Recent evidence and implications concerning road vehicle emissions of NO_X and NO_2

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21 September 2010

Acknowledgements

This work has relied on significant input from others:

Tim Murrells and Yvonne Li (AEA)

Ben Barratt and Martin Williams (ERG, King's College London)

James Tate (ITS, University of Leeds)

Outline

1. Introduction
2. Trends in NO_X, NO_2 and primary NO_2
3. Vehicle emissions
4. Concluding remarks

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Taking stock

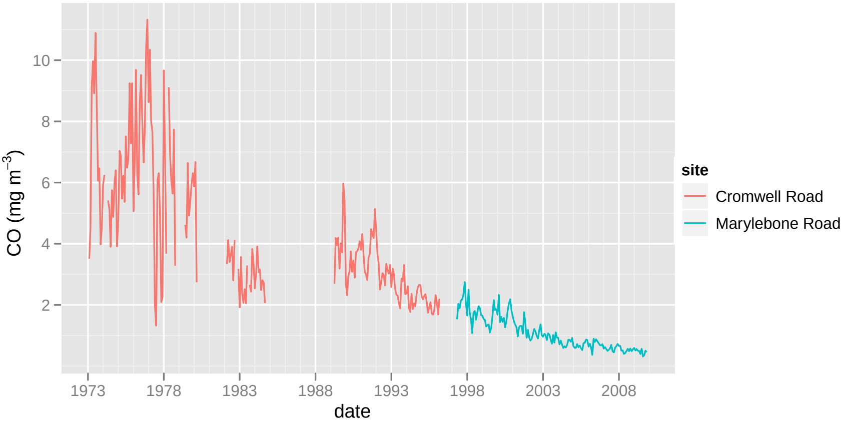
...or how things have or have not changed over the years

Some questions

- How have concentrations of NO_X and NO_2 changed over the past few decades?
- How does the UK compare with the rest of Europe?
- Do these trends agree with emissions inventory estimates?
- Does recent vehicle emissions remote sensing data improve understanding?
- What are the implications for measures to control NO_X and NO_2?

Trends in a strong traffic emissions tracer

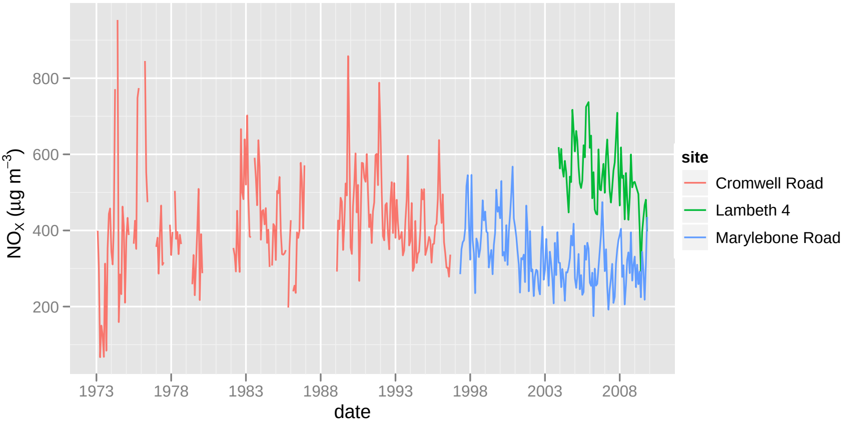
CO concentrations at busy road in London over four decades



