# $NO_x$ and $NO_2$ concentrations, trends and sources

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KING'S College LONDON

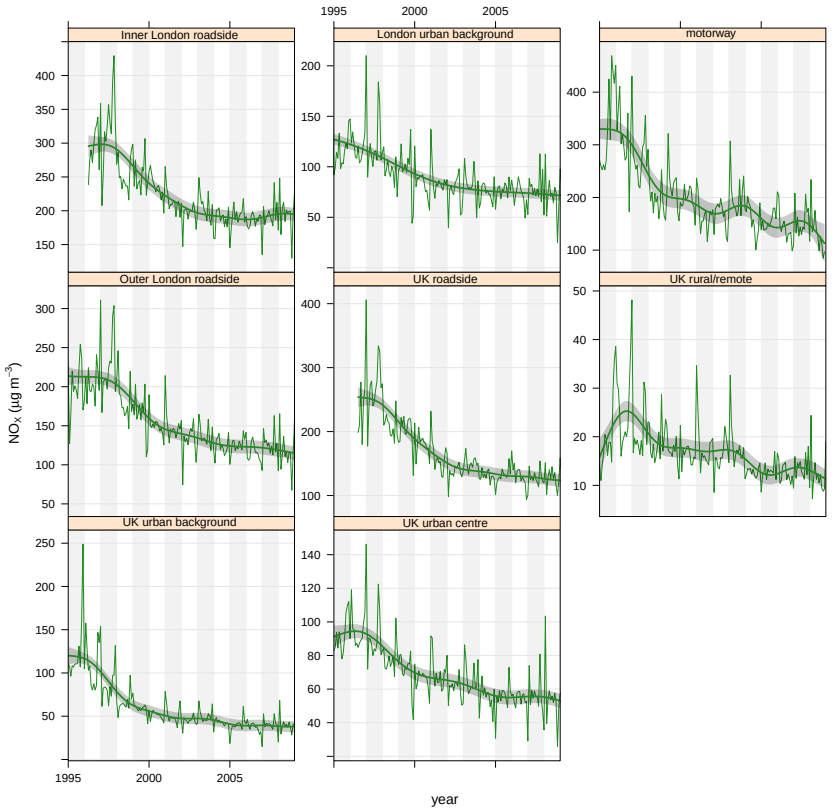
## Outline

# 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

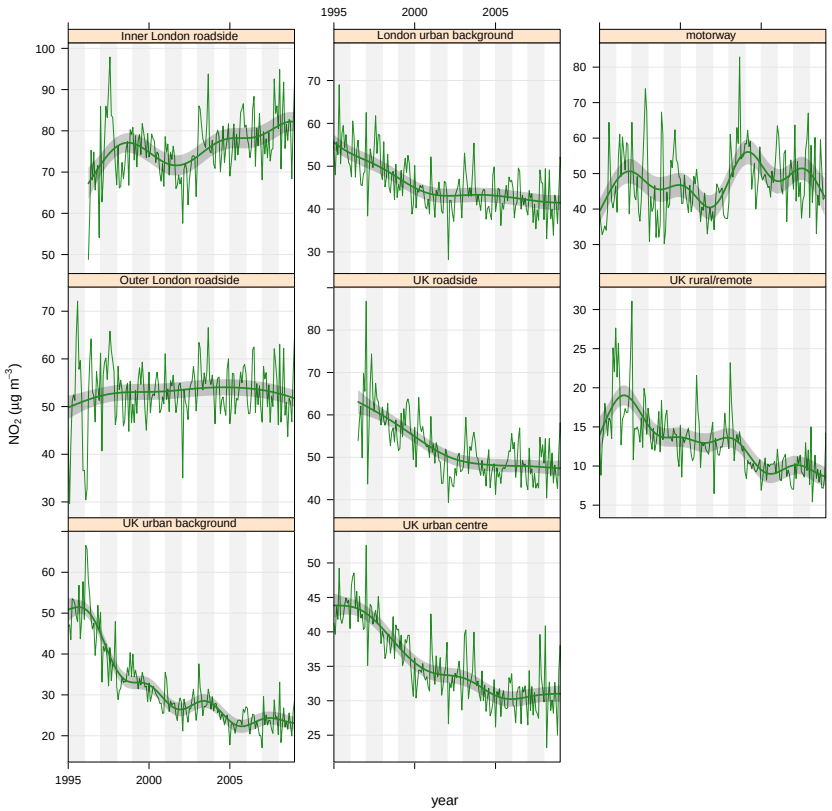
$\Rightarrow$ What conclusions can be drawn from this information?

