UNIVERSITY of York

The European NO_2 problem – insights from vehicle emission remote sensing

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Outline of talk

- The European NO_2 problem, causes and consequences
- Insights from comprehensive vehicle emission remote sensing
  - Evolution of NO_x and primary NO_2 emissions
  - Effect of diesel after-treatment technology
  - Ambient temperature effects and implications
  - Vehicle mileage and emissions of NO_2
- Concluding remarks

The NO_x issue

- The emission of NO_x is of key importance to a very wide range of adverse health and environmental impacts
  - Formation of ground-level ozone, secondary fine particulate, acid deposition, eutrophication, direct exposure to NO_2 , …
- The recent focus in Europe has been local scale issues related to NO_2
  - Meeting the annual mean NO_2 Limit Value of 40 μg m^{-3} (same as WHO Guideline)
  - Essentially an issue dominated by road vehicle emissions in urban areas
  - Close to roads, the emission of total NO_x ***and*** primary NO_2 are both important contributors to NO_2 concentrations
  - Real-world vehicle emission measurements are needed to understand these issues

Vehicle emission remote sensing

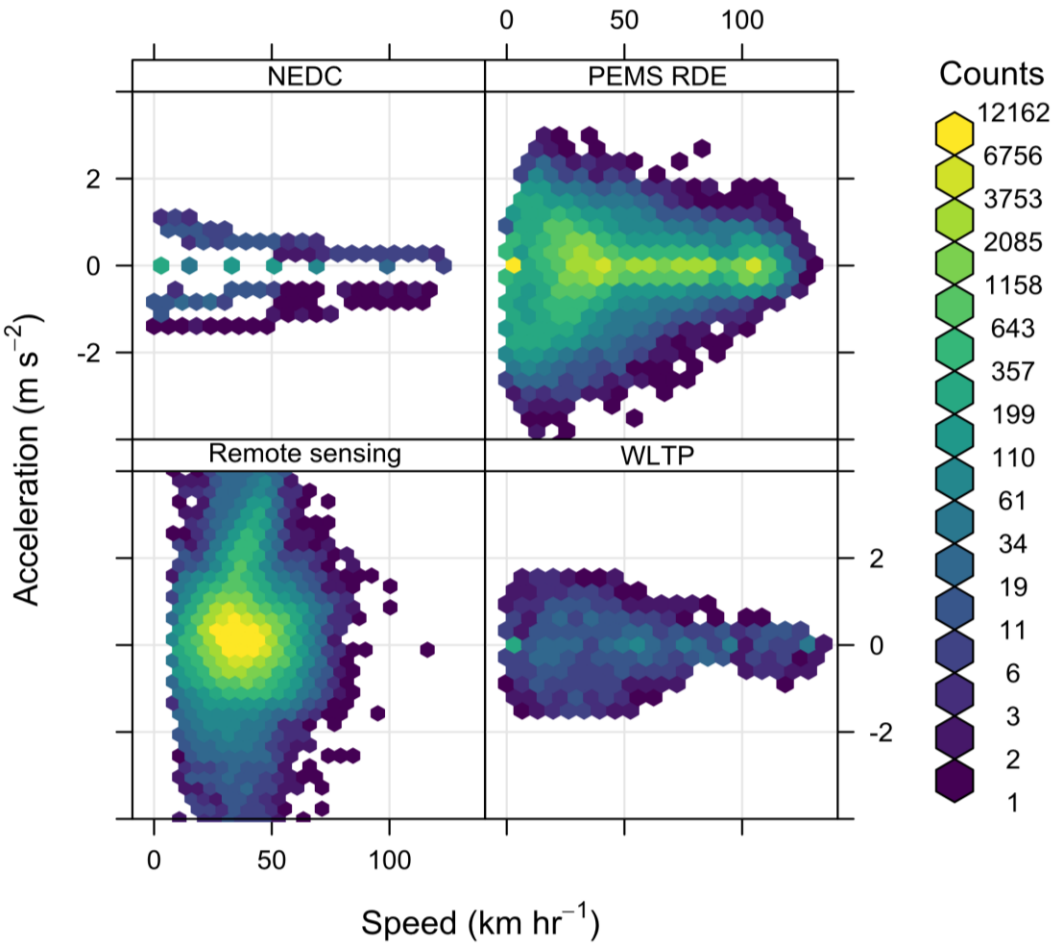
- Have collected > 400,000 measurements
- University of Denver FEAT
- Opus RSD 5000
- NO, NO_2, NH_3, CO, HC, opacity (PM)
- Photo shows both instruments, co-located in London