Trends in CO have been clearly downward ≈ order of magnitude reduction

Trends in a strong traffic emissions tracer

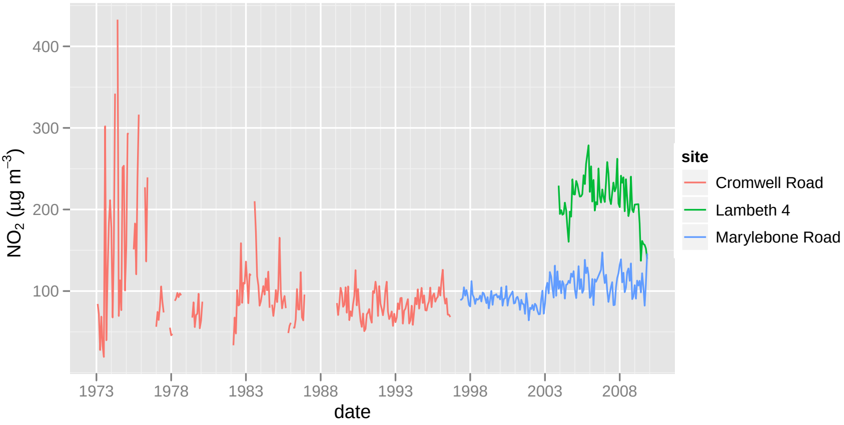
NO_X concentrations at busy road in London over four decades



Trends in NO_X are much less clear on this basis — or at least different to CO

Trends in a strong traffic emissions tracer

NO_2 concentrations at busy road in London over four decades



Many sites have shown increases in NO_2 concentrations in recent years

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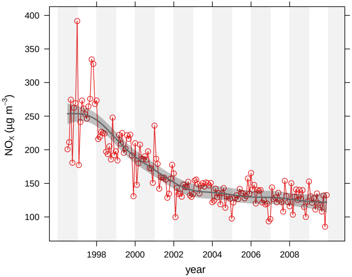
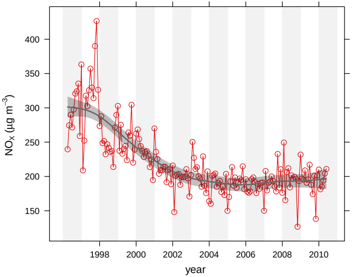
Recent trends in roadside NO_X concentrations

UK and London

12 UK sites



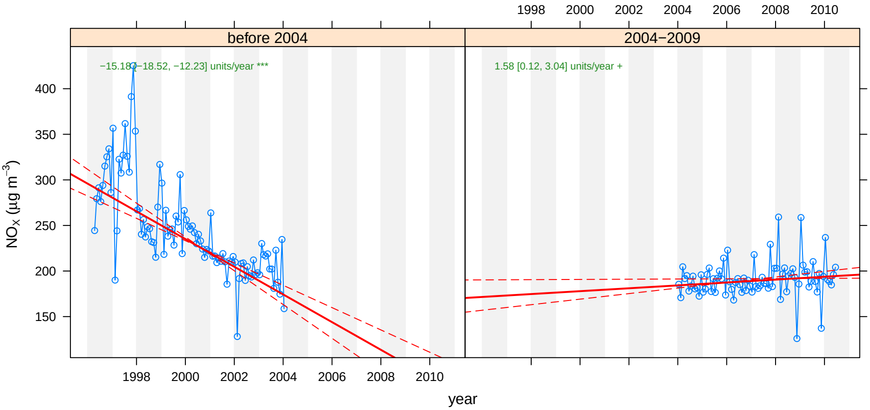
10 Inner London sites



- Generally concentrations have been weakly downward over the past 6–8 years

Recent trends in roadside NO_X concentrations

Trends split by period in inner London



We can split trend periods and consider last 6–8 years in more detail

Trend summary for NO_X

Measurement trends by site type 2004–2009 (% per year)

Location	median trend (2004–2009)
Inner London	−0.6 [−2.8, +1.0]
Motorway	−3.4 [−8.1, +2.1]
Outer London	−1.7 [−3.7, +0.6]
UK roadside	−1.4 [−3.3, +0.2]
UK rural	−1.9 [−4.4, +1.0]
UK urban background	−2.1 [−4.2, −0.2]
UK urban centre	−0.8 [−2.8, +1.1]

Trends in road vehicle **emissions** over the same period are ≈5–6 %/year based on current UK emission factors

Trend summary for NO_2

Measurement trends by site type 2004–2009 (% per year)

Location	trend (2004–2009)
Inner London	−0.5 [−0.7, +0.9]
Motorway	−0.8 [−7.1, +3.7]
Outer London	−0.8 [−2.7, +1.0]
UK roadside	−0.6 [−2.2, +1.1]
UK rural	−1.4 [−3.7, +1.1]
UK urban background	−0.8 [−3.0, +0.9]
UK urban centre	−0.4 [−1.9, +2.2]