# $NO_x$ trends across the UK



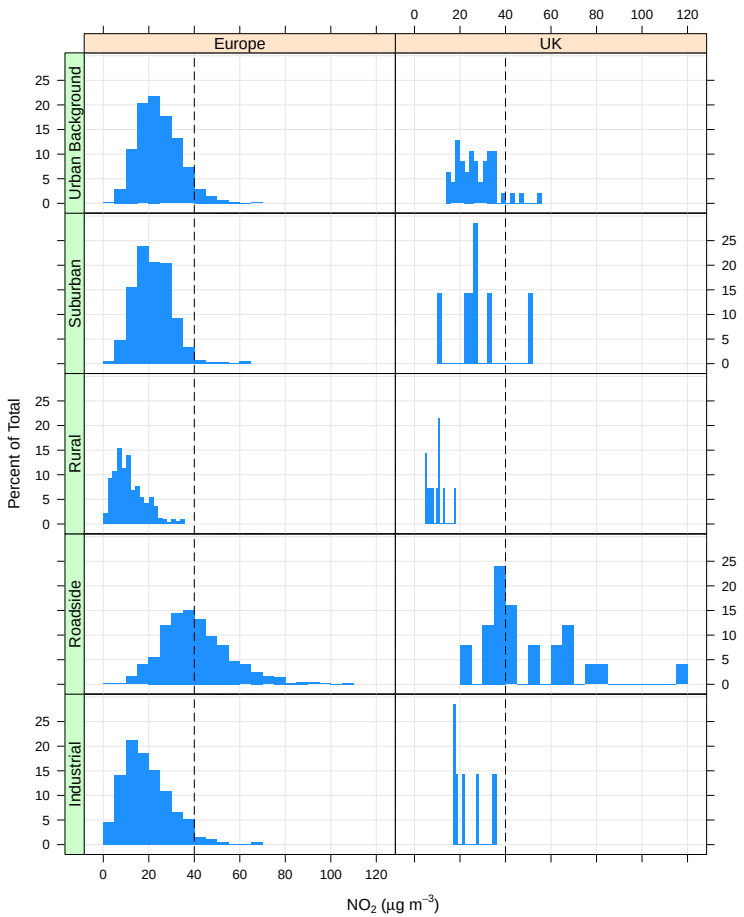

- Similar patterns observed at most site types — levelling off of $NO_x$ concentrations
- Reduction in concentration from late 1990s; weakly decreasing since 2002/4–2010
- Median changes 2002–2009:
  - −0.6 %/year in inner London
  - −1.7 %/year in outer London
  - −1.4 %/year in rest of UK

