PEMS measurements of Euro 6 diesel car exhaust emissions & comparisons with COPERT

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Agenda

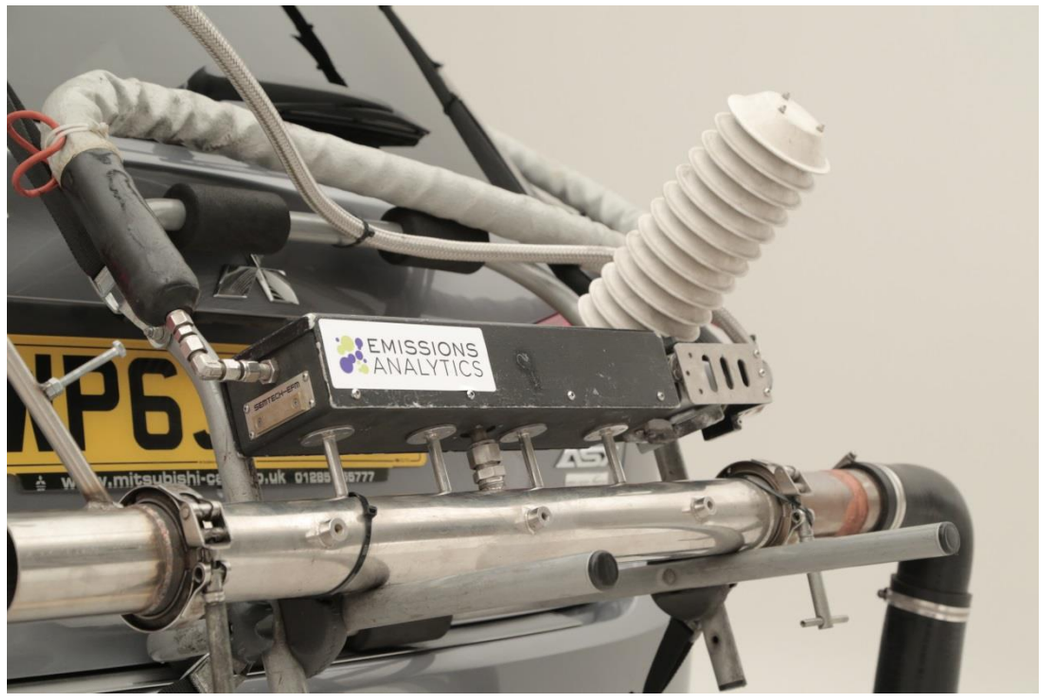
- Credentials
- Portable Emissions Measurement System (PEMS)
- Headline CO_2 results
- Analysis of NO_x measurements and comparison with COPERT
- Fraction of NO_x emitted as primary NO_2
- Conclusions and future development

Emissions Analytics credentials

- Only exclusive PEMS test house in the UK, since 2011
- International experience
- Tested over 800 vehicles
- Real-world drive cycles only
- Expert in cycle design to meet multiple and complex objectives
- Data analysis skills to extract maximum value from testing work

Benefits of PEMS

- Real on-road testing using PEMS is a powerful research method
- Authentic and cost effective
- Works on all vehicle types
- No permanent vehicle modification required
- Flexible location
- High rate of data acquisition – 1 Hertz



EQUIPMENT

Equipment (1)

- Laboratory-grade equipment
  - Precision of +/- 2-3%
- Portable Emissions Measurement System connects to tailpipe
  - Captures emissions for CO_2, CO, NO, NO_2, total hydrocarbons
  - At 1 Hertz
- Air temperature, pressure, humidity
- GPS for speed and altitude
- Engine data via CANBUS
- Weights approximately 95kg if running with auxiliary batteries

Equipment (2)

- Pegasor Mi2
- Real-time tailpipe concentrations
- Particle mass and number
- Sub-23nm particles
- No filter papers

- Flexible, economic, real-world data collection
- Likely to become regulatory grade

PEMS in action

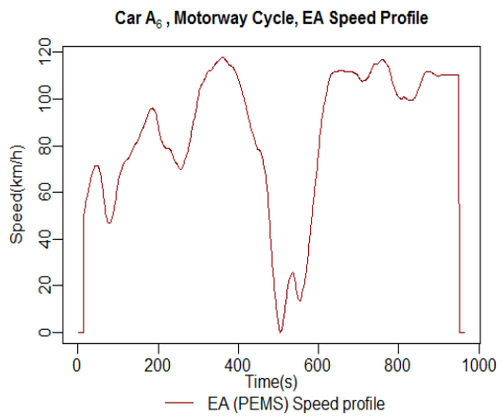
Real Driving Emissions

- Drafting of regulations being finalised
- Monitoring phase to start mid 2015
  - Unclear the requirements during monitoring
  - Two validation tools: EMROAD, CLEAR
- Full implementation targeted for 2017
  - Remaining issues and resistance may delay
  - Preferred validation tool to be chosen
  - Likely to be EMROAD
- Particle number regulations to follow
  - Many technical and methodological issues
- WLTC application for MPG and CO_2 in parallel, likely transition 2017-2020

METHOD

Analysis

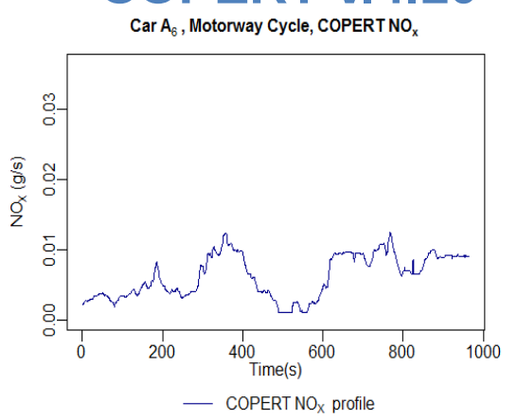
1. Cycle selected by GPS



2. Test cycle speed profile fed into iMove

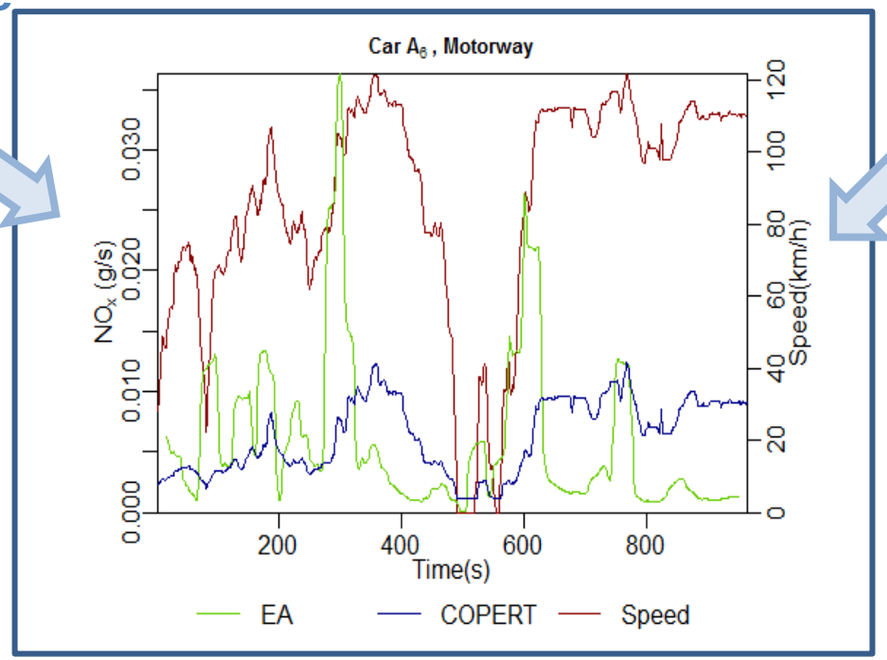
iMove

3. iMove generates CO_2/NO_x profile from COPERT v.4.10



PEMS CO_2/NO_x profile

COPERT CO_2/NO_x profile



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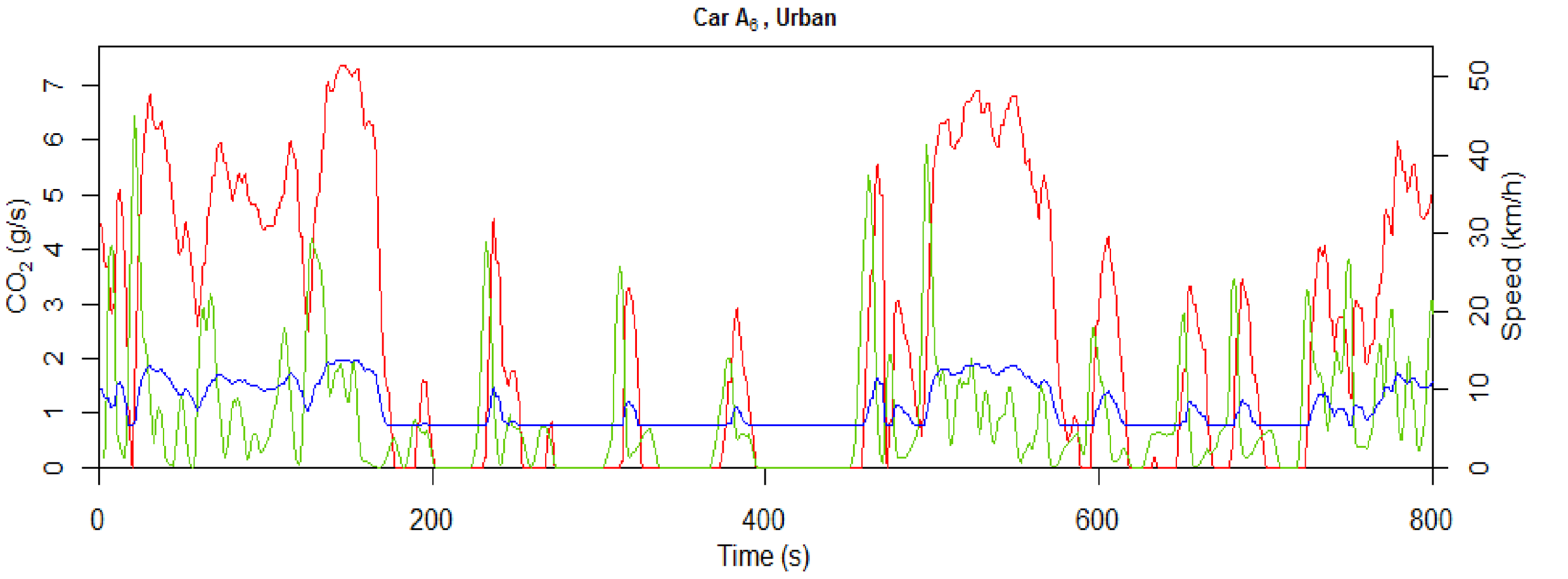
CO_2 EMISSIONS

