Standards, Emissions and Concentrations

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Workshop on current issues regarding nitrogen dioxide
2–3 March 2011

KING'S College LONDON

Outline

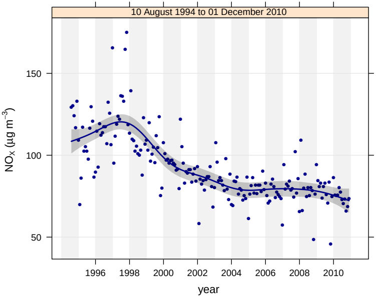
1. Trends in ambient measurements of NO_x and NO_2
2. Vehicle emissions of NO_x and NO_2
3. Concluding remarks

1 Trends in ambient measurements of NO_x and NO_2

- How have NO_x and NO_2 concentrations changed in the UK over the past decade or so?
- How do these trends compare with Europe?
- Estimated trends in primary NO_2 emissions — derived from ambient measurements

$\Rightarrow$ What conclusions can be drawn from this information?

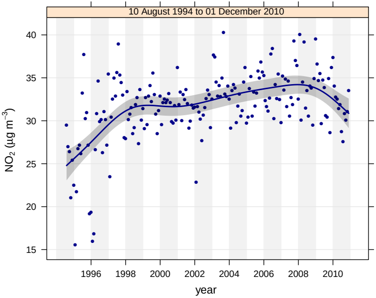
NO_x trends in London



- Typical of pattern seen elsewhere in the UK[a]
- 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

[a] Mean of 23 long-term roadside sites.

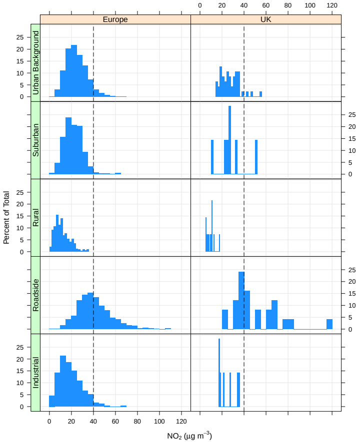
NO_2 trends in London



- NO_2 concentrations have increased at many sites[a]
- Median changes 2002–2009:
  - −0.5 %/year in inner London
  - −0.8 %/year in outer London
  - −0.6 %/year in rest of UK

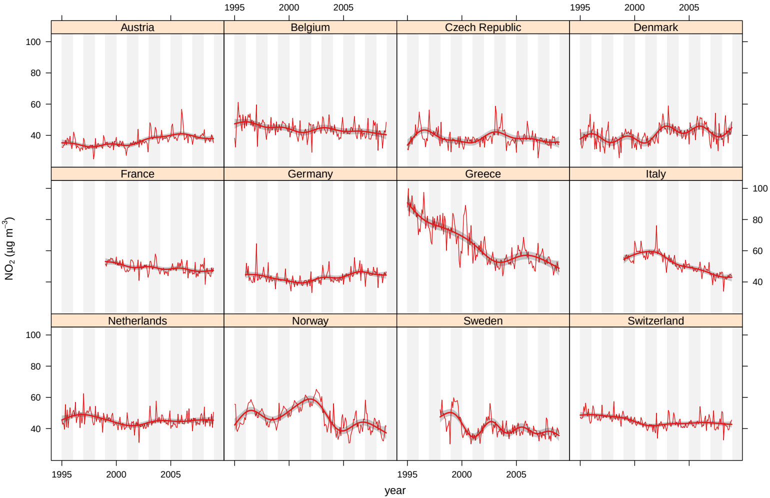
[a] Mean of 23 long-term roadside sites.

How does the UK compare with the rest of Europe?

