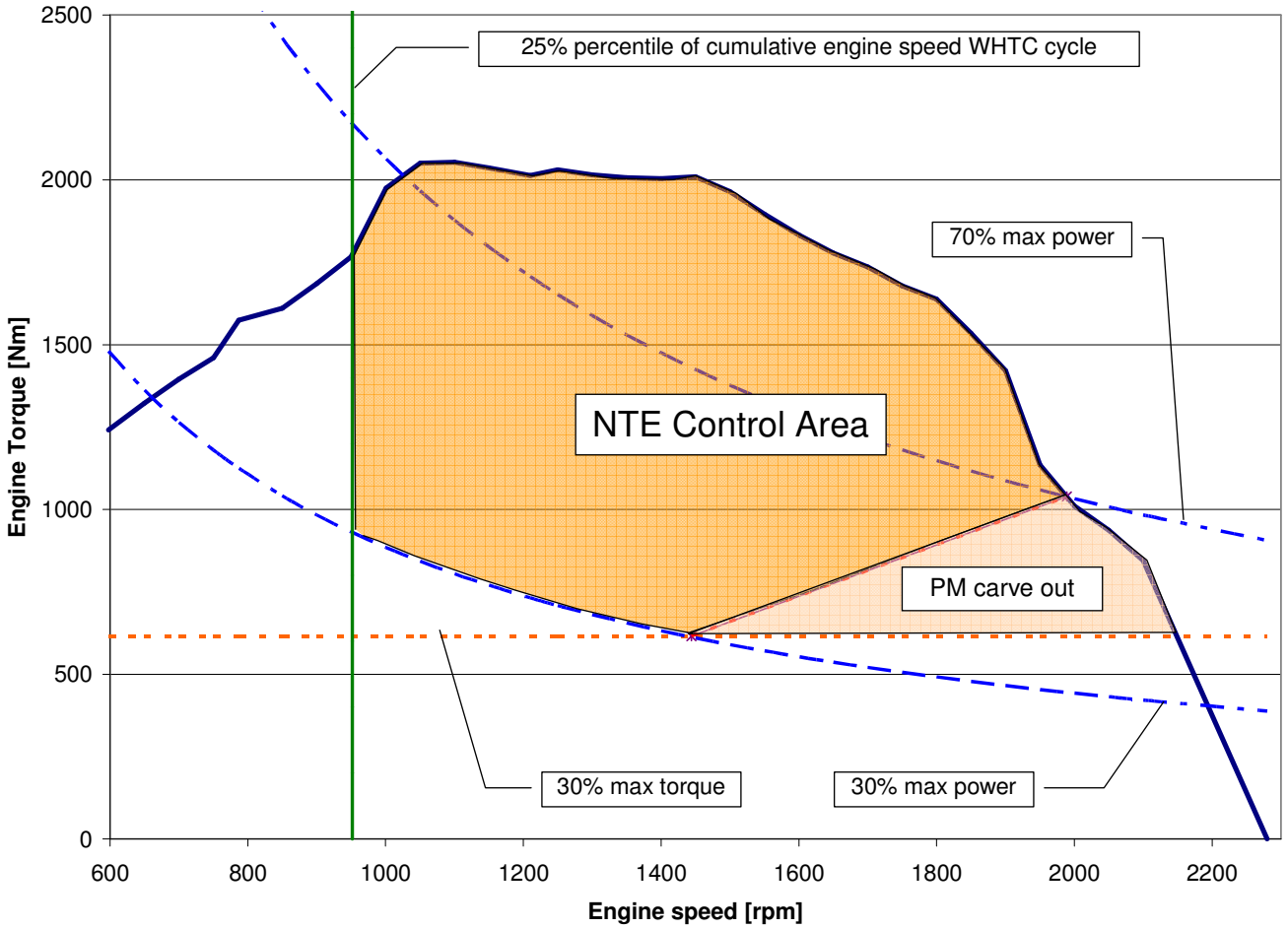
EURO III



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