Car A_6: section of urban cycle for CO_2



speed PEMS COPERT 4.10

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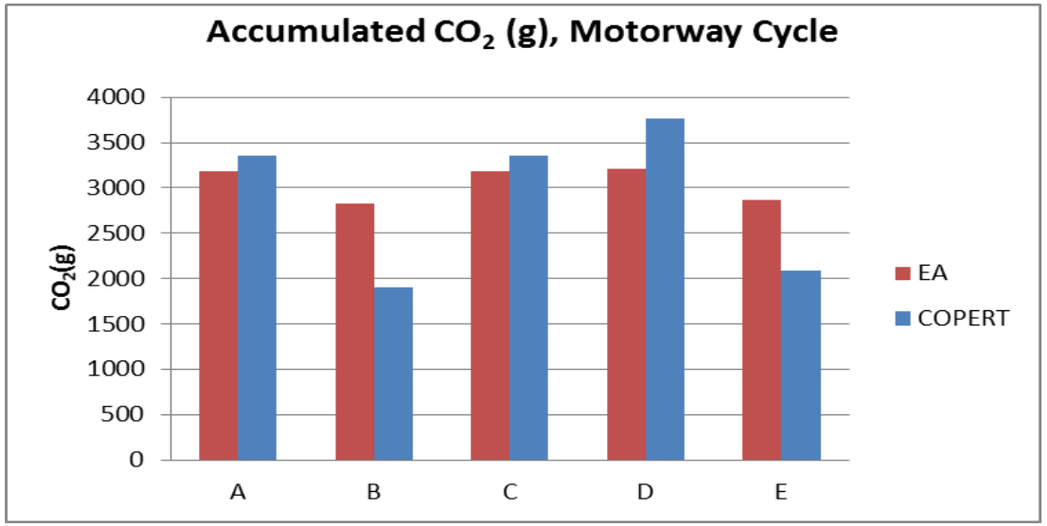
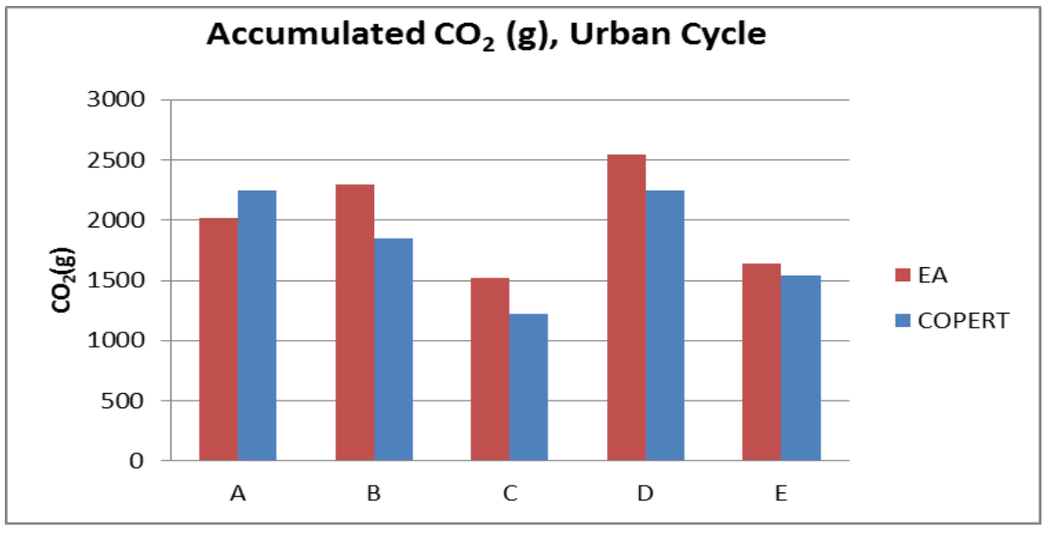
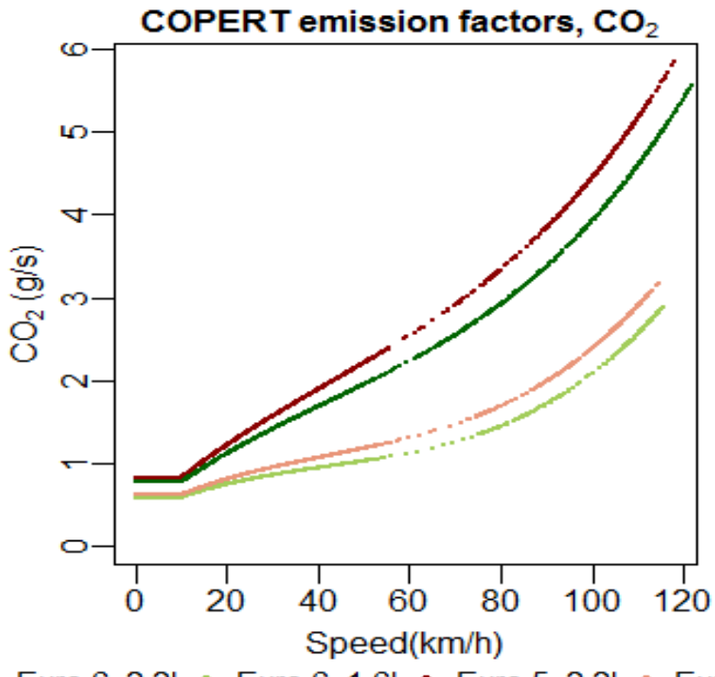
Accumulated CO_2





Comparison of accumulated CO_2 emissions from COPERT and from EA PEMS for 3 x Euro 6 diesels: A-2.2l, B&C-1.6l & 2 x Euro 5: D2.2l, E1.6l



- COPERT predicts slight reduction in CO_2 from Euro 5 to Euro 6 (dark red line to dark green line)
- COPERT places much more emphasis on engine size (pale red and pale green are 1.6l engines)

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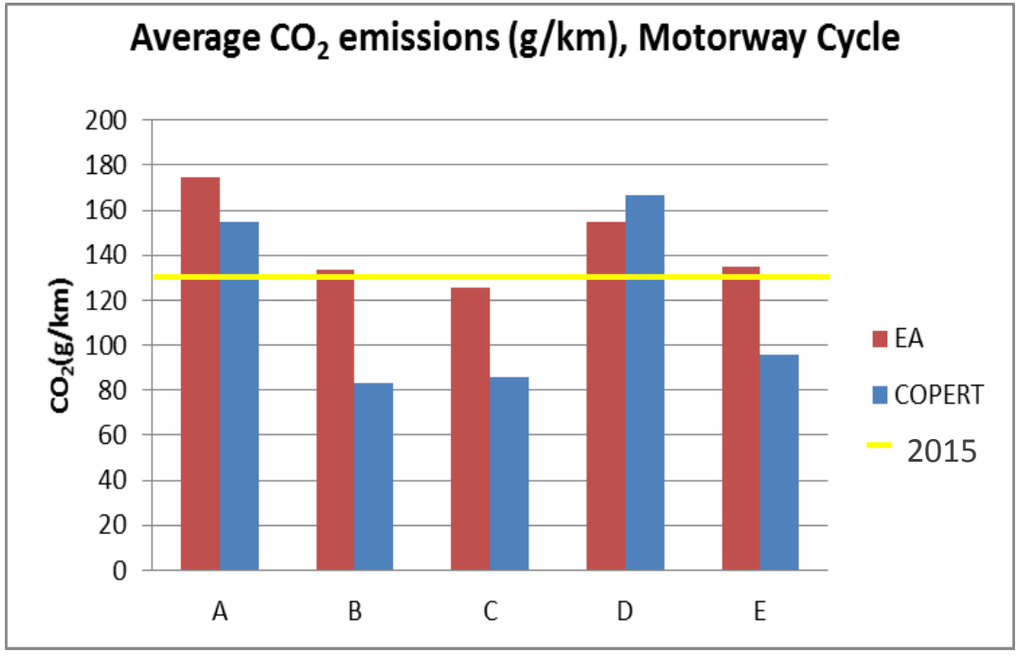
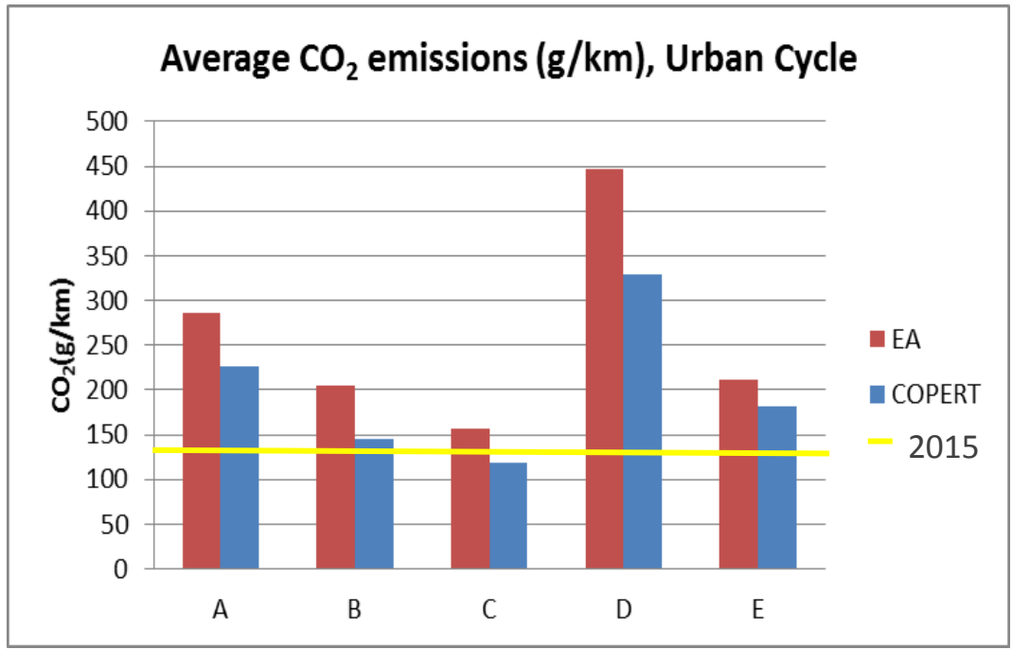
Average CO_2 Emission

- Only one vehicle met the 2015 limit (130g/km) on one cycle
- Some improvement suggested from 5 -> 6, and dependence on engine size
- COPERT returned moderate estimates for CO_2, though seemed to continually underestimate





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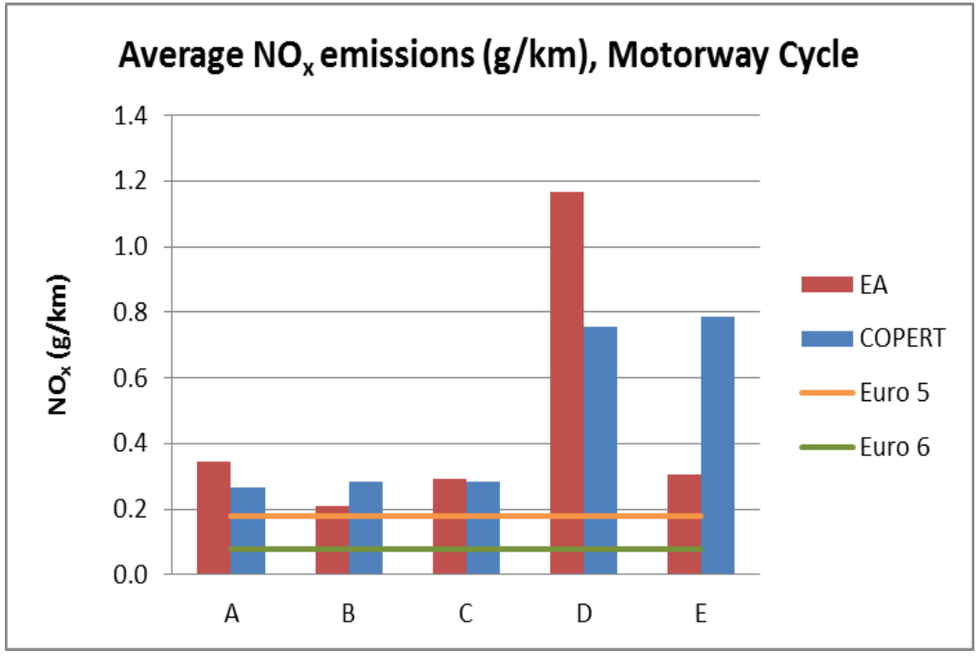
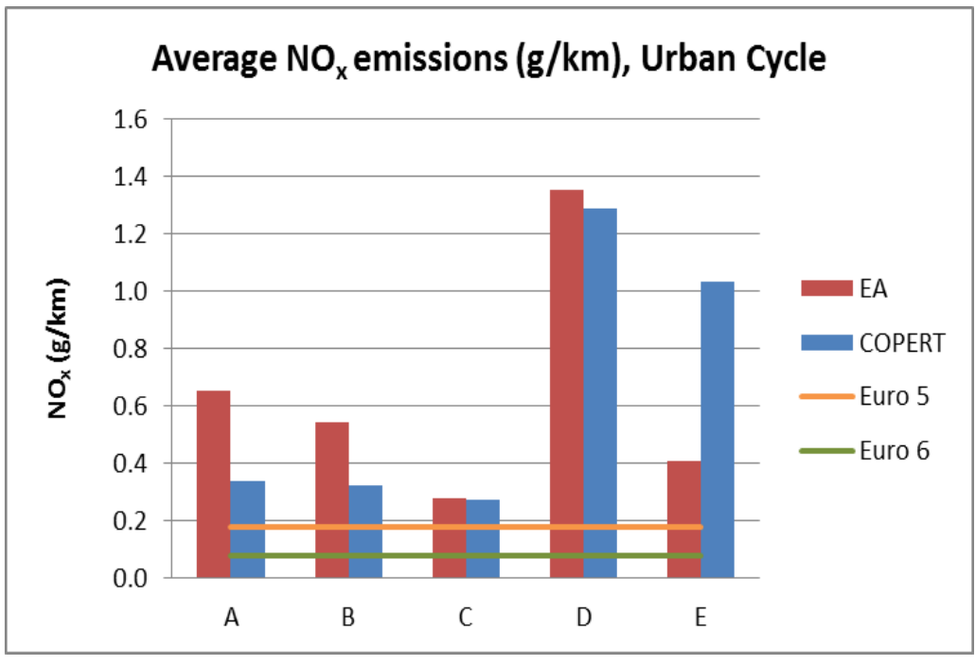
NO_x EMISSIONS