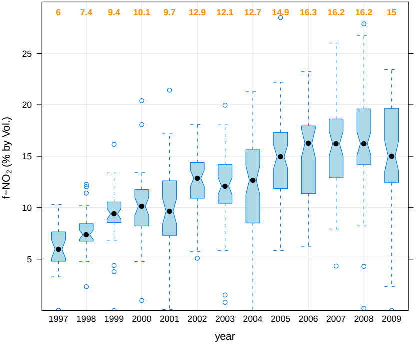


- Analysis of hourly data from 2,728 sites in Europe from *Airbase*
- Similar proportion of sites in 2008 exceed annual mean LV of 40 µg m^{-3}
- Also evidence of stabilising concentrations of NO_2 for most countries

Standards, Emissions and Concentrations



Primary NO_2 trends — UK

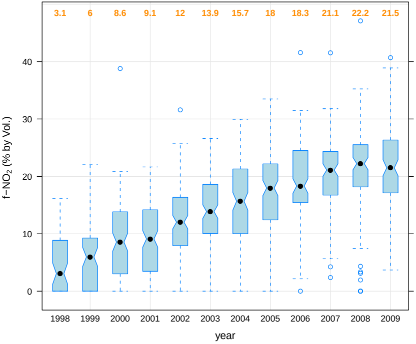


- The ratio of NO_2:NO_x has clearly increased over the past decade[a]
- Values today in the UK are around 15–17% by vol.

$\Rightarrow$ Maybe some evidence that this ratio is stabilising?

[a] see Carslaw (2005) for more details.

Primary NO_2 trends — London



- The ratio of NO_2:NO_x has clearly increased over the past decade
- Values today in the UK are around 20–25% by vol.

$\Rightarrow$ Higher in London than the rest of the UK — on average

Bit of an aside: NO_2 at an extreme location

Modelled primary NO_2 scenarios

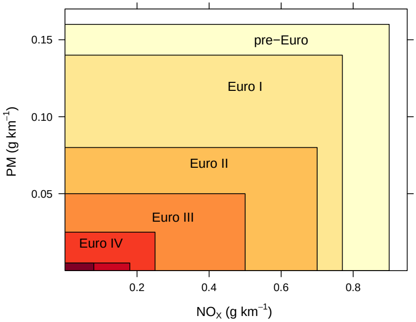
primary NO_2 (% by vol.)	annual mean ($\mu g\ m^{-3}$)	hours > 200 $\mu g\ m^{-3}$
5	84	2
10	106	99
15	128	709
20	151	1563
25	173	2423
30	195	3086
35	**217**	**3559**

- Highest NO_2 concentrations in Europe/World? Highest NO_2 concentrations of any time over the last few centuries?
- In 2008 the annual mean NO_2 was **217** $\mu g\ m^{-3}$ and there were **4015** exceedences of the hourly limit value ...
- In-car exposure and similar environments?

2 Vehicle emissions of NO_x and NO_2

- What we expected to happen
- Recent evidence from vehicle emission remote sensing
- Links with emissions inventories and ambient measurements

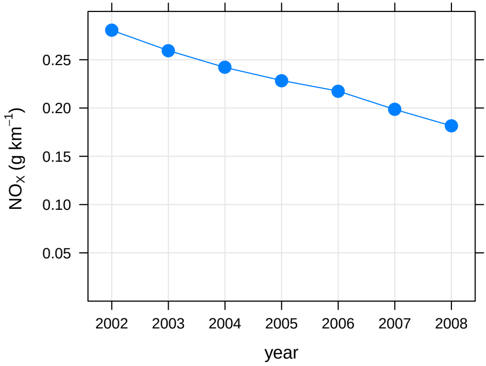
Vehicle emissions legislation in Europe



- Approximate limits of NO_x and PM — for diesel cars
- $\approx$ order of magnitude reduction in NO_x g km^{-1} emissions since early 1990s

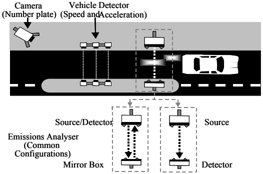
$\Rightarrow$ Expect considerable effect on ambient concentrations of NO_x and NO_2

Emission inventory projections of NO_x



- For UK urban areas expect a 5–6% reduction in NO_x per year
- Comparable ambient measurement sites suggest $\approx$1–2% per year