Main origins of NO_2 in the urban atmosphere

And types of conditions where they are important

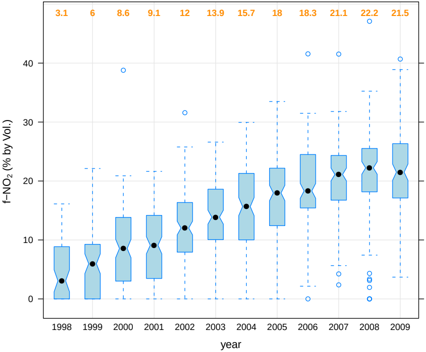
- The character of NO_2 pollution has changed over the years
  - The $\mathbf{NO + O_3} \rightarrow \mathbf{NO_2 + O}_2$ has always been important and is dominant
  - For high concentrations of NO_X the (slow) $\mathbf{NO + NO + O}_2 \rightarrow \mathbf{2NO}_2$ reaction *was* important, along with conjugated diene chemistry (UK episode in December 1991)[1]
  - More recently, the direct emission of *primary* NO_2 has emerged as being important
- Historically the amount of NO_2 has widely been assumed to be **5–10%** (by volume) of the NO_X.

[1] Bower et al. (1994); Shi and Harrison, 1997

Trend in primary NO_2 in London

23 London sites with long time series

- Use the simple chemical model
- Clear increase in f-NO_2 over past 12 years
- Quite a lot of site to site variation
- Typical values in recent years around 22% by vol.

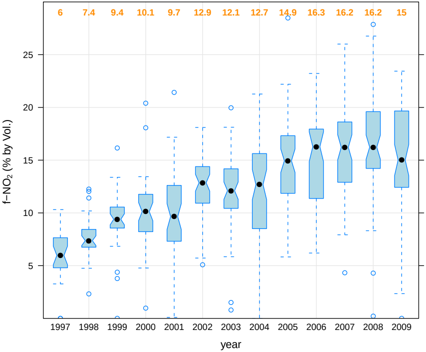


Carslaw and Beevers, (2005). Estimations of road vehicle primary NO_2 exhaust emission fractions using monitoring data in London. *Atmos. Env.* 39(1), 167177.

Trend in primary NO_2 across the UK

12 UK roadside sites with long time series

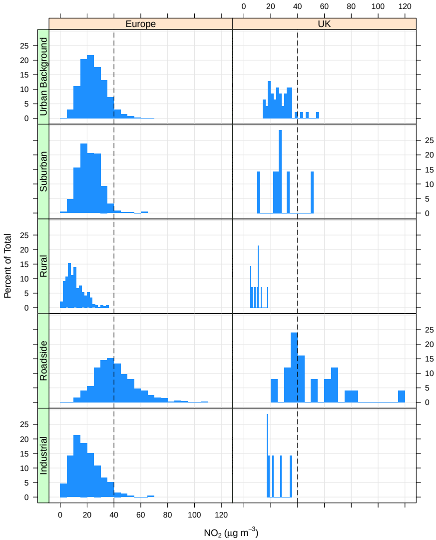
- Use the simple chemical model
- Clear increase in f-NO_2 over past 13 years
- Quite a lot of site to site variation
- Typical values in recent years about 15–16% by vol.



Analysis of data from Europe

NO_2 concentrations in 2008 split by site type

- Analysis 2,728 sites from a wide range of counties and site types
- Remarkably consistent between UK and rest of Europe
- In Europe 18.9% of all sites exceeded the annual mean NO_2 limit value in 2008, which is very similar to that in the UK of 18.0%