Average NO_x Emission

- **Diesel cars: A,B,C Euro 6, D&E Euro 5: No vehicle met the Euro Standard (even tighter Euro 6c standard ~50% Euro 6 feasible?)**
- **Seemed to be improvement from Euro 5 to Euro 6 (especially on motorways)**
- **COPERT returned reasonable estimates for NO_x, sometimes overestimate, sometimes underestimate**





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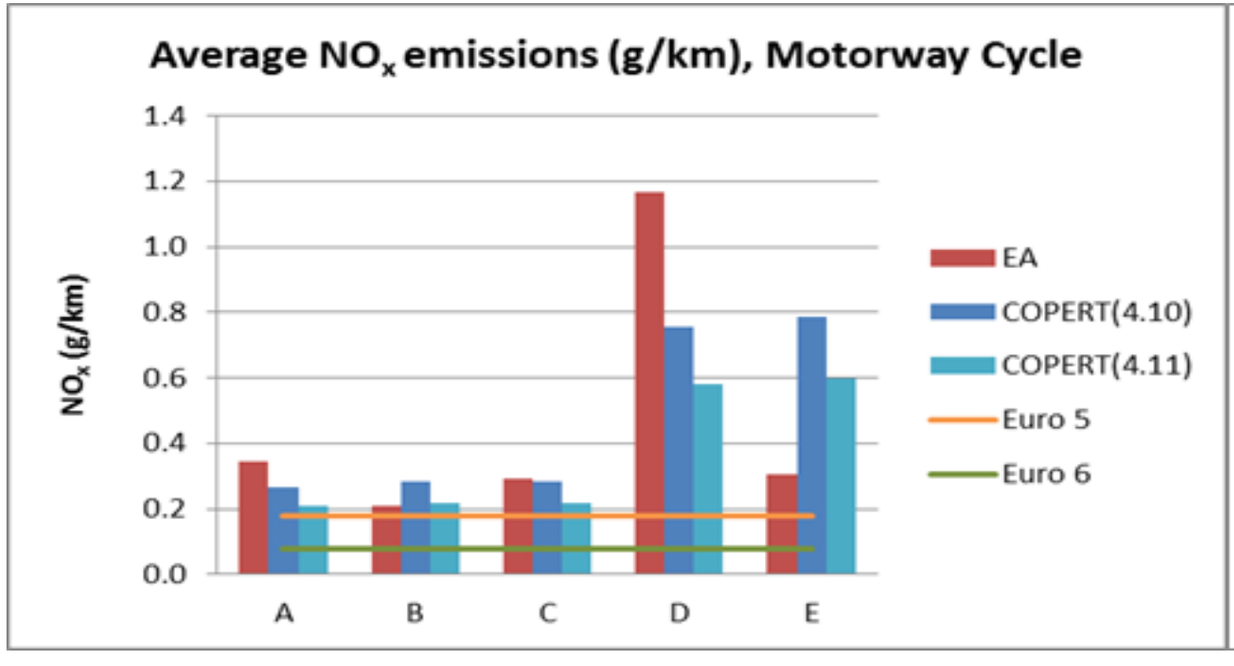
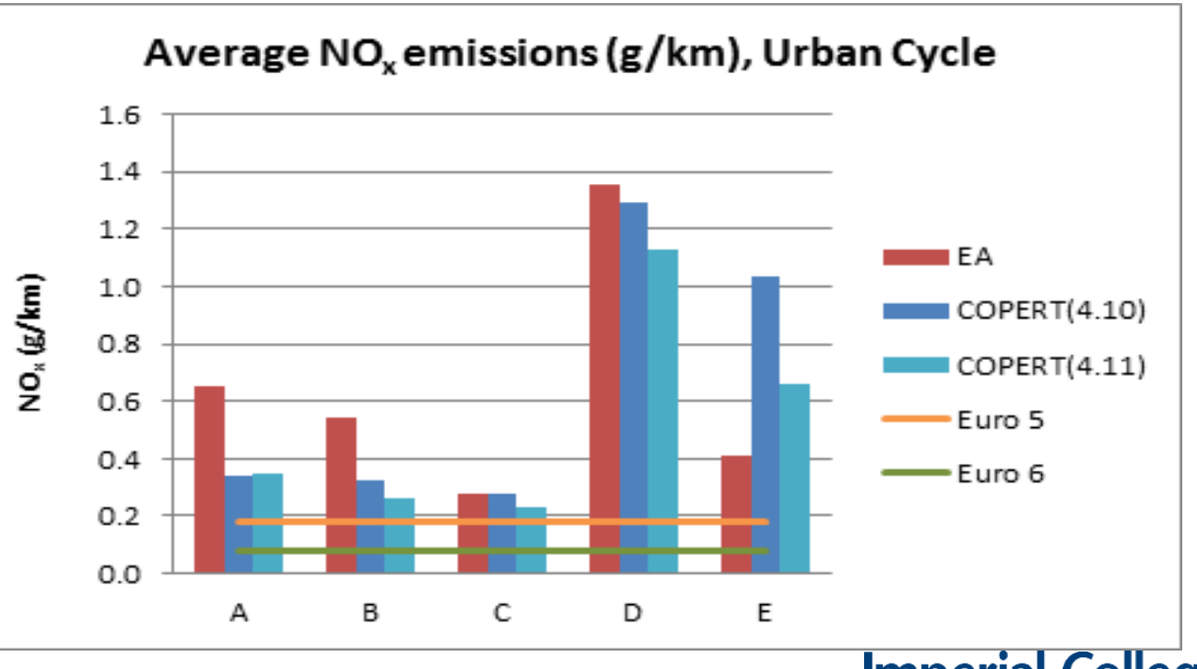
Average NO_x Emission

- **COPERT v4.11 generally gives lower values than v4.10**
- **Gap between PEMS and COPERT is higher for v4.11 than v4.10 in majority of cases studied**