Vehicle emissions remote sensing

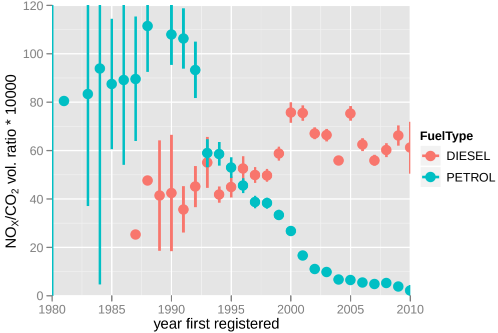


- Remote sensing
  - Infrared/UV beam across road using ESP Remote Sensing Detector (RSD-4600)
  - Individual vehicle exhausts measured
  - Measures ratios of NO, CO, HC, "smoke" to CO_2 i.e fuel-based emission factors
  - Some practical limitations
- Several campaigns from 2008–2010 in 5 urban areas
  - About 72,000 vehicles sampled
  - Number plates matched by CarweB (http://www.carwebuk.co.uk/)

Typical NO_2:NO_x emission ratios

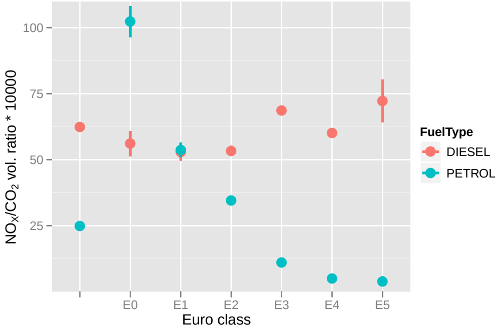
Vehicle class	Euro class	% NO_2 (by volume) Grice et al. (2009)	% NO_2 (by volume) Jerksjö et al. (2008)
Petrol cars			
	All	3	≈1 [12551]
Diesel cars and LGVs			
	Euro 2 and earlier	11	14–20 [177]
	Euro 3	30	30–47 [538]
	Euro 4–6	55	55–60 [881]
HGVs			
	Euro II and earlier	11	7 [218]
	Euro III	14	9 [353]
	Euro IV–VI	10	13 [52]
Buses			
	Euro II and earlier	11	10 [78]
	Euro III (no trap)	14	30 [93]
	Euro III (trap)	35	25–52 [45]
	Euro IV–VI	10	48

Petrol and diesel car emissions of NO_x by year



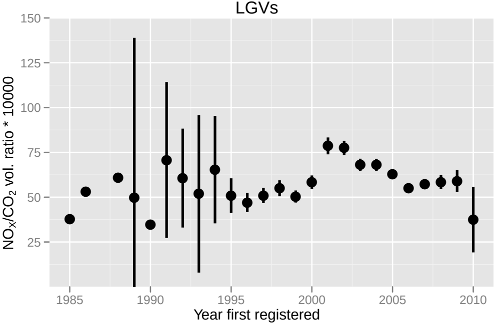
- NO_x emissions from petrol cars have decreased by ≈96% since the early 1990s
- Diesel car emissions have increased, or at best been stable for the past 25 years or so
- Possible to see the effects of different Euro class legislation

Petrol and diesel car emissions of NO_x by Euro class



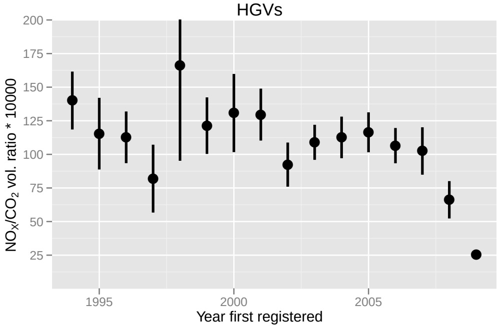
- Effectiveness of the progressive improvement of petrol catalysts is apparent
- Highlights the relative stability of diesel car NO_x emissions