Vehicle emission remote sensing

- Wide range of locations and location types throughout UK (about 20)
- Photograph each vehicle to obtain number plate
  - Detailed cross reference with SMMT-derived databases … more than 80 vehicle characteristics
  - Recently possible to cross-refence **vehicle mileage** at last technical inspection (useful to understand deterioration effects)
- Additional work to identify whether Euro 6 diesel cars have LNT (Lean NO_x Traps) or SCR (selective Catalytic Reduction)
  - Identified for > 90% of vehicles
- Adopted flexible Generalized Additive Model (GAM) approach for data analysis

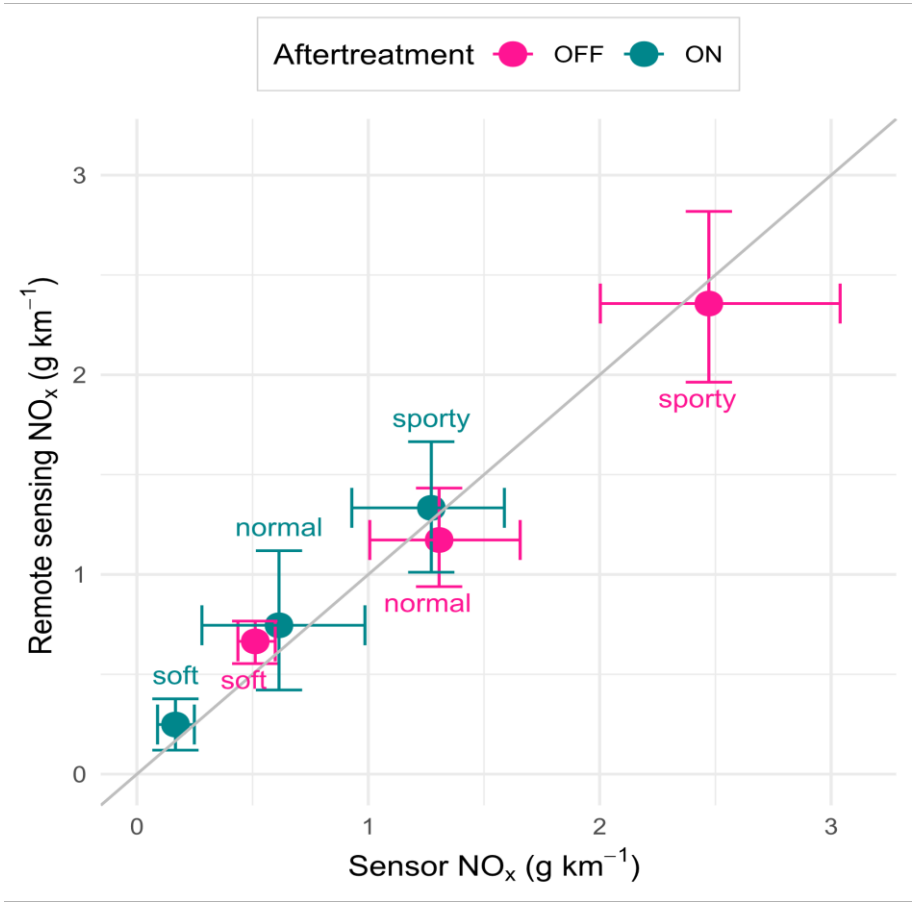
What driving conditions does remote sensing cover?