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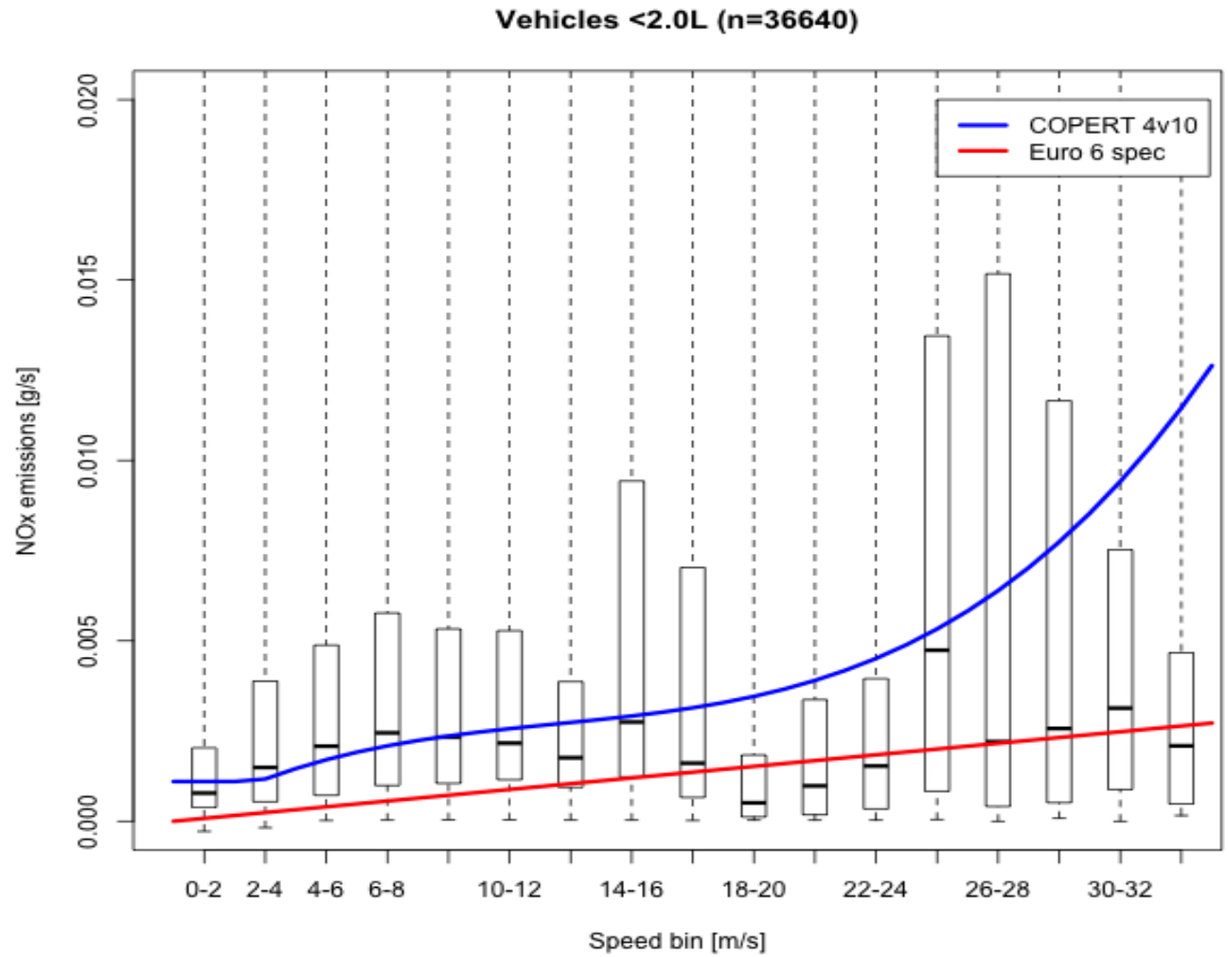
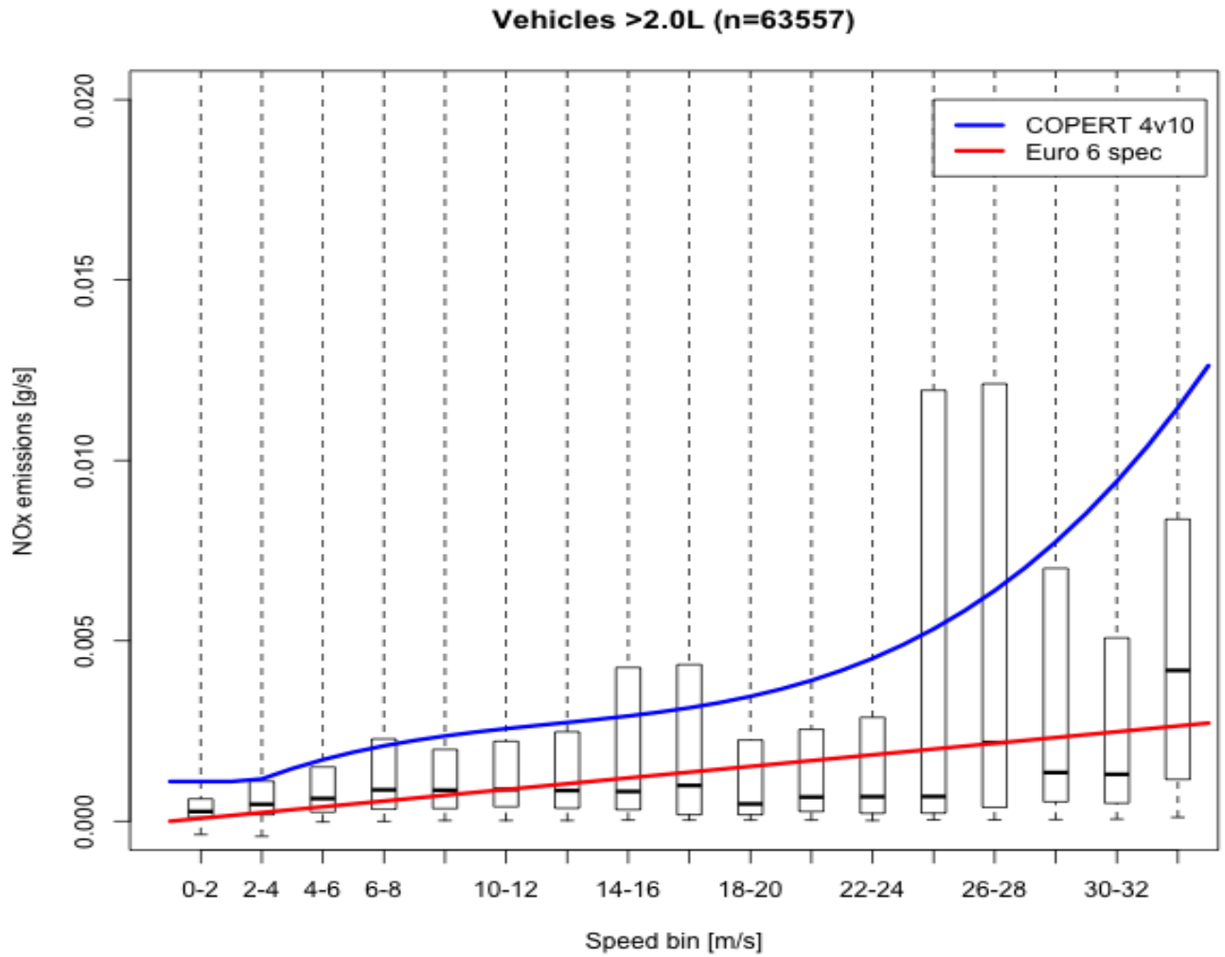
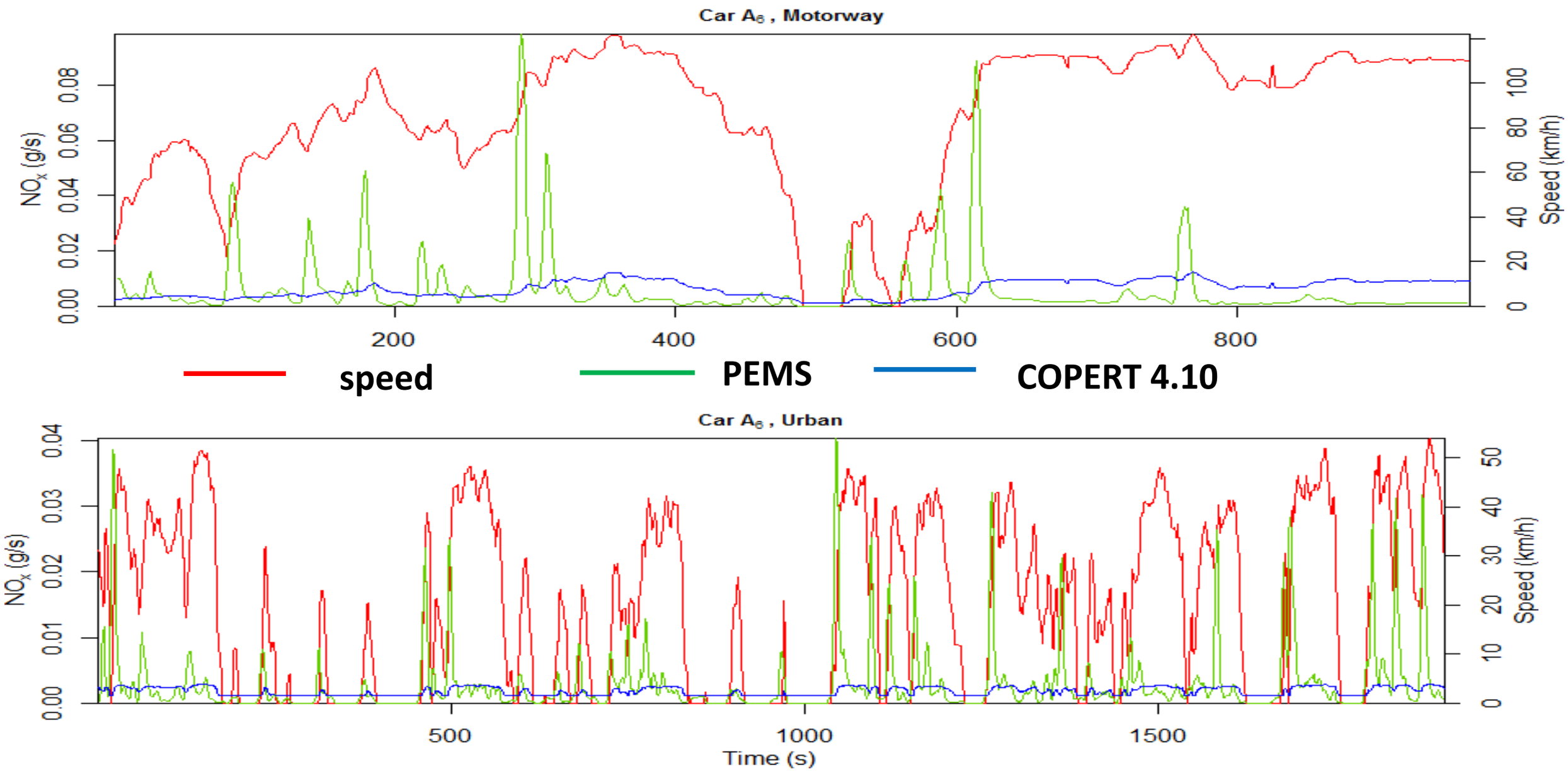
Real world v Euro 6 spec & COPERT 4v10





- Box and whisker plots show real world emissions from EA collected data (12 Euro 6 vehicles)
- Euro 6 emissions reduced compared to Euro 5
- Some deviation above Euro 6 COPERT v4.10 curve
- Small sample sizes, so conclusions limited so far



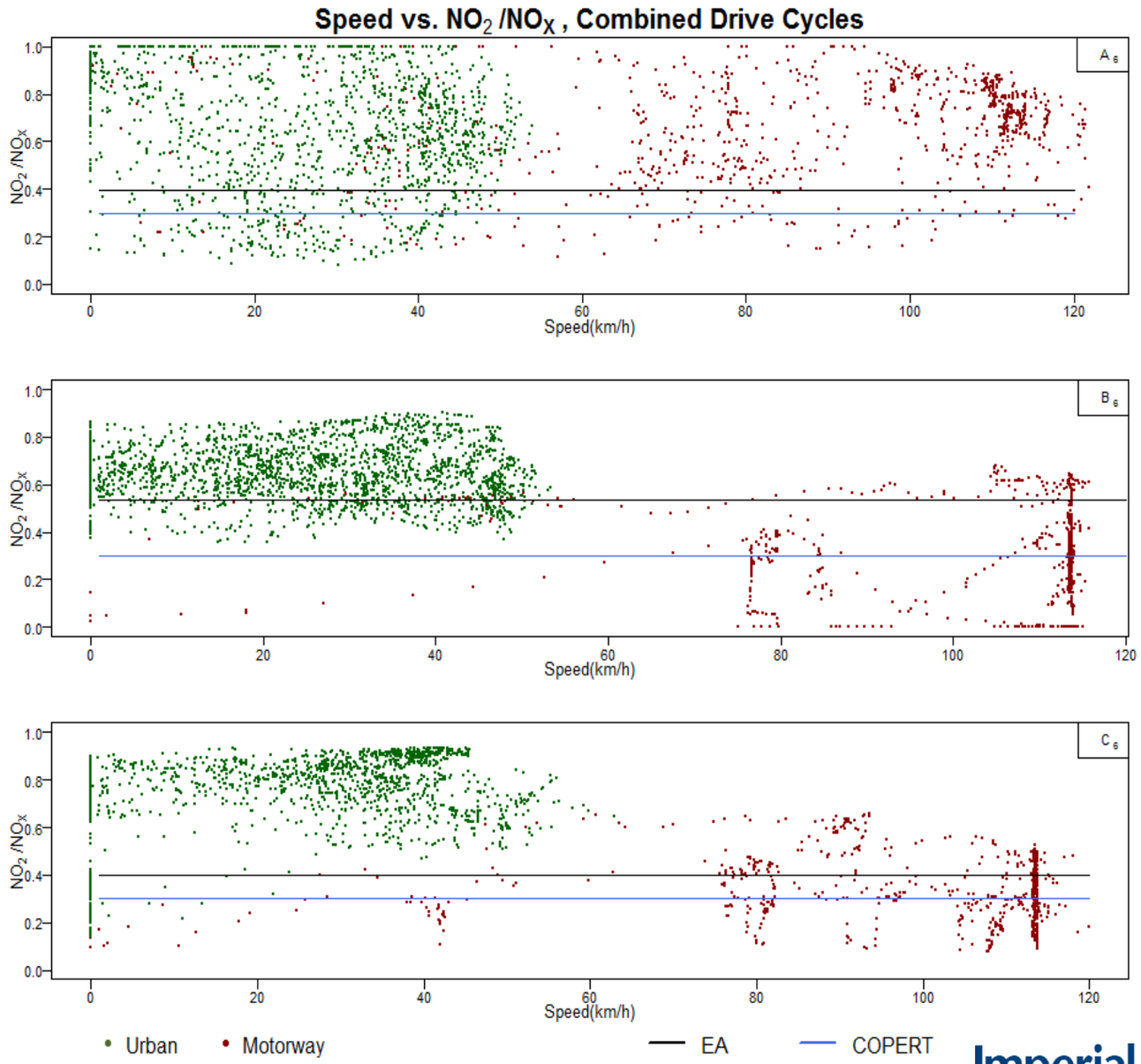
Temporal pattern: poor correlation with speed; coincidence of peaks with acceleration

-> comparison with more detailed model such as EnViVer

Fraction of NO_x emitted as NO_2

NO_2/NO_x ratio as a function of speed

- No consistent relationship is found between NO_2/NO_x ratio and speed
- COPERT consistently underestimates primary NO_2 emissions in urban areas where public exposure is greatest
- Implies very high % of primary NO_2 in urban areas
- COPERT v4.11 assumes a ratio of 0.3 for diesel passenger Euro 6 cars



