

Recent Evidence and Future Prospects Relating to NO_x and NO₂ Emissions from Road Vehicles

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Towards the 2013 Revision of the Ambient Air Quality Directive —
Issues and Solutions, 12–13 December 2011

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Outline

- 1 Trends in ambient measurements of NO_x and NO₂
- 2 Vehicle emissions of NO_x and NO₂
- 3 Concluding remarks

Lancet article from 1965

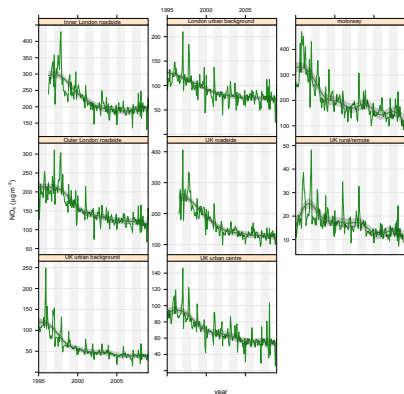
Animosity towards diesel fumes was general and lively. Many felt that the existing regulations should be properly enforced and made, as soon as practicable, more stringent.^a

^aLancet, July 1965, reporting on an air pollution meeting in Leeds, UK.

1 Trends in ambient measurements of NO_x and NO₂

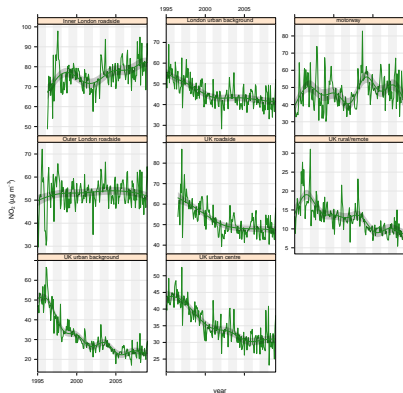
- How have NO_x and NO₂ concentrations changed in the UK over the past decade or so?
 - How do these trends compare with Europe?
 - Estimated trends in primary NO₂ emissions — derived from ambient measurements
- ⇒ What conclusions can be drawn from this information?

NO_x trends across the UK



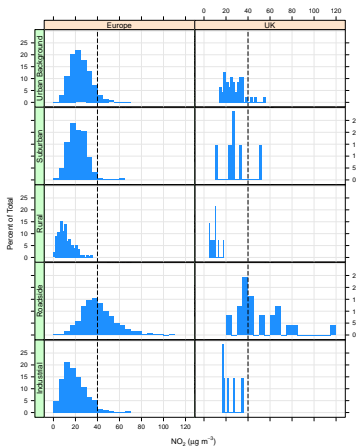
- Similar patterns observed at most site types — levelling off of NO_x concentrations
- Reduction in concentration from late 1990s; weakly decreasing since 2002/4–2010
- Median changes 2002–2009:
 - –0.6 %/year in inner London
 - –1.7 %/year in outer London
 - –1.4 %/year in rest of UK

NO₂ trends across the UK



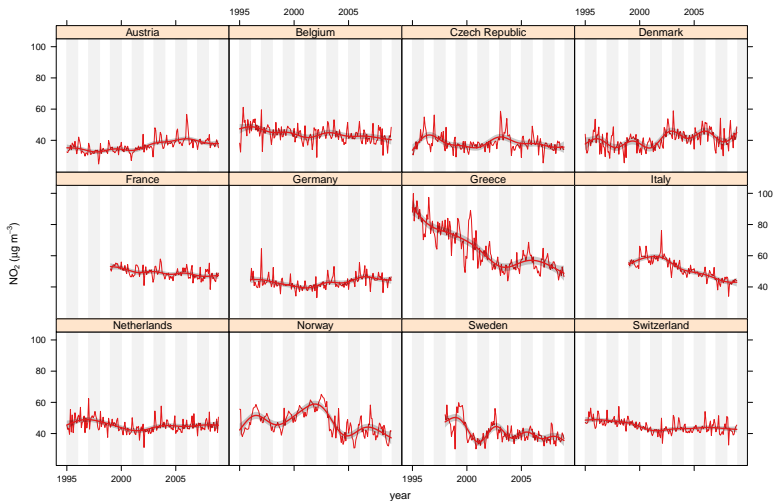
- NO₂ concentrations have increased at some sites
- Median changes 2002–2009:
 - –0.5 %/year in inner London
 - –0.8 %/year in outer London
 - –0.6 %/year in rest of UK

How does the UK compare with the rest of Europe?