# $NO_2$ trends across the UK



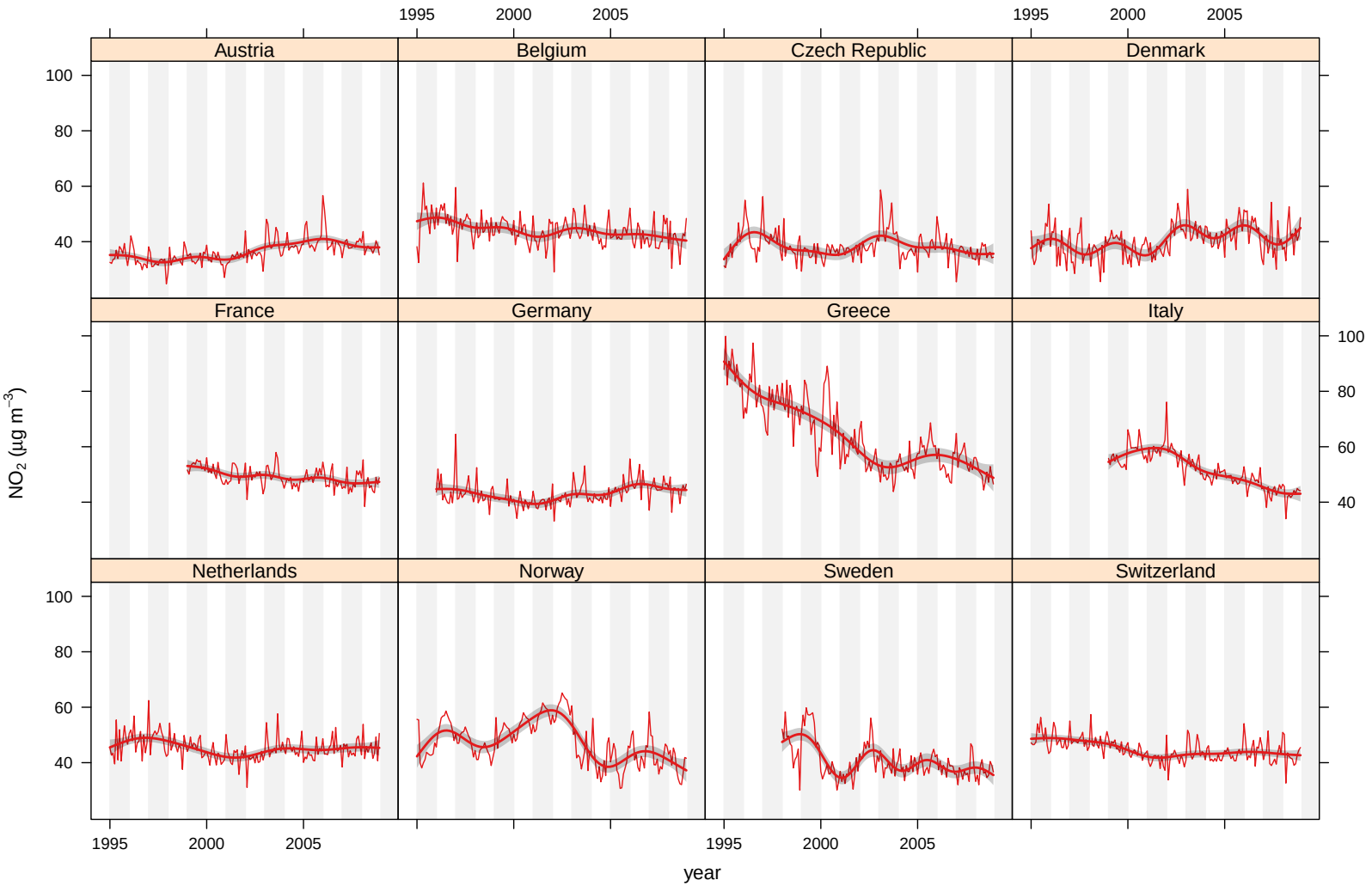

- $NO_2$ concentrations have increased at some sites
- Median changes 2002–2009:
  - −0.5 %/year in inner London
  - −0.8 %/year in outer London
  - −0.6 %/year in rest of UK

## How does the UK compare with the rest of Europe?

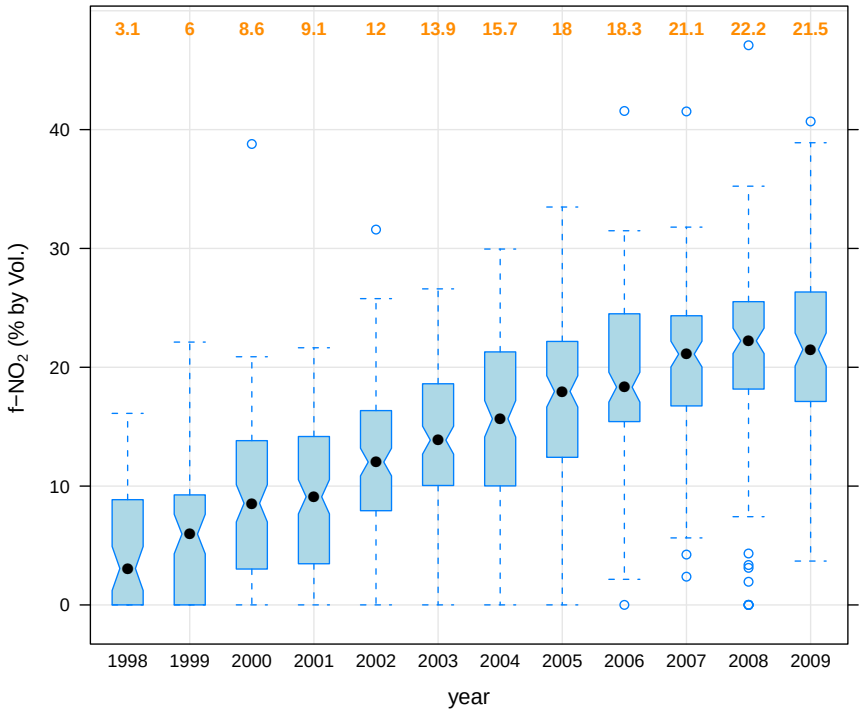



- Analysis of hourly data from 2,728 sites in Europe from *Airbase*
- Similar proportion of sites in 2008 exceed annual mean LV of 40 µg $m^{-3}$
- Also evidence of stabilising concentrations of $NO_2$ for most countries