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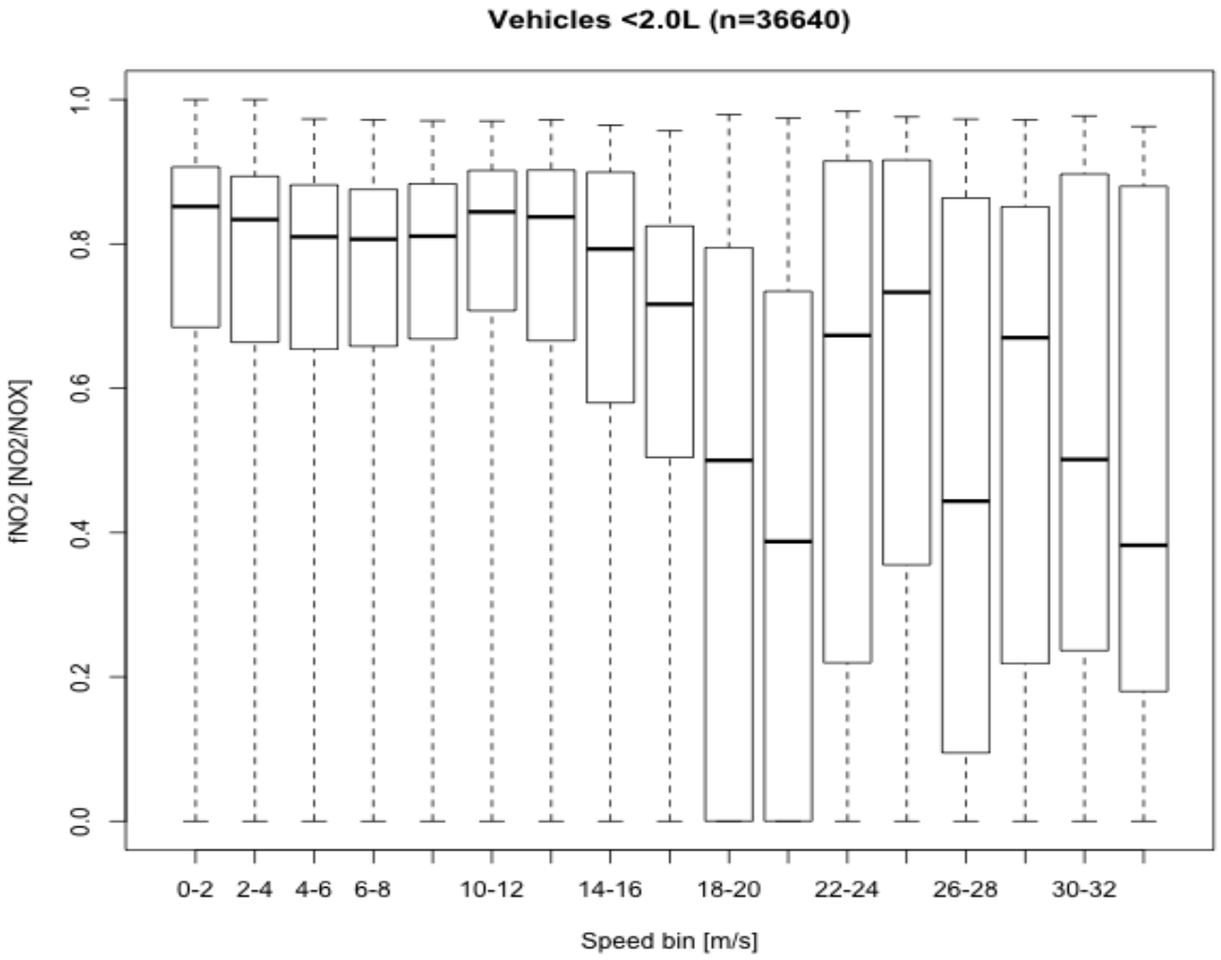
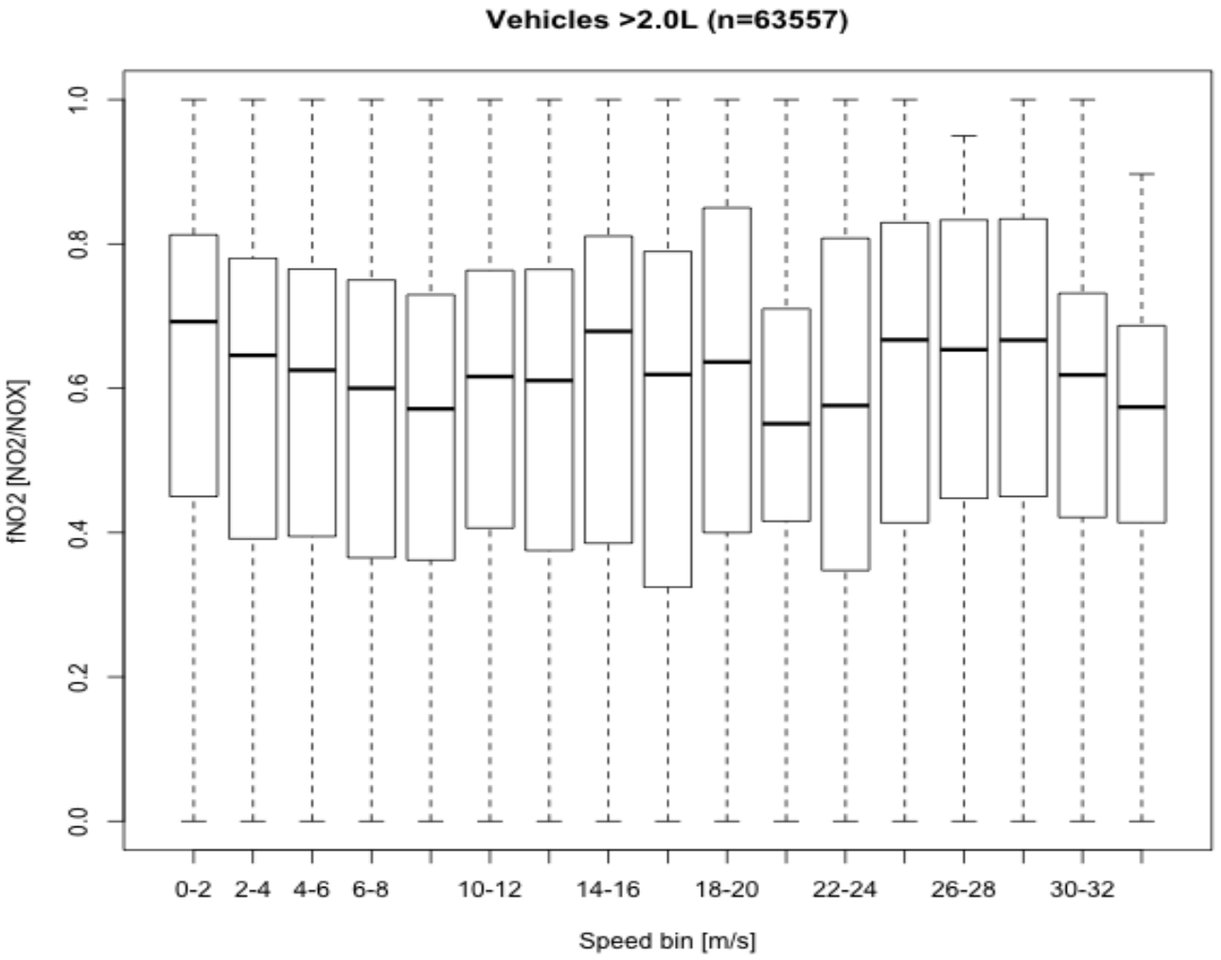
Euro 6 – fNO_2 emissions rates by speed bin





- Euro 6 fNO_2 generally higher than Euro 5
- Variability for smaller engines at higher speed bins – effect of loading?
- Small sample size… (12 vehicles)

SUMMARY

Summary and further development

1. PEMS gives temporal pattern of “real world” emissions and associated vehicle parameters to analyse variability
2. Peaks of emission coinciding more with acceleration and changes in engine power, and not correlated with speed
    - Implications for urban test cycles
3. COPERT reasonable for integrated emissions but speed dependence not reflected by PEMS data
    - Can repeat comparisons with COPERT v4.11
4. Future comparison with more detailed modelling of instantaneous engine emissions
    - Comparisons of PEMS with EnViVer model
5. Evidence of some very high fNO_2 ratios for Euro 6, especially in urban areas
6. More research needed with PEMS with more vehicles and taking account of control equipment used and how it is configured.

Data inventory

Engine size class (litres)	Powertrain				
	Diesel	Diesel hybrid	Petrol	Petrol hybrid	Total
0			7		7
1	120		147	6	273
2	154	4	41	3	202
3	37		13	4	54
4	2		7		9
5			3		3
Total	**313**	**4**	**218**	**13**	**548**
%	57%	1%	40%	2%	100%

	Gases measured		
	Ex-NOx	NOx	Total
Euro5	140	361	501
Euro6	21	26	47
Total	161	387	548
%	29%	71%	100%

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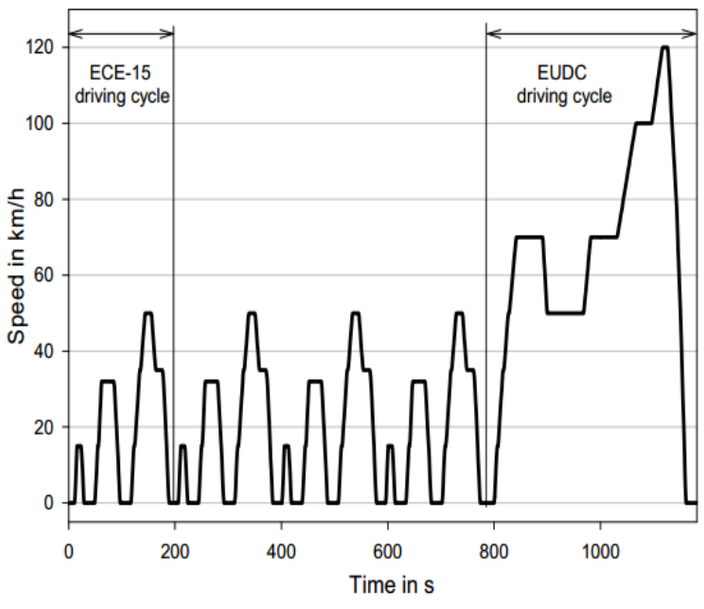
Many thanks to the Imperial College team.

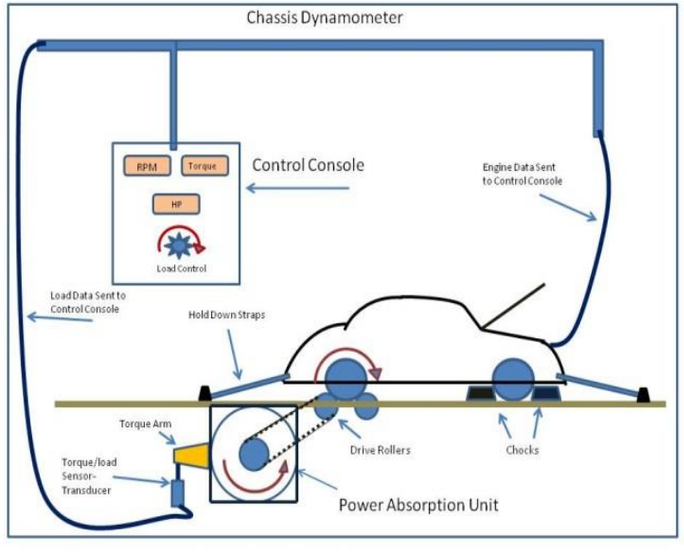
Current Euro Standards Test

- 4 urban driving cycles
- 1 “extra” urban driving cycles
- 11.007 km in 1180 s at an average speed of 34 km/h

- Chassis dynamometer (rolling road)
- Standardised + Repeatable



Speed profile of the New European Driving Cycle (NEDC)