Diesel LGV emissions of NO_x by year



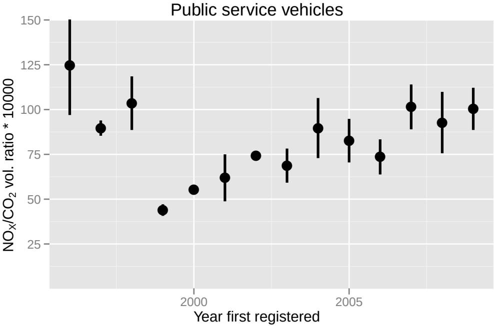
- Similar to diesel cars
- Little evidence of any reduction in NO_x emissions

HGV emissions of NO_x by year



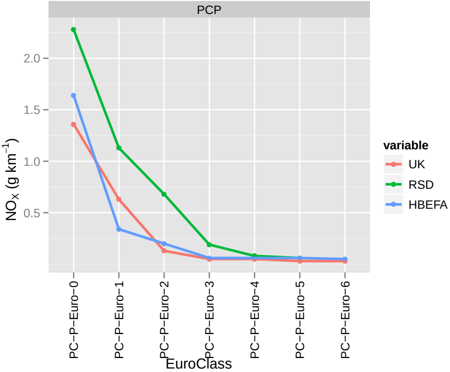
- Evidence that introduction of Euro IV led to a NO_x reduction of about one third cf. Euro III

Bus emissions of NO$_x$ by year



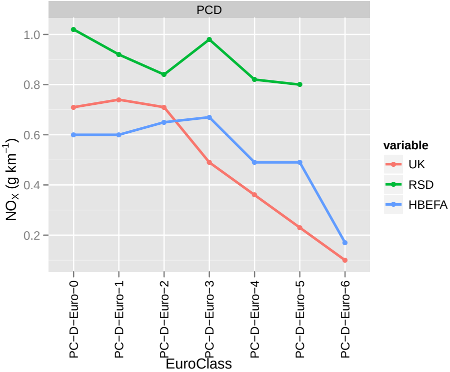
- Emissions, if anything, have increased, but —
- Need to be careful about specific bus fleets

Effect of different emission factor assumptions for petrol cars



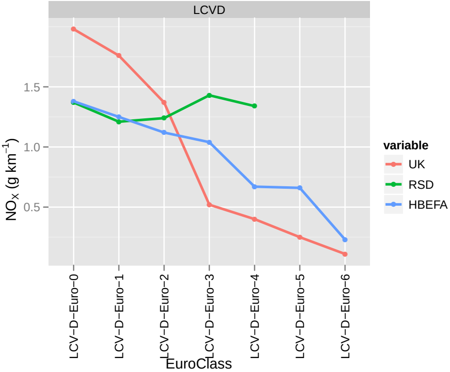
- Current UK emission factors show rapid and considerable reduction in NO_x emissions through the Euro classes
- Remote sensing data suggest that old (Euro 1/2/3) cars emit more NO_x than previously thought — emissions system degradation

Effect of different emission factor assumptions for diesel cars



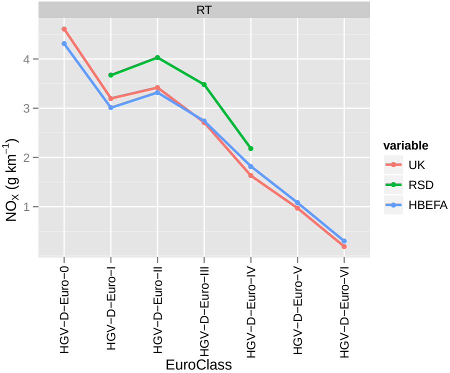
- Current UK emission factors show considerable reduction in NO_x emissions from Euro onwards
- Remote sensing data suggest NO_x emissions have been relatively stable from pre-Euro to Euro 5
- Euro 6 estimates should be considered speculative
- Also note increased *absolute* emissions of NO_x according to remote sensing data