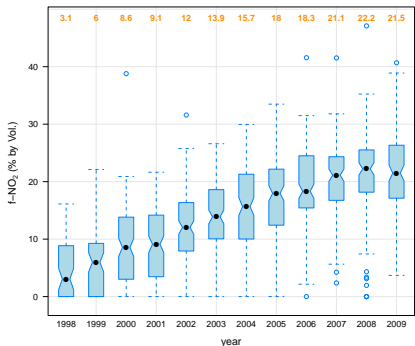


- Analysis of hourly data from 2,728 sites in Europe from *Airbase*
- Similar proportion of sites in 2008 exceed annual mean LV of 40 µg m⁻³
- Also evidence of stabilising concentrations of NO₂ for most countries

NO_x and NO₂ Emissions from Road Vehicles



Primary NO₂ trends — London

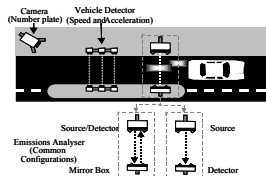


- The ratio of NO₂:NO_x has clearly increased over the past decade
 - Values today in London are around 20–25% by vol.
- ⇒ Higher in London than the rest of the UK — on average

2 Vehicle emissions of NO_x and NO₂

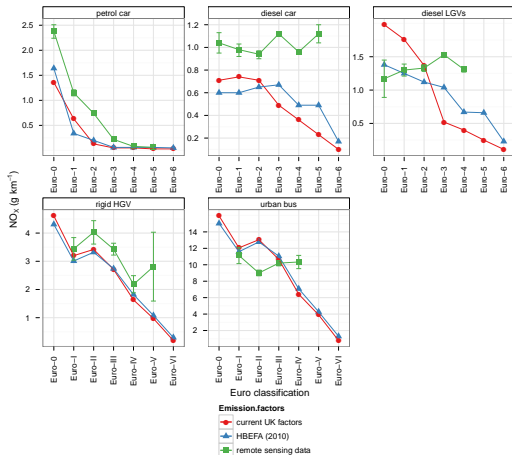
- Recent evidence from vehicle emission remote sensing
- Modelling vehicle emissions using quantile regression
- Findings and implications

Vehicle emissions remote sensing



- Remote sensing
 - Infrared/UV beam across road using ESP Remote Sensing Detector (RSD-4600)
 - Individual vehicle exhausts measured
 - Measures ratios of NO, CO, HC, “smoke” to CO₂ i.e. fuel-based emission factors
 - Some practical limitations
- Several campaigns from 2008–2010 in 5 urban areas
 - About 84,000 vehicles sampled
 - Number plates matched by CarWeb (<http://www.carwebuk.co.uk/>)

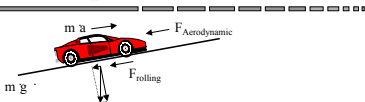
Derived vehicle emission factors for NO_x (g km⁻¹)



- Some important differences between the different emission factors
- Reveals important areas of disagreement

Vehicle specific power as an emissions metric¹

Vehicle Specific Power (VSP)



$$VSP = \frac{\text{Power}}{\text{Mass}} = \frac{\frac{d}{dt}(E_{\text{Kinetic}} + E_{\text{Potential}}) + F_{\text{Rolling}} \cdot v + F_{\text{Aerodynamic}} \cdot v + F_{\text{internal friction}} \cdot v}{m} =$$

$$\approx v \cdot a \cdot (1 + \epsilon_1) + g \cdot \text{grade} \cdot v + g \cdot C_R \cdot v + \frac{1}{2} \rho_a C_D \frac{A}{m} (v + v_w)^2 \cdot v + C_{if} \cdot v$$

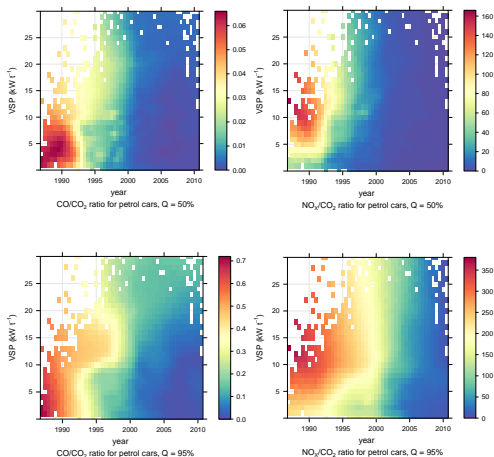
- Relates to actual forces a vehicle must overcome
- Vehicle speed alone is not a good indicator of emissions
- VSP is the basis of the US-EPA emissions calculations for vehicles

¹Jiménez, J., McClintock, P., McRae, G., Nelson, D., Zahniser, M., 1999. Vehicle Specific Power: A Useful Parameter for Remote Sensing and Emission Studies . 9th CRC On-Road Vehicle Emissions Workshop San Diego, April 21st 1999