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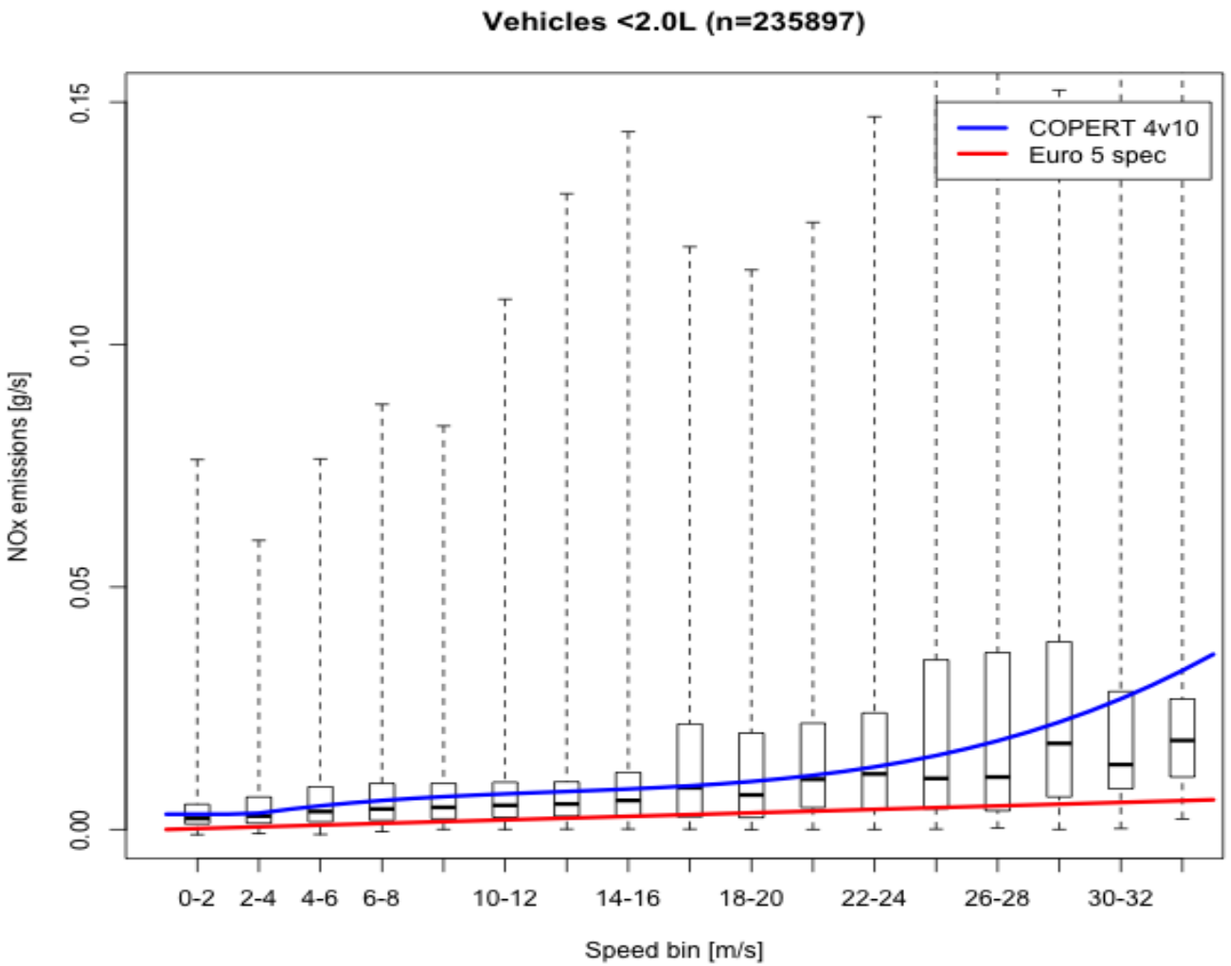
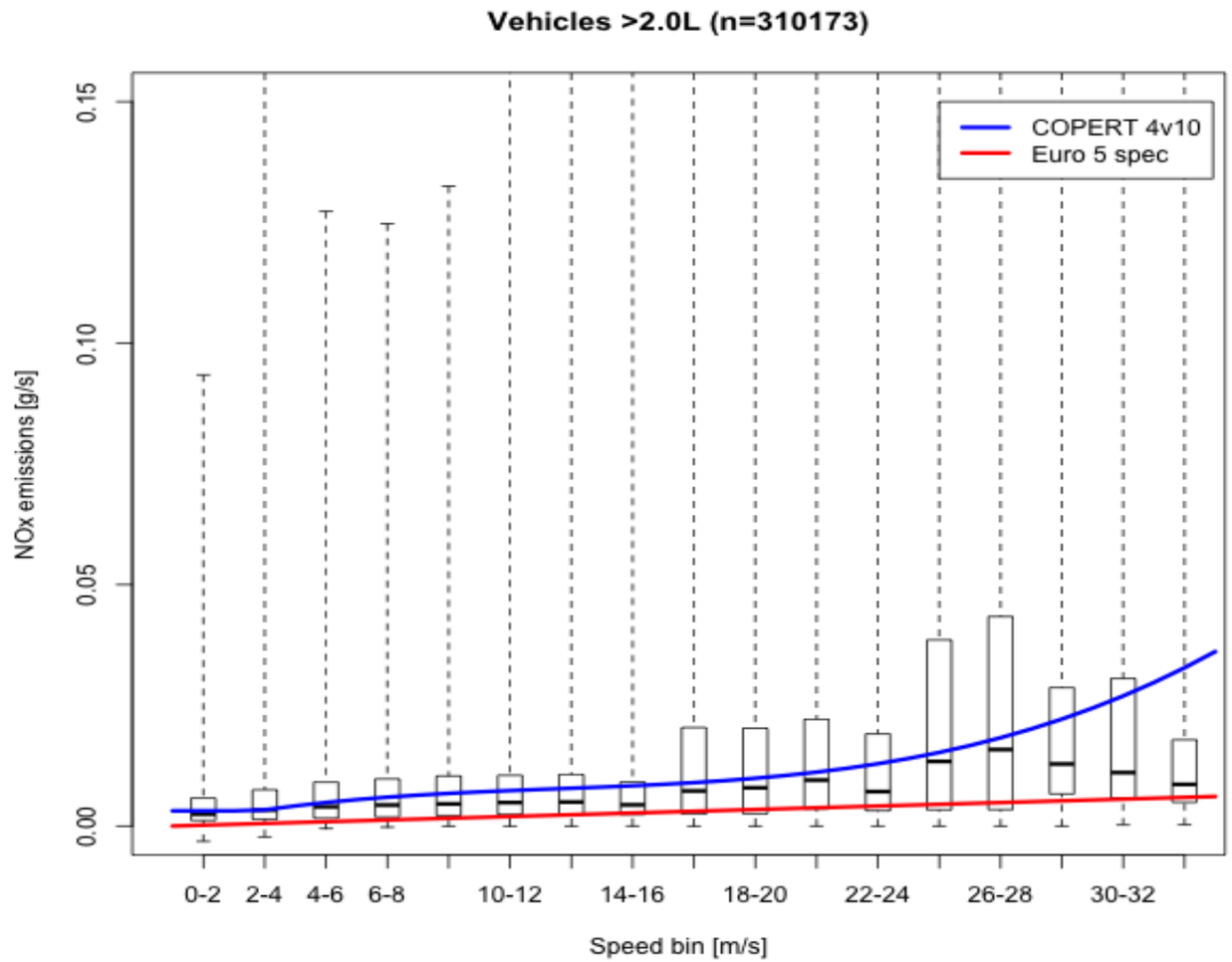
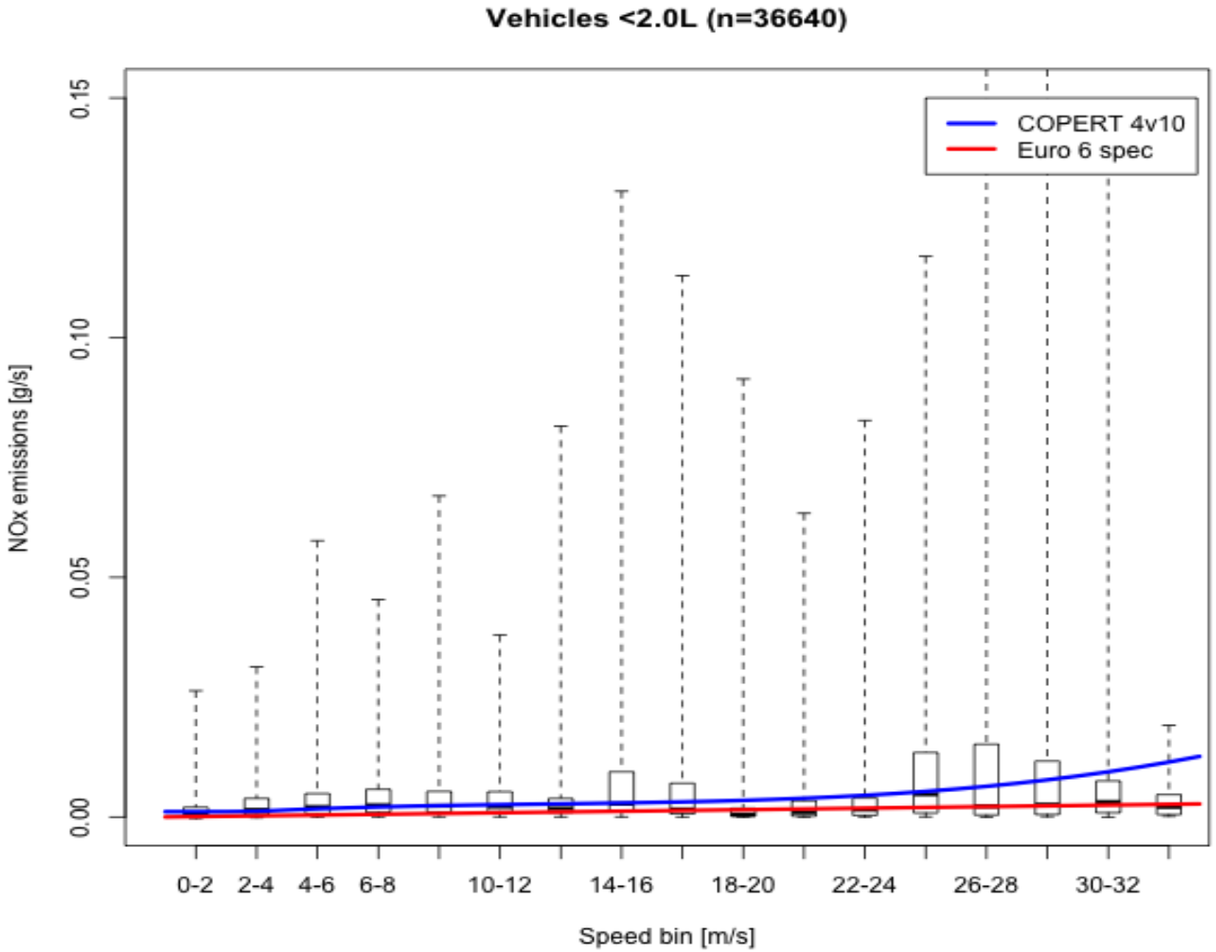
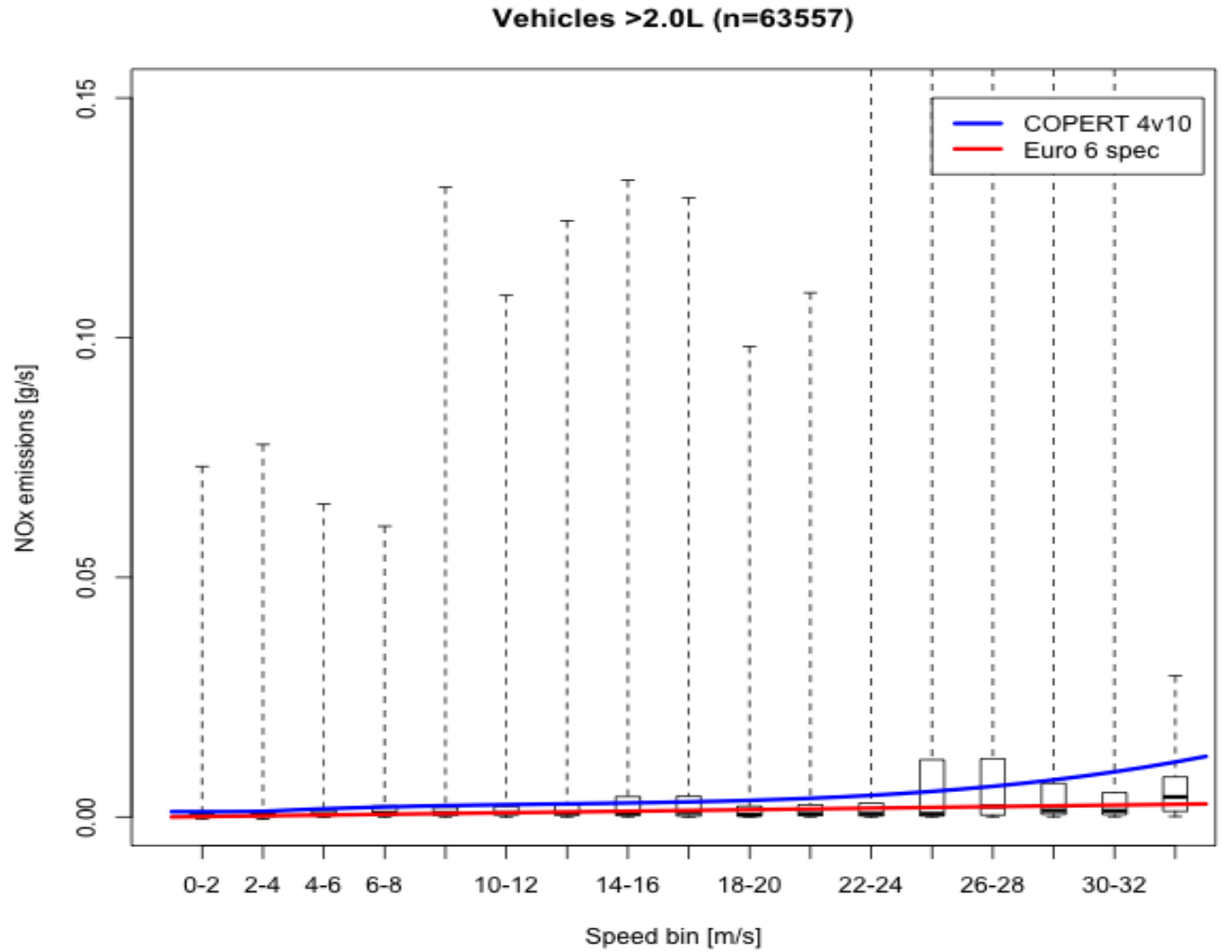