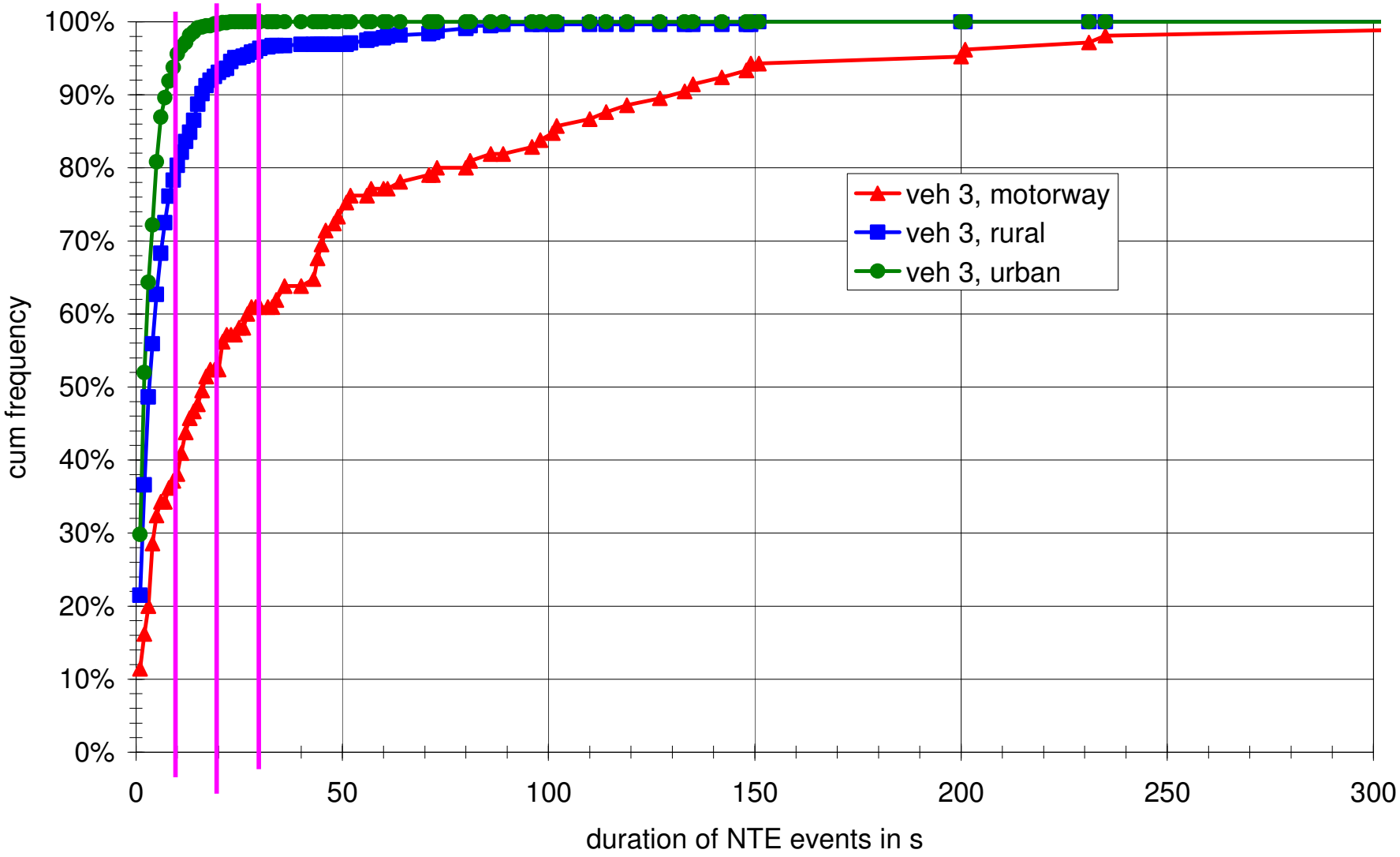
20 s time window

	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