- Consider speed and acceleration and compare with Type Approval test cycles and PEMS
- Remote sensing has very good coverage of driving conditions
- The limitation is higher speed driving e.g. motorway / highway driving
  - … but mostly interested in urban emissions and urban air pollution problems



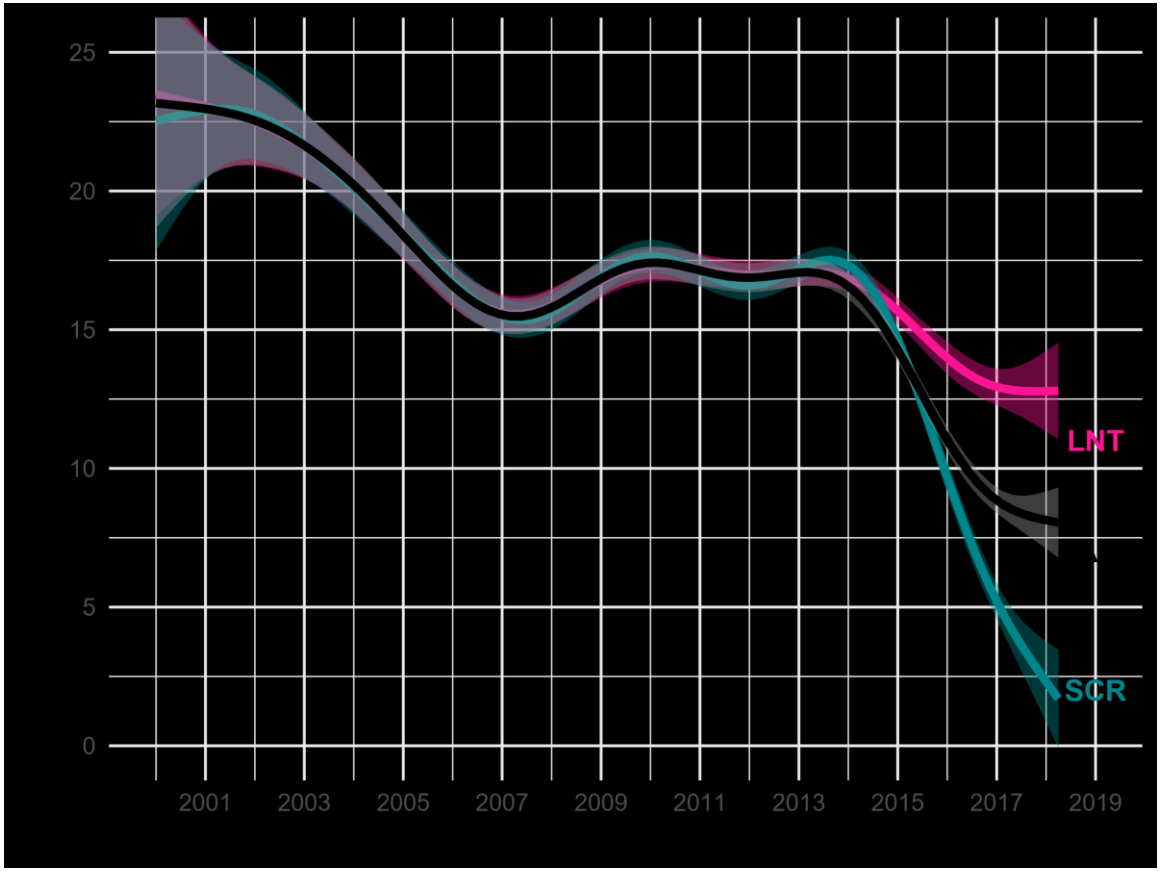
Comparison with PEMS

- Euro 6d-temp passenger car with Lean NO_x Trap
- Even with few measurements, remote sensing:
  - Agrees well with PEMS overall
  - Could clearly distinguish vehicle aftertreatment being on / off
  - Distinguish between driving conditions of 'soft', 'normal' and 'sporty'