# $NO_x$ and $NO_2$ concentrations, trends and sources



## Primary $NO_2$ trends — London



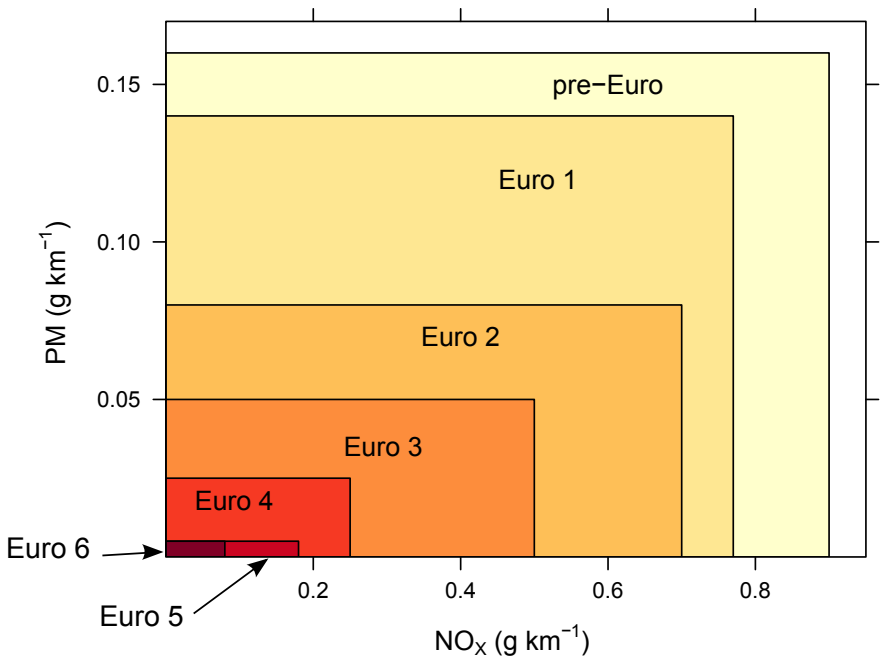

- The ratio of $NO_2$:$NO_x$ has clearly increased over the past decade
- Values today in London are around 20–25% by vol.

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

# 2 Vehicle emissions of $NO_x$ and $NO_2$

- What we expected to happen
- Recent evidence from vehicle emission remote sensing
- A closer look at diesel cars

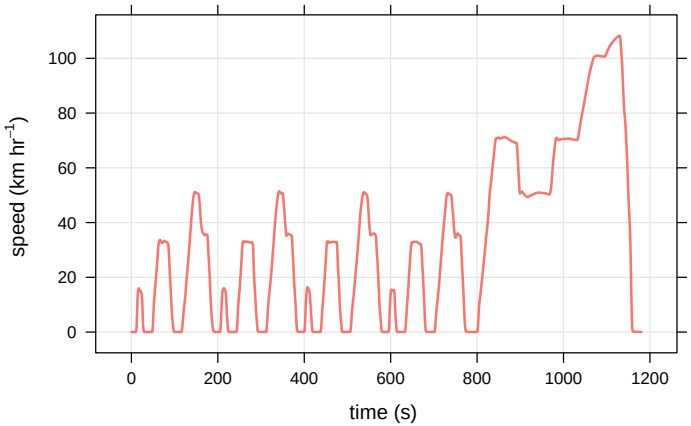
## Vehicle emissions legislation in Europe