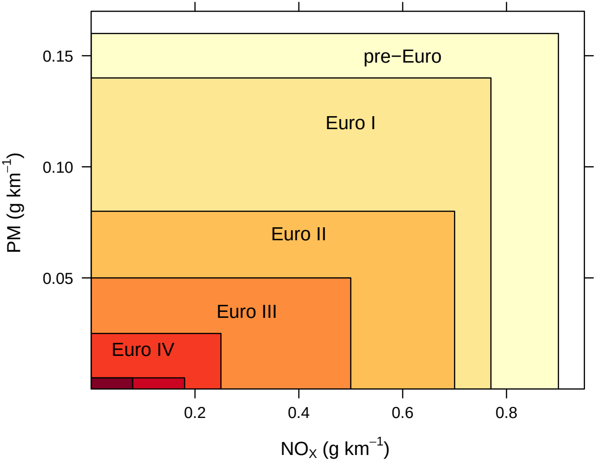


http://air-climate.eionet.europa.eu/databases/airbase

Outline

European emissions legislation over the years

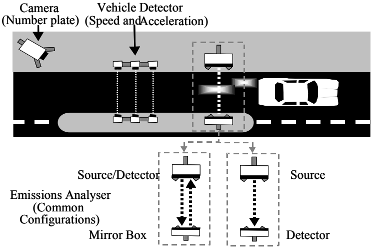
For diesel car NO_X and PM_{10} from pre Euro to Euro VI



Plot indicates approximate reduction in NO_X and PM_{10} vehicle emissions expected due to tightening vehicle emissions legislation

Remote sensing

- Remote sensing
  - Infrared/UV beam across road
  - 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
  - About 72,000 vehicles measured
  - Number plates matched by SMMT (CarweB `http://www.carwebuk.co.uk/`)



Thanks to Dr James Tate, ITS, University of Leeds and Enviro Technology

Assumptions regarding f-NO_2

Used for the remote sensing

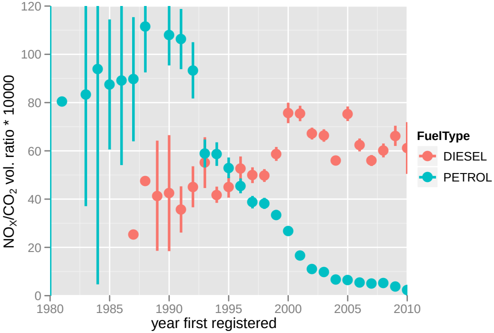
Vehicle class	Euro class	% NO_2 (by volume) Grice et al. (2009)	% NO_2 (by volume) Swedish RSD
Petrol cars			
	All	3	≈1 [12551]
Diesel cars and LGVs			
	Euro II and earlier	11	14–20 [177]
	Euro III	30	30–47 [538]
	Euro IV–V1	55	55–60 [881]
HGVs			
	Euro II and earlier	11	7 [218]
	Euro III	14	9 [353]
	Euro IV–V1	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–V1	10	48

Jerksjö, M., Sjödin, A., Bishop, G.A. and Stedman, D.H. (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.

Remote sensing

Petrol and diesel car NO_X emissions

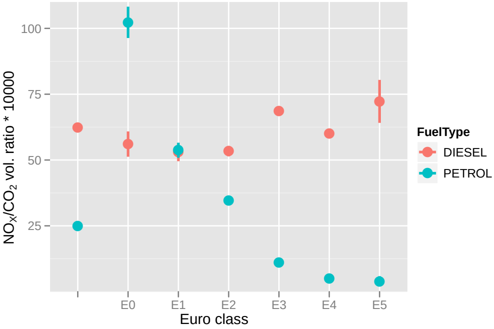
- NO_X emissions from petrol cars have decreased by ≈96% since the early 1990s
- Diesel car emissions have increased, or at best been stable for the past 25 years or so
- Possible to see the effects of different Euro class legislation



Remote sensing

Petrol and diesel car NO_X emissions

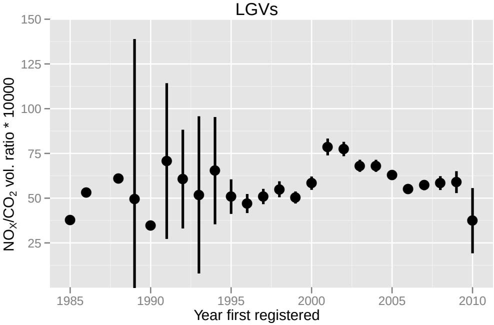
- Vehicle emissions by Euro class
- Highlights the stability of diesel NO_X emissions over the years