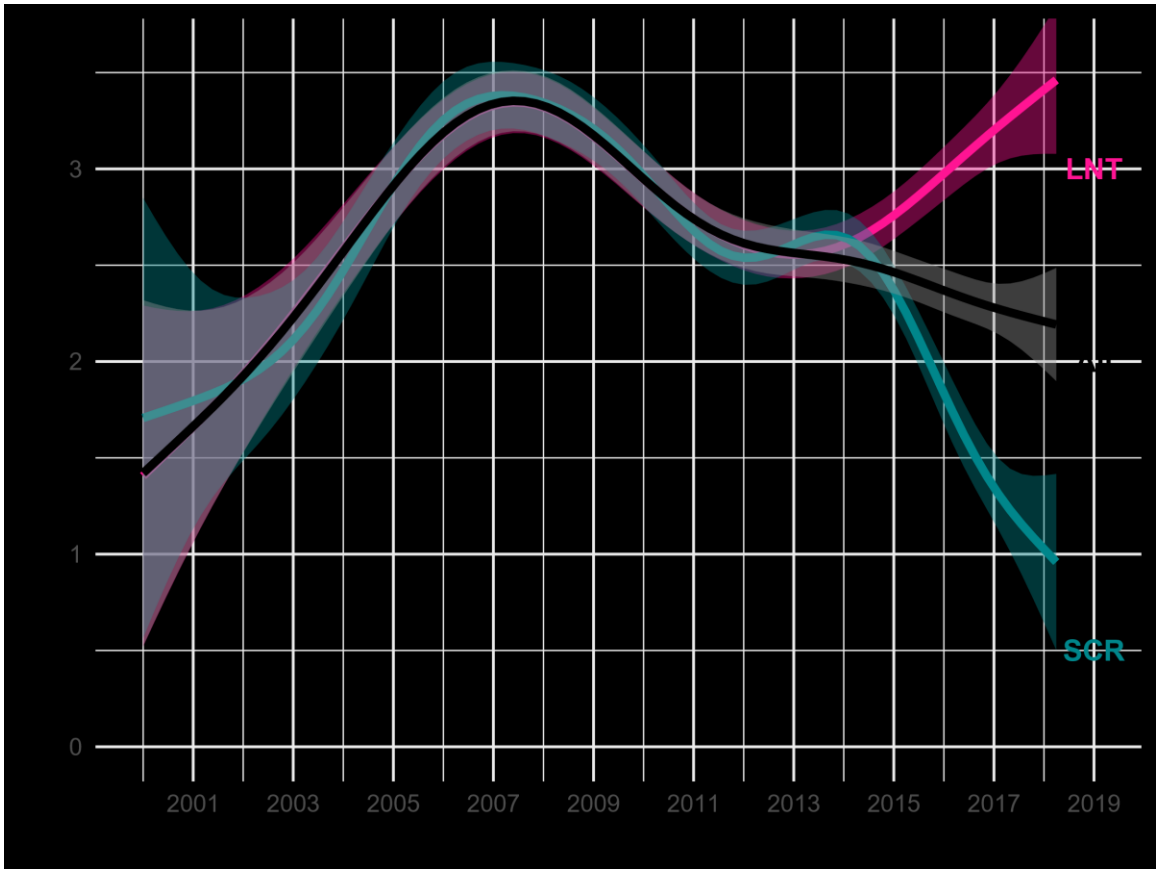
Diesel NO_x progression by main technology

- Euro 6 is not a single thing
- The introduction of Euro 6 is an important change in the history of NO_x emissions
- We see large differences between the two main technology types: LNT (Lean NO_x Traps) and SCR (Selective Catalytic Reduction)
  - Emission factor models do not differentiate between LNT and SCR