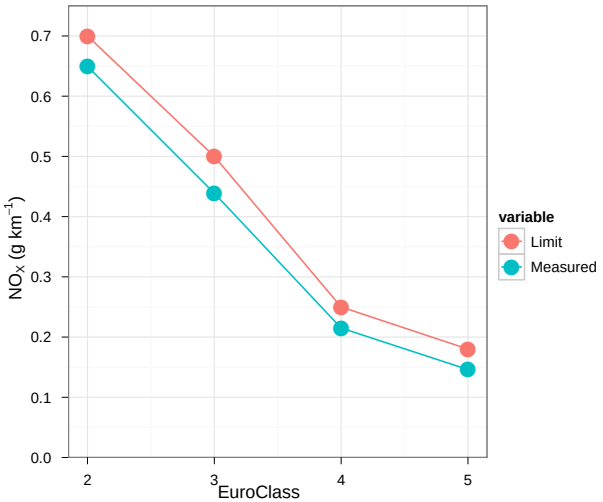



- Approximate limits of $NO_x$ and PM — for diesel cars
- $\approx$ order of magnitude reduction in $NO_x$ g km$^{-1}$ emissions since early 1990s

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

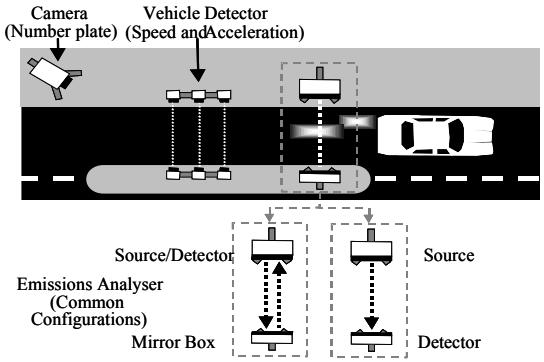
# Vehicle emissions legislation — test cycles



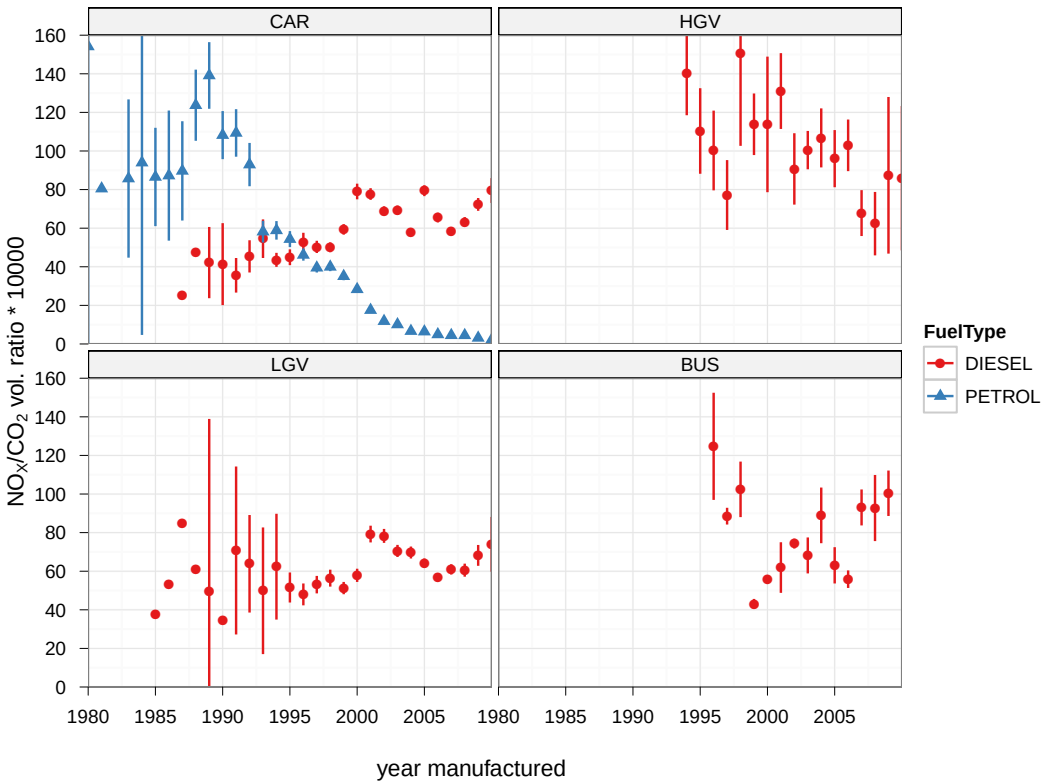

- Vehicles driven over a standard test cycle and emissions measured and expressed in g km$^{-1}$
- Each new model car produced by a manufacturer is tested in this way
- Thousands of vehicles — diesel cars in this case