Remote sensing

Diesel LGV NO_X emissions

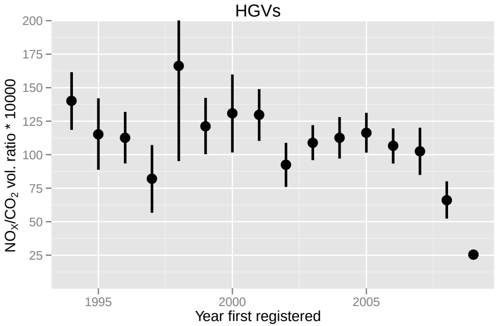
- The diesel van NO_X trend in emissions are similar to diesel cars



Remote sensing

HGV emissions NO_X emissions

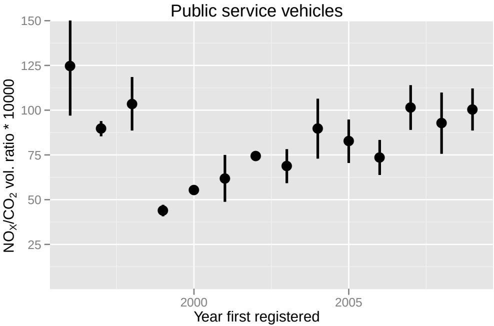
- HGV emissions have been relatively stable, with some evidence of a decrease in NO_X for Euro IV



Remote sensing

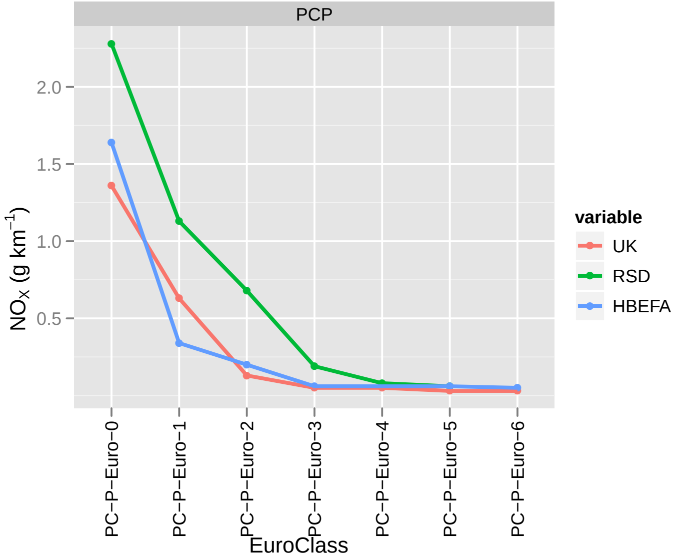
Bus emissions of NO_X

- Emissions from public service vehicles (buses) have tended to increase with time
- Need to be careful about specific fleets