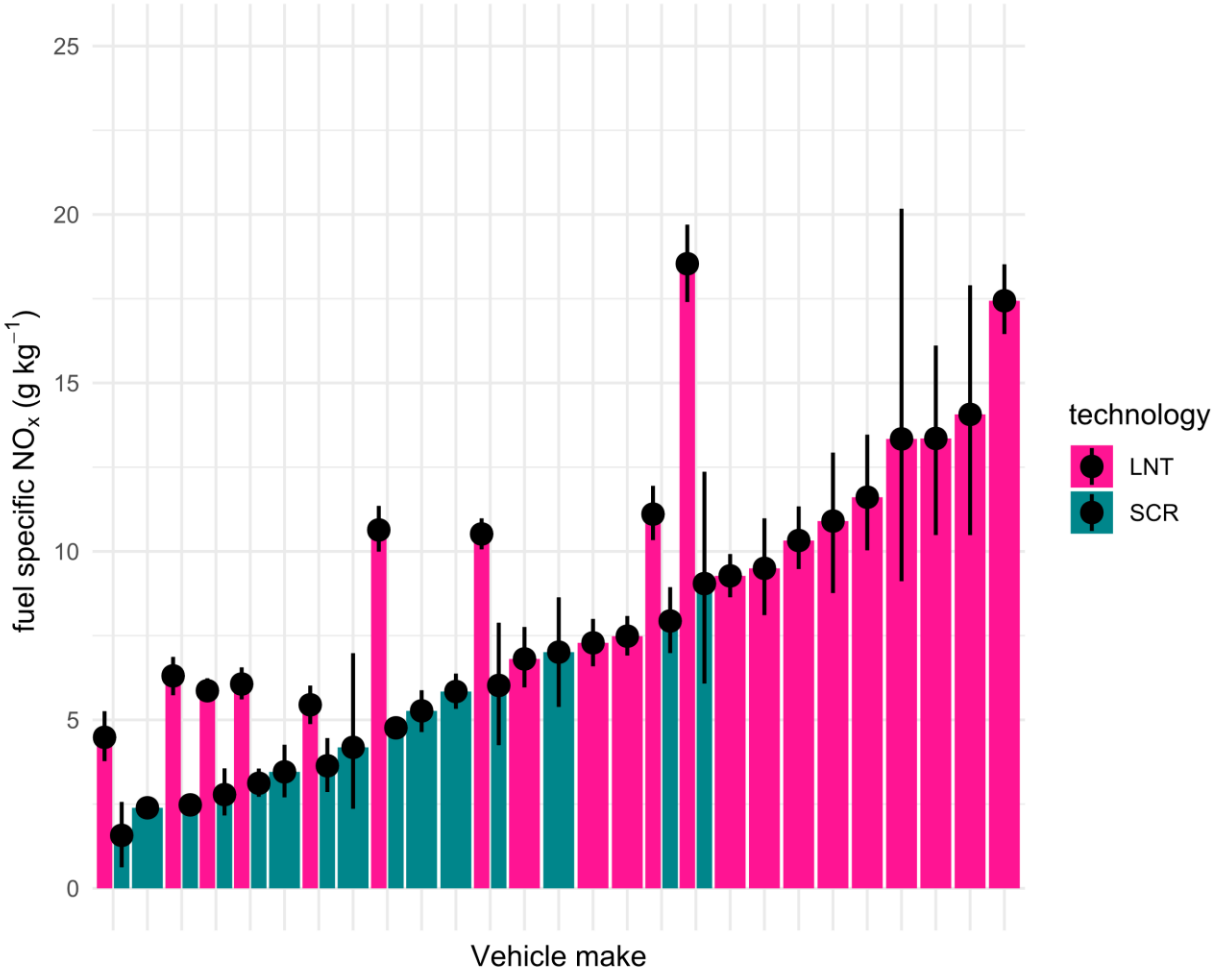
Diesel NO_2 progression by main technology

- Increase in NO_2 emissions since introduction of diesel oxidation catalysts from ~ 2000 and DPF from ~ 2005
- NO_2 is a powerful oxidant and acts to reduce CO, HC and PM
- Overall emissions of NO_2 have been decreasing since year 2007 vehicles were introduced
- LNT-equipped vehicles emit considerably more NO_