# Vehicle emissions remote sensing



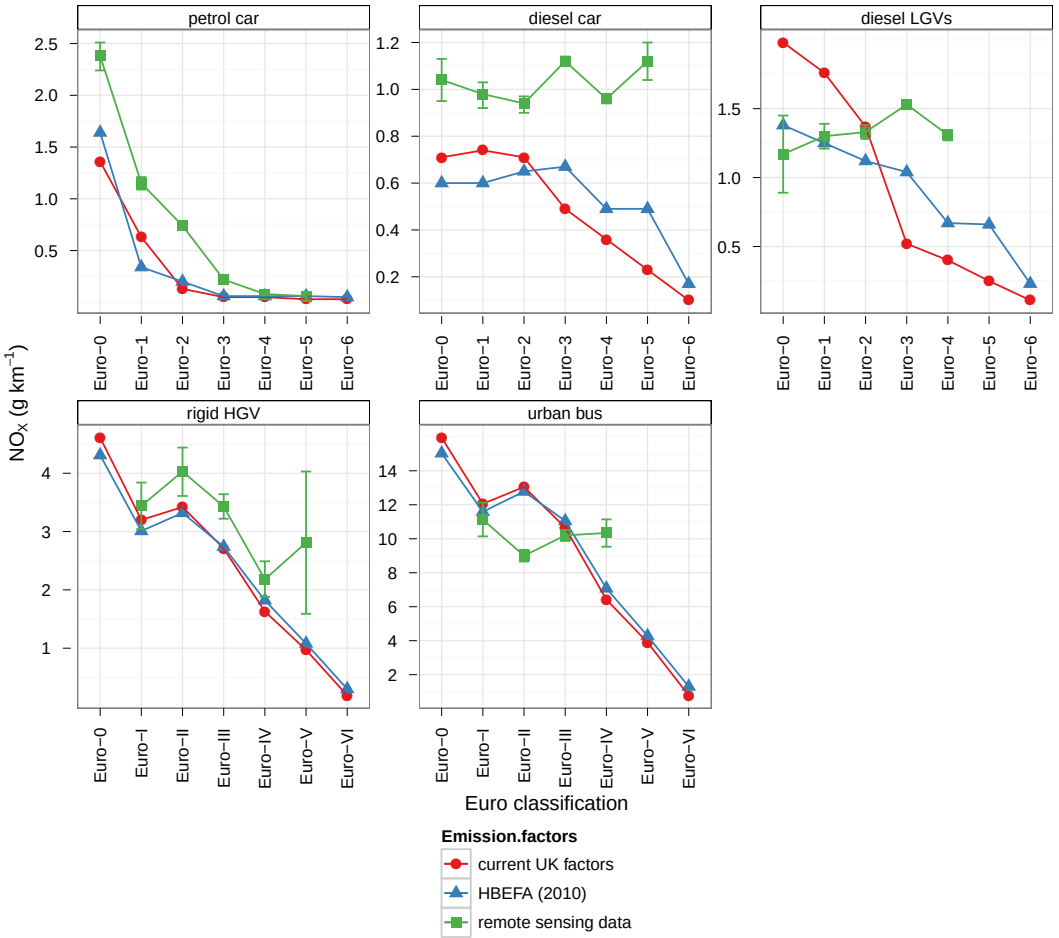

- Remote sensing
  - Infrared/UV beam across road using ESP Remote Sensing Detector (RSD-4600)
  - Individual vehicle exhausts measured
  - Measures ratios of NO, CO, HC, "smoke" to $CO_2$ i.e fuel-based emission factors
  - Some practical limitations
- Several campaigns from 2008–2010 in 5 urban areas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

## $NO_x/CO_2$ ratio 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

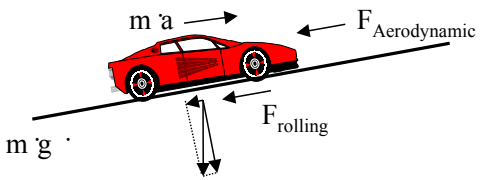
# Derived vehicle emission factors for $NO_x$ (g $km^{-1}$)




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

## Vehicle specific power as an emissions metric[1]

Vehicle Specific Power (VSP)