- Box and whisker plots show real world emissions from EA collected data (82 vehicles)
- For every speed bin, real world emissions greater than Euro 5 specification values
- COPERT 4v10 overestimates median NO_x emissions for every speed bin – difference is greater for higher speed bins (effects of 2013-14 PEMS data vs COPERT tests?)

Real world v Euro 6 spec & COPERT 4v10





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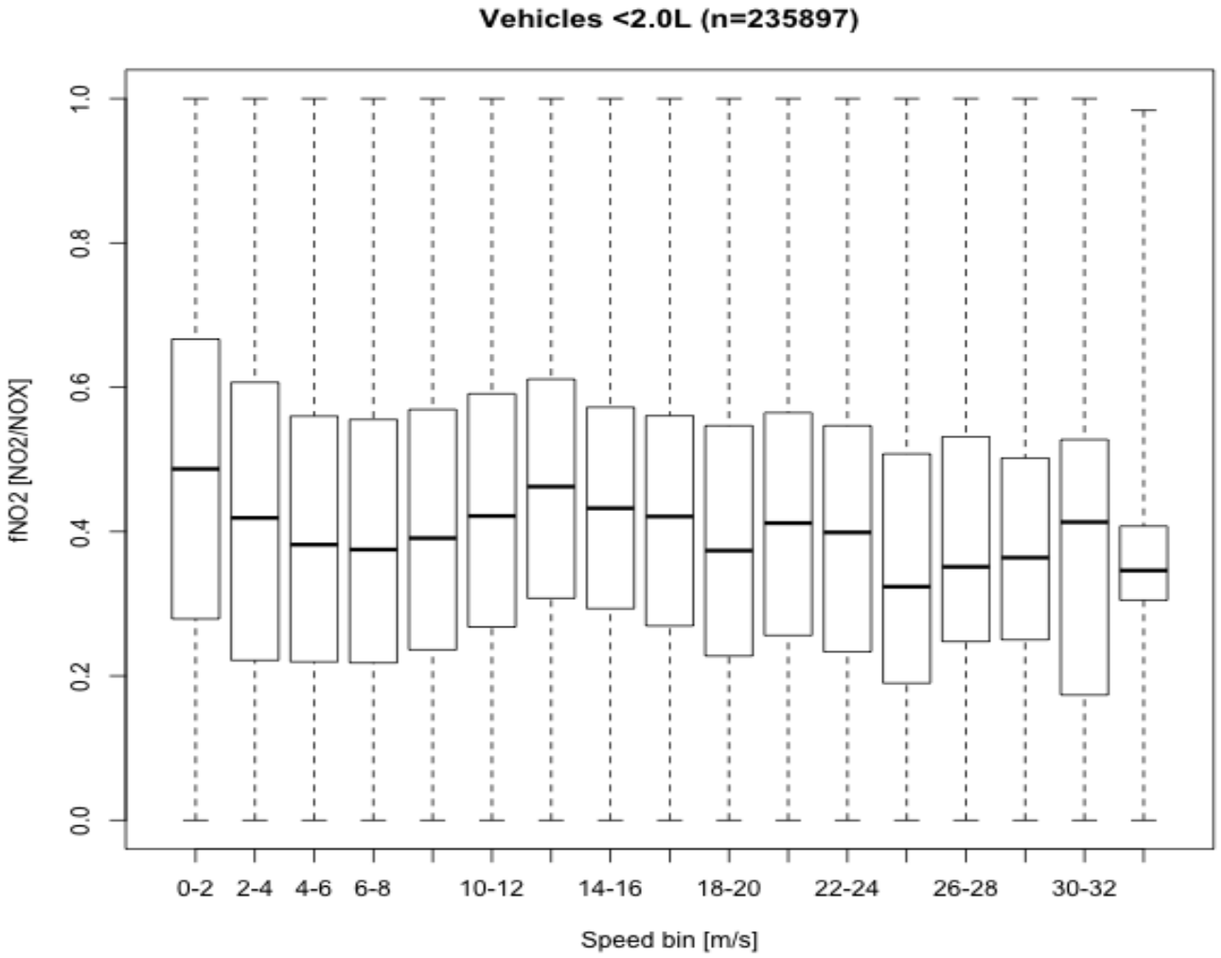
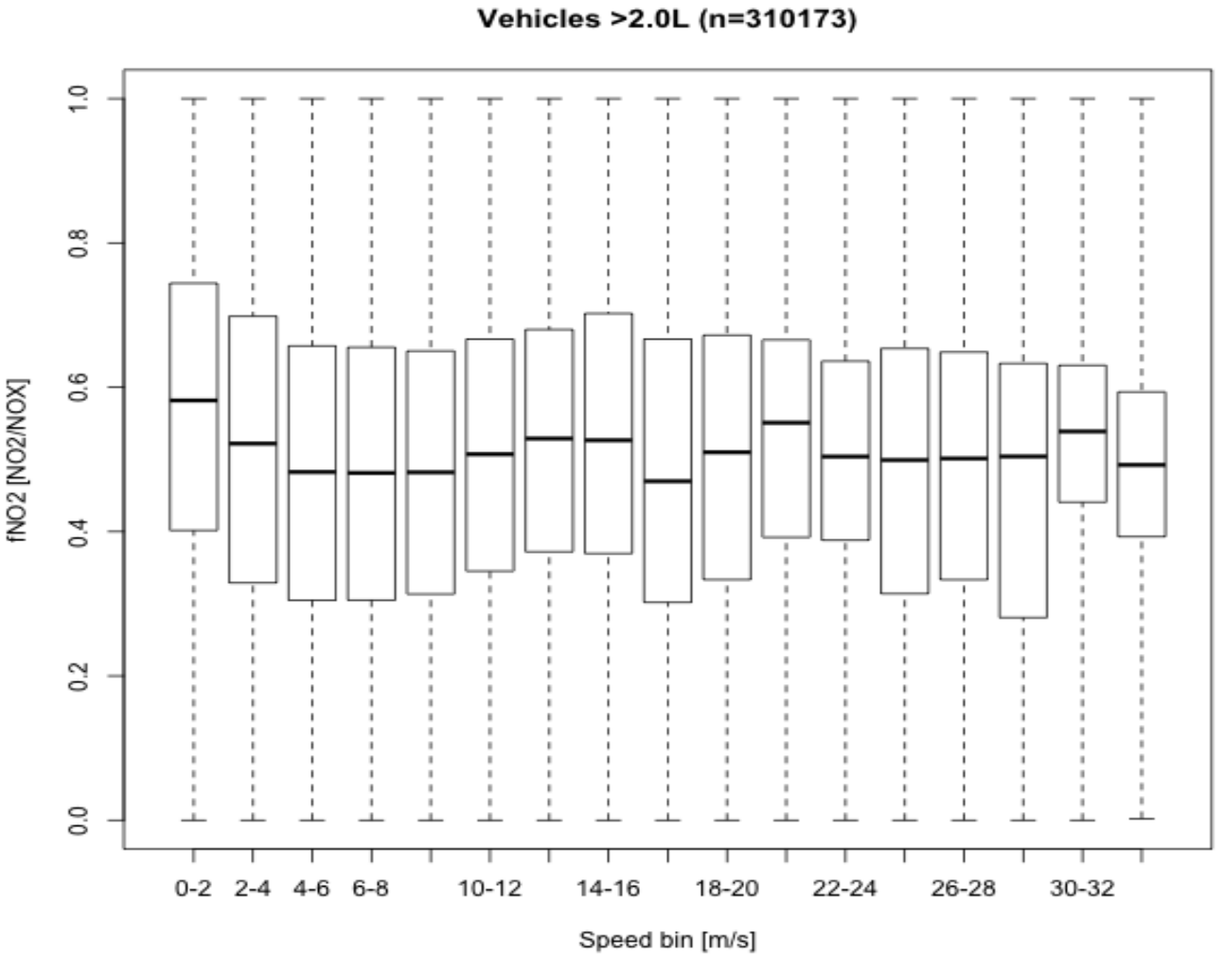
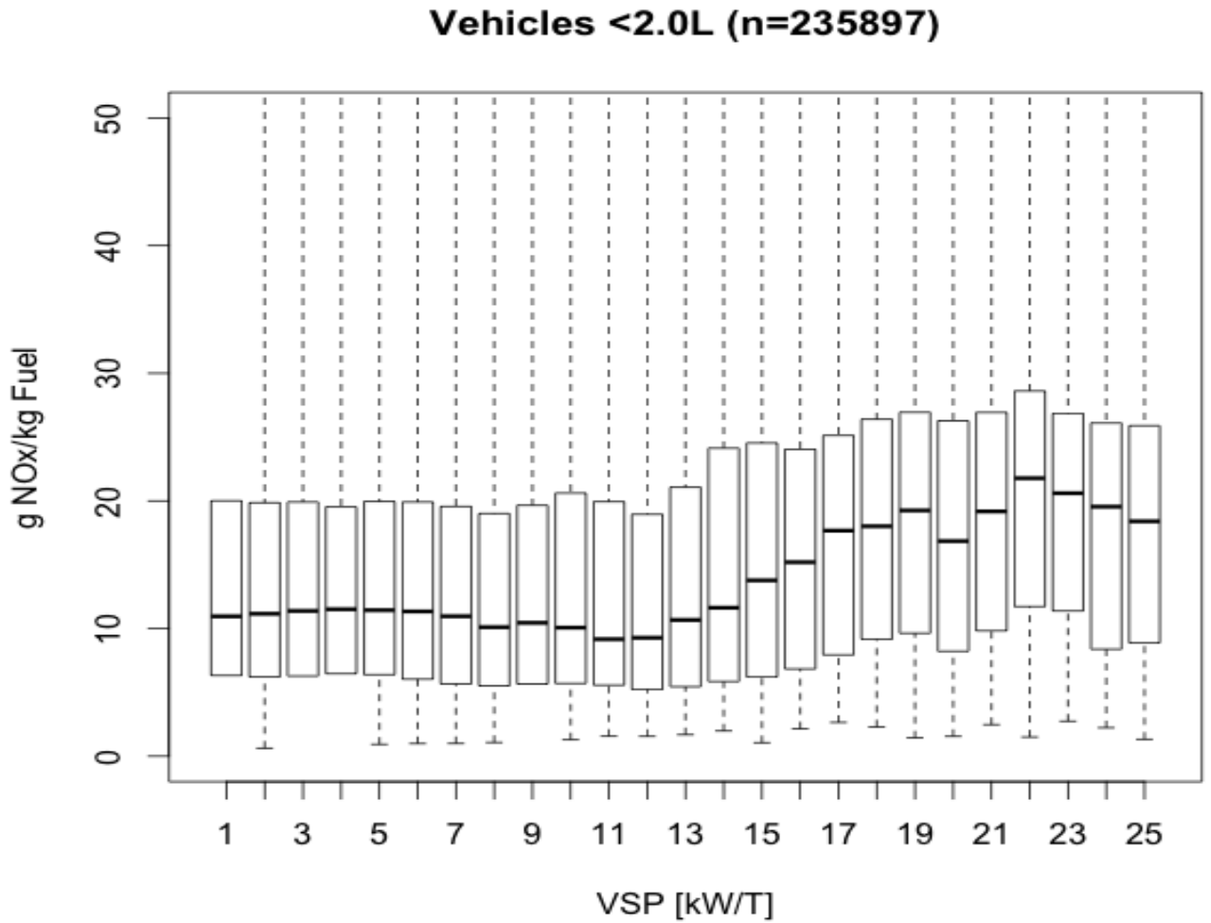
Euro 5 – fNO_2 emissions rates by speed bin