Effect of different emission factor assumptions for diesel LGVs



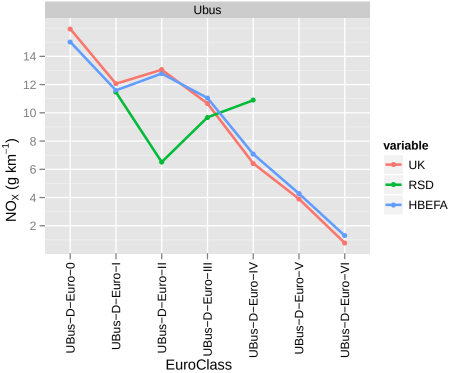
- Similar findings to diesel cars

Effect of different emission factor assumptions for HGVs



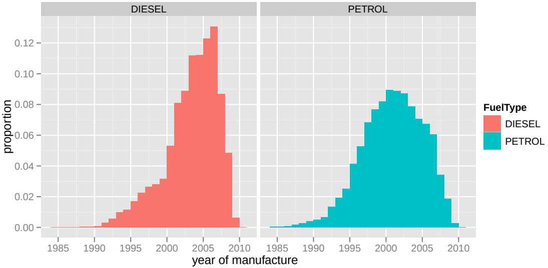
- Generally good agreement in both magnitude and trend in NO_x emissions

Effect of different emission factor assumptions for buses



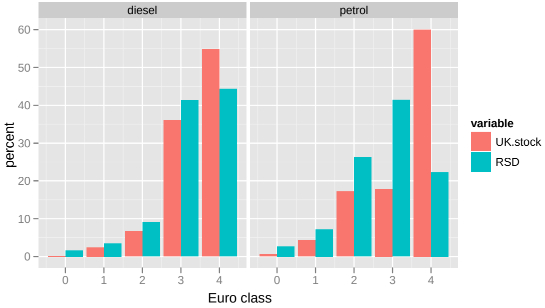
- Care needed because of specific bus fleets
- Dip for Euro II can be explained (London buses with catalytic particle filters)
- Euro IV somewhat higher for remote sensing data

Have we got the fleet right for inventories?



- Inventories do not used “observed fleets”
- Remote sensing data captures mileage-weighted fleet statistics

Have we got the fleet right for inventories?



- Inventories do not used "observed fleets"
- Remote sensing data captures mileage-weighted fleet statistics

$\Rightarrow$ In other words: more higher emitting petrol cars than we thought (Euro 1/2) **and** increased use of modern diesel cars which are high NO_x *and* NO_2 emitters

3 Concluding remarks

- Trends in NO_x and NO_2 have levelled off in the past 6–8 years
  - UK inventories are in clear disagreement with ambient trends
  - The situation in much of the rest of Europe looks similar
- Vehicle emission remote sensing data has proved to be extremely valuable
  - Key has been linking with comprehensive vehicle information databases (CarweB)
  - Can re-calculate NO_x emissions and compare with inventories

  - Light duty vehicle emissions seem to account for most of the dis-agreement

- Understanding emission inventory trends is far from simple
  - Many, many influences — which change over time
  - Seems that changes in emission factors (even large changes) on their own are not enough to reconcile modelled trends with ambient trends
  - Raises many questions concerning how inventories are constructed
- Future trends in NO_2
  - 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

- Draft report for Defra should be available on `http://uk-air.defra.gov.uk/library/`

  - Will cover far more information than presented here along with implications for measures and policy development

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References

Carslaw, D. C. (2005). “Evidence of an increasing NO_2/NO_X emissions ratio from road traffic emissions.” In: *Atmospheric Environment* 39.26, pp. 4793–4802.

Grice, Susannah et al. (2009). “Recent trends and projections of primary NO_2 emissions in Europe.” In: *Atmospheric Environment* 43.13, pp. 2154 –2167. ISSN: 1352-2310. DOI: DOI:10.1016/j.atmosenv.2009.01.019. URL: http://www.sciencedirect.com/science/article/B6VH3-4VDS8MT-3/2/4a692307ac35ebf6ba37560cf32b4cf9.

Jerksjö, M. et al. (2008). *On-road emission performance of a European vehicle fleet over the period 1991–2007 as measured by remote sensing. 18th CRC On-Road Vehicle Emissions Worskhop San Diego, March 31 – April 2, 2008*.

Thank you for your attention!!