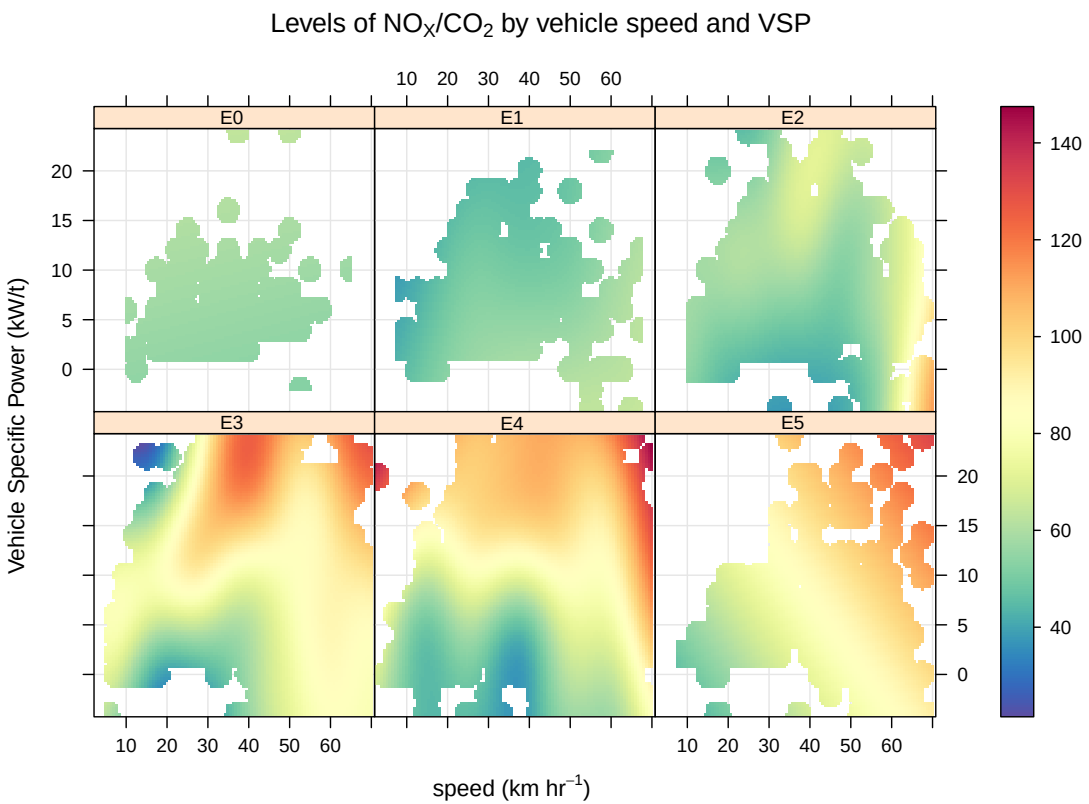

$$VSP = \frac{Power}{Mass} = \frac{\frac{d}{dt}(E_{Kinetic} + E_{Potential}) + F_{Rolling} \cdot v + F_{Aerodynamic} \cdot v + F_{int\ ernal\ friction} \cdot v}{m} =$$

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

- 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

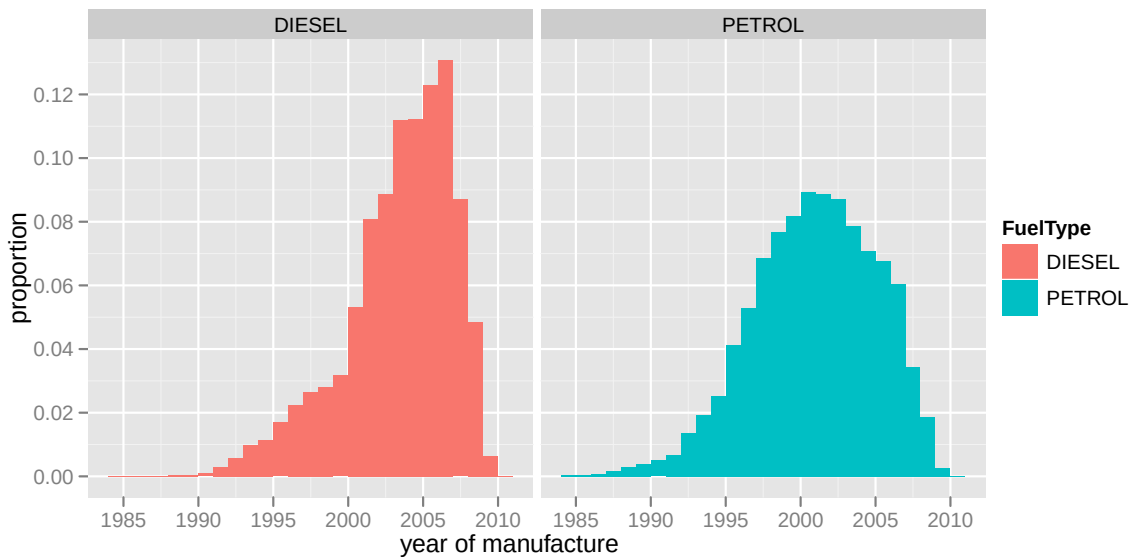
[1] Jiménez, J., McClintock, P., McRae, G., Nelson, D., Zahniser, M., 1999. Vehicle Specific Power: A Useful Parameter for Remote Sensing and Emission Studies . 9th CRC On-Road Vehicle Emissions Workshop San Diego, April 21st 1999