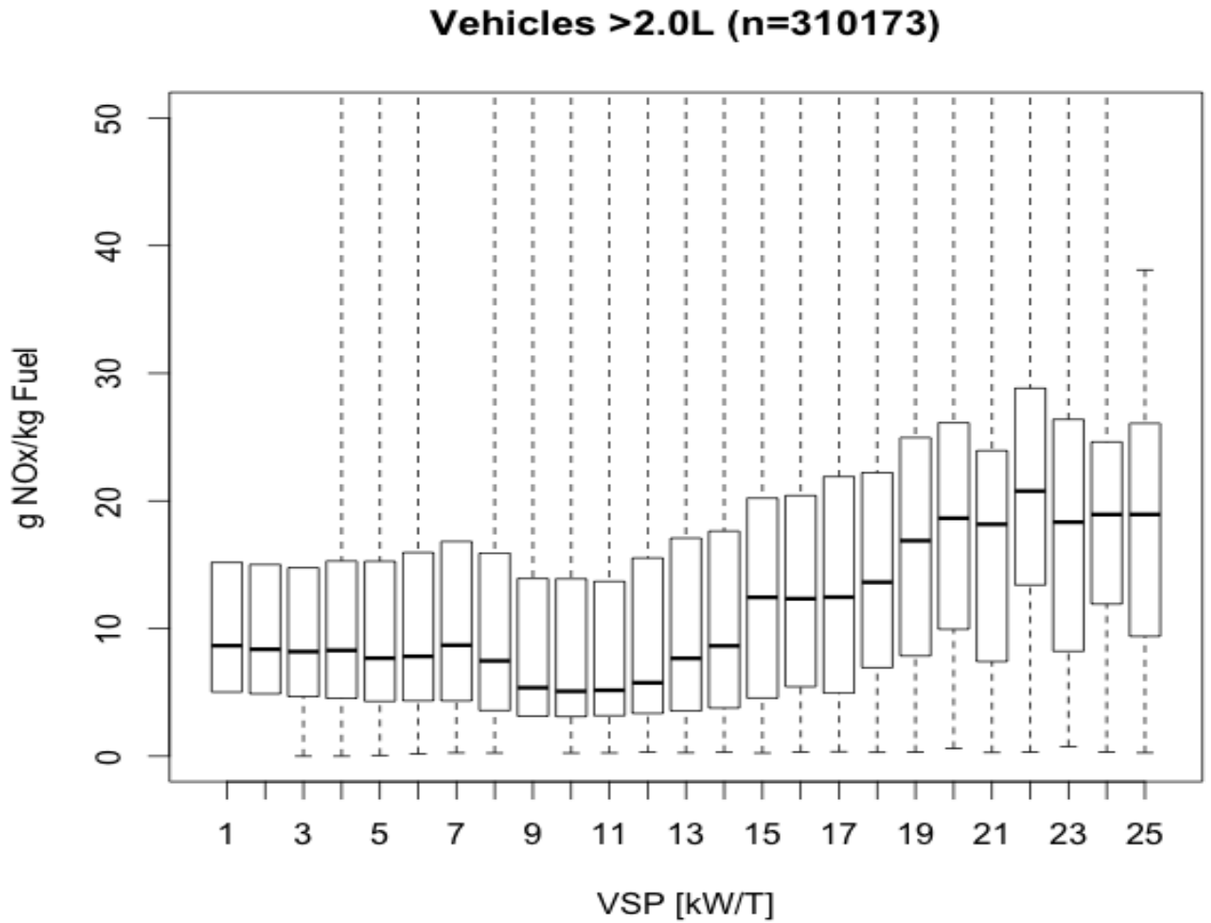




- Vehicles with a larger engine capacity have higher fNO_2 emission rates across all speed bins
- Consistent with other real world studies – e.g. Carslaw's remote sensing studying in London where larger engine capacity vehicles (>2l) had up to 60% higher NO_2 emissions

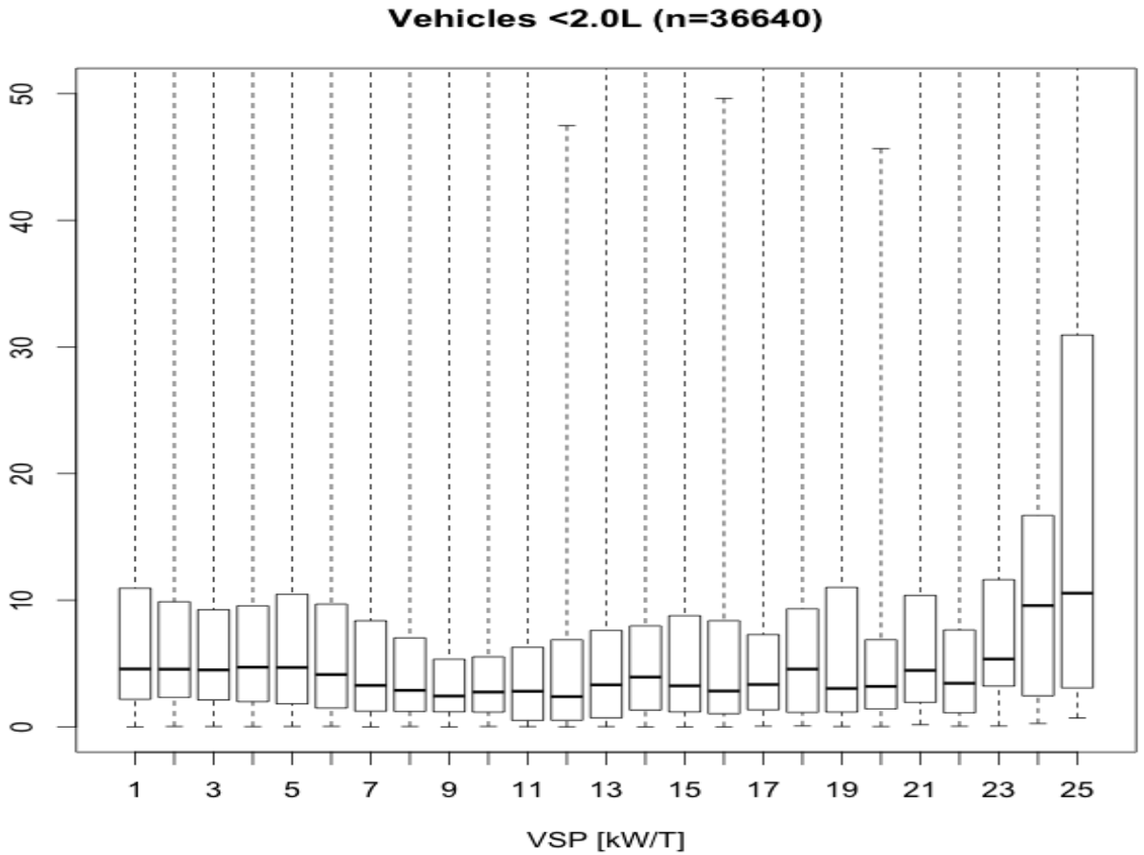
Euro 5 – Fuel-specific NO_x (positive VSP only)

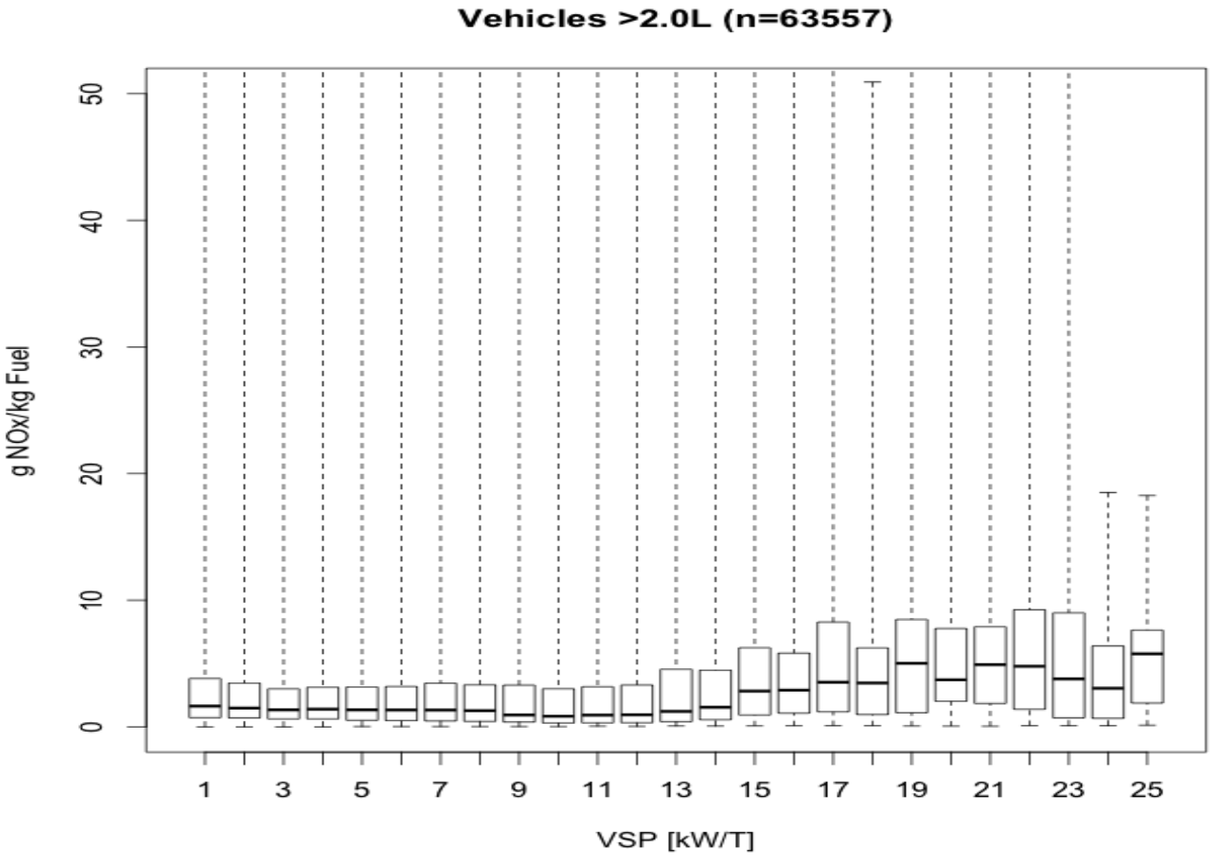




- CO_2 used as a proxy for fuel usage, VSP calculated from road gradient
- Generally slightly lower NO_x/kg-fuel for larger engines (for 2013MY and 2014MY)
- Flat ratio at low VSP, increasing above ~12 kW/t (<2.0l) and ~14kW/t (>2.0l)

Euro 6 – Fuel-specific NO_x (positive VSP only)





- CO_2 used as a proxy for fuel usage, VSP calculated from road gradient
- Fuel-specific NO_x reduced for Euro 6 and potentially lower for larger-engine vehicles