Comparison of different emission estimates for petrol cars

Comparing UK, HBEFA and RSD



Comparison of different emission estimates for diesel cars

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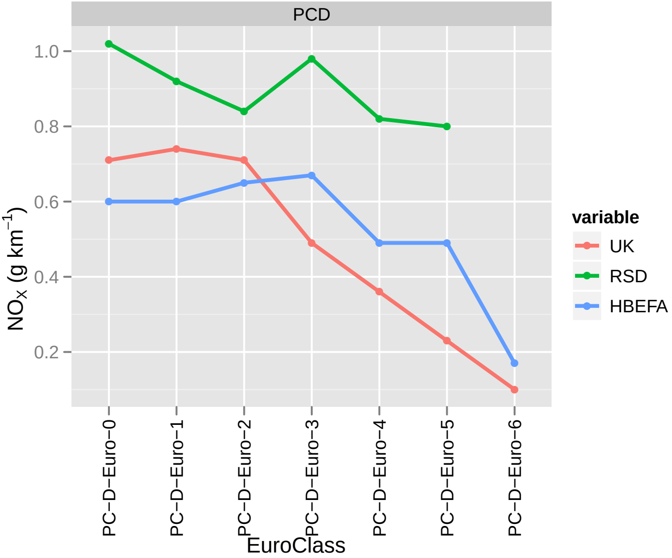
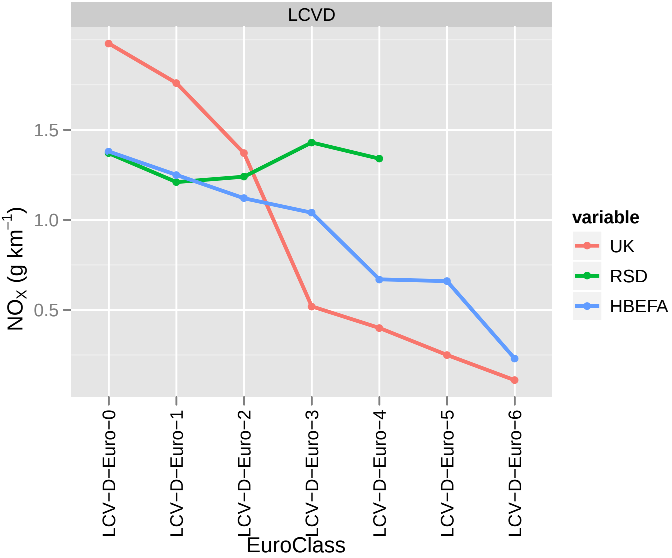


Comparison of different emission estimates for diesel LGVs

Comparing UK, HBEFA and RSD



Comparison of different emission estimates for rigid HGVs

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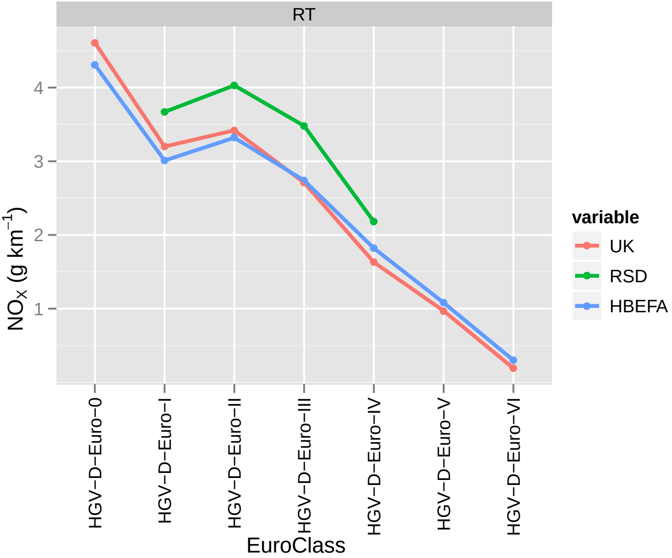
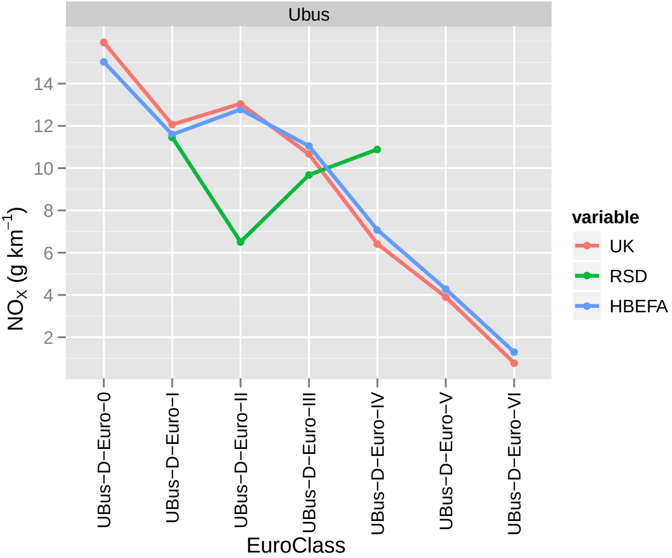