# Effect of vehicle specific power on emissions of $NO_x$




- Clear effect for diesel cars by emissions technology
- Euro 3 to Euro 5 emit much higher levels of $NO_x$ when the engine is under load
- Diesel cars have got more powerful over time (use of turbo-charging)

## Have we got the fleet right for inventories?




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

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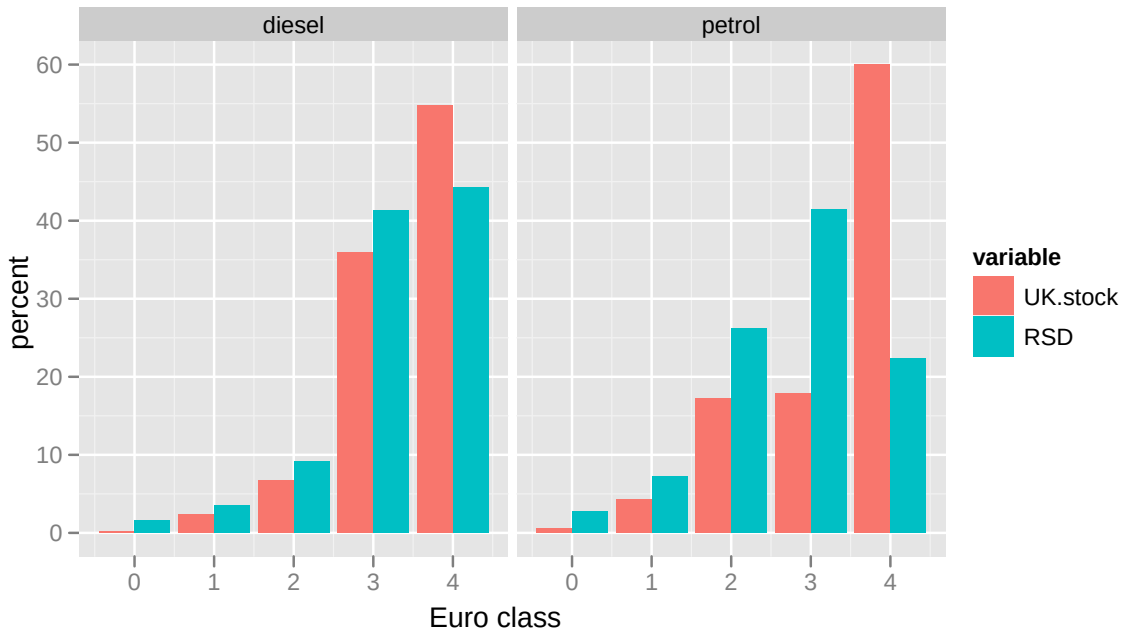


- Inventories do not used "observed fleets"
- Remote sensing data captures mileage-weighted fleet statistics

⇒ 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 is 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 disagreement

# $NO_x$ and $NO_2$ concentrations, trends and sources

- Increased power of diesel cars over past 20 years is important

- 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

# $NO_x$ and $NO_2$ concentrations, trends and sources

- Draft report available at http://uk-air.defra.gov.uk/library/ and revised version with Defra
    - Covers far more information than presented here along with implications for measures and policy development

# Acknowledgements

This work has relied on significant input from others:

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**Thank you for your attention!!**

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