Modelling the remote sensing data using quantile regression

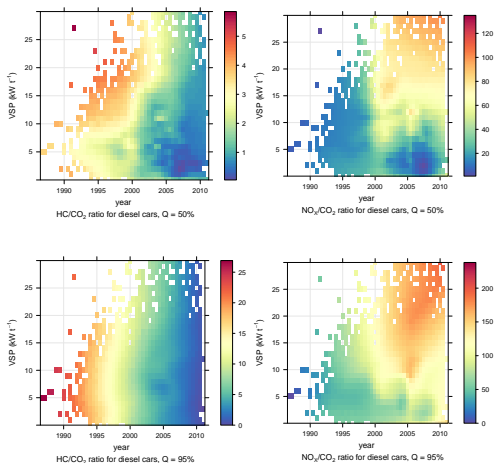
- More insight can be gained if statistical models are developed to explain emissions in terms of different variables
 - Quantile regression is analogous to ordinary linear regression but considers the full distribution rather than only the mean
 - Very useful in situations where there is interest in the extremes of behaviour
- ⇒ what controls the higher emissions from vehicles?

Effect of VSP on emissions from petrol cars



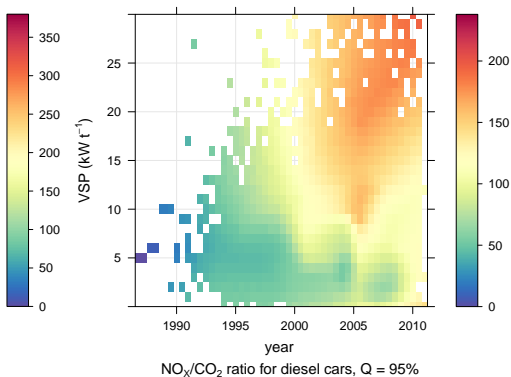
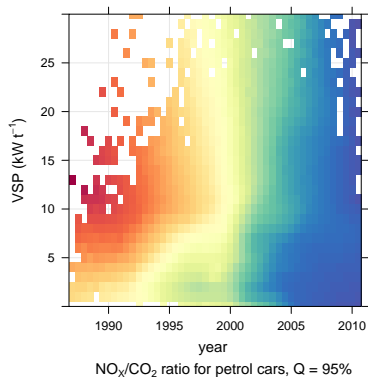
- Clear effect of catalyst introduction in 1993 for CO and both the median quantile and 95th quantile
- For higher quantiles of emissions NO_x remains important for Euro 1/2 catalyst vehicles

Effect of VSP on emissions from diesel cars

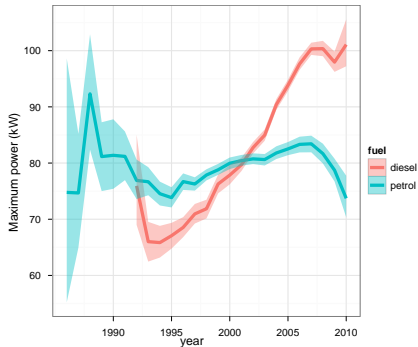


- Hydrocarbon emissions effectively controlled by 2000 (Euro 3)
- Clear increase in NO_x for median and 95th quantile emissions **from Euro 3 onwards — including Euro 5**

Putting it together — petrol and diesel passenger car NO_x



Vehicle power trends for passenger cars



- Petrol car power has been relatively stable over the last 20 years
 - Indication of decrease in last few years
 - Diesel car power has inexorably increased over the same period
- ⇒ Effect on NO_x?

Implications of these findings

- Higher engine loads have a strong effect on emissions of NO_x from modern diesel and older catalyst-equipped petrol vehicles — not seen for other pollutants
 - Driving style, engine power etc. might have a stronger influence NO_x emissions than before
 - A single drive cycle may not capture these effects very well
- ⇒ what is the contribution to explaining recent ambient trends in NO_x and NO₂?

3 Concluding remarks

- Trends in NO_x and NO₂ have levelled off in the past 6–8 years
 - UK inventories are in clear disagreement with ambient trends
 - Ambient trends in NO₂ in much of the rest of Europe looks similar
- Vehicle emission remote sensing data is extremely valuable
 - Can re-calculate NO_x emissions and compare with inventories
 - Light duty vehicle emissions seem to account for most of the disagreement
 - Increased power of diesel cars over past 20 years is important

- Future trends in NO₂
 - Turn over in vehicle stock will be important e.g. number of older petrol cars on the road
 - The emissions performance of Euro 6/VI is of critical importance and evidence of 'real-world' performance is key
- Vehicle emission remote sensing surveys in London, May/June 2012
 - Hiring equipment from the University of Denver
 - Defra-funded

- Further information:
 - **Defra report:** http://uk-air.defra.gov.uk/library/reports?report_id=673
 - **Paper:** Carslaw, D.C., Beevers, S.D., Tate, J.E., Westmoreland, E. and M.L. Williams, 2011. Recent evidence concerning higher NO_x emissions from passenger cars and light duty vehicles. *Atmospheric Environment* 45 (2011) 7053-7063.

Acknowledgements

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Thank you for your attention!!

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