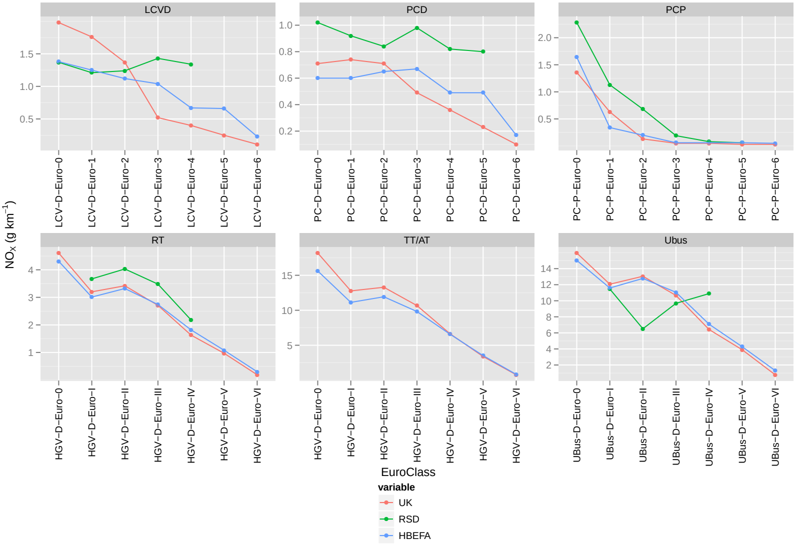
Comparison of different emission estimates for urban buses

Comparing UK, HBEFA and RSD



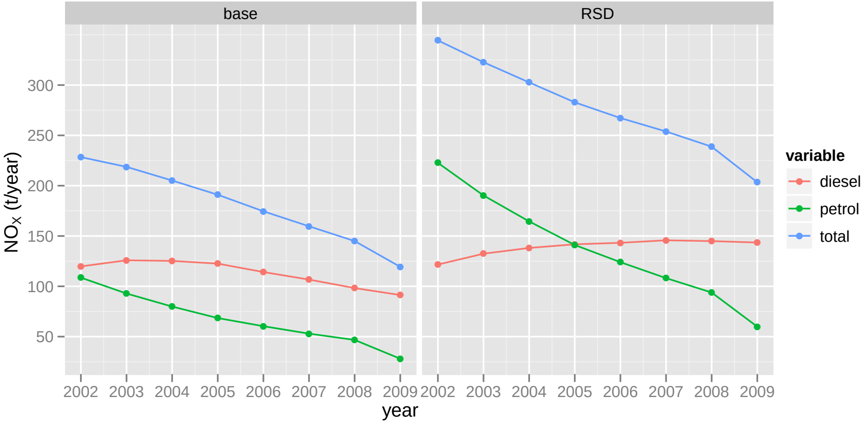
Overall comparison of different emission estimates

Comparing UK, HBEFA and RSD



Provisional impacts on emission inventories

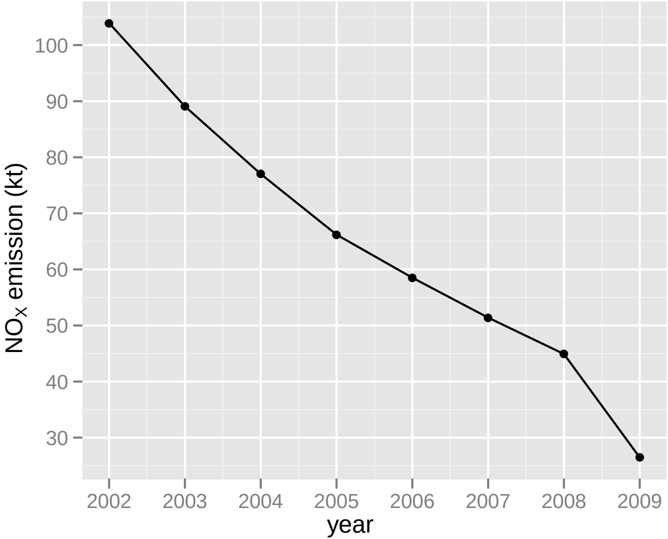
NAEI base case and RSD for UK urban NO_X emissions



Note! As currently calculated the RSD assumptions do not account for catalyst degradation over time. This turns out to be a thorny problem . . .

Closer look at UK urban NO_X trends for petrol vehicles

Catalyst failure assumptions are evident



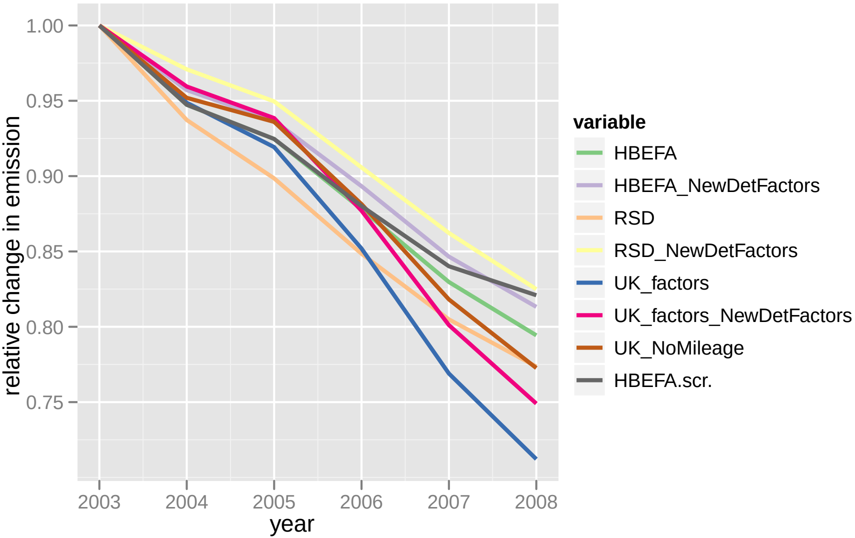
Refining the petrol vehicle estimates

Issues to do with catalyst failure/degradation

- The downward trend in NO_X in UK urban areas (including London) is dominated by what happens with petrol vehicles
  - The reduction is such that it swamps even increases in diesel NO_X emissions
- The assumptions concerning emission degradation/catalyst failure are very important, and there are some important effects:
  - It is assumed some vehicle emissions **improve** over time — sometimes substantially e.g. a Euro II petrol car emits 42% less NO_X in 2009 than when it was first introduced and a Euro III diesel car emits 31% less NO_X on the same basis
  - Because of the way these calculations are made, it is not straightforward to apply alternative assumptions

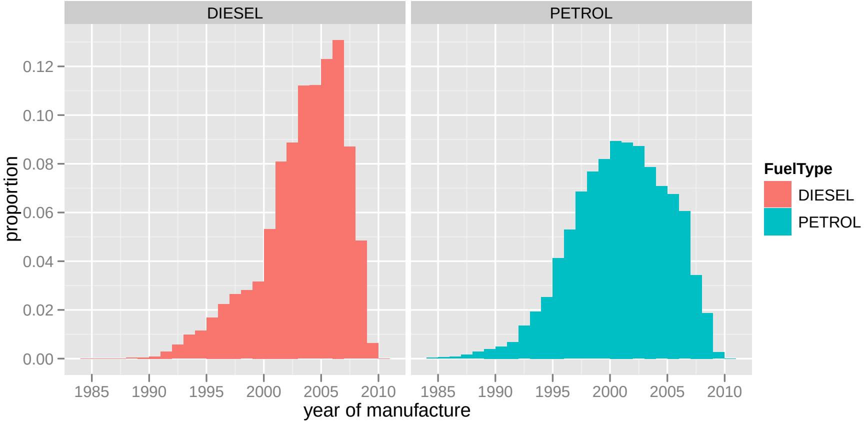
Scenarios for NO_X emissions change for the LAEI

Based on predictions at a series of monitoring sites



Other more basic questions

Have we got the fleet mix right in inventories?



Data based on mean remote sensing vehicle stock ≈2009

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Summary points

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    - UK inventories are in clear disagreement with ambient trends
    - The situation in much of the rest of Europe looks similar

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   - Light duty vehicle emissions seem to represent most of the disagreement

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2. 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 represent most of the disagreement
3. Understanding emission inventory trends is far from simple
   - Many, many influences — which change over time
   - Beginning to unpick the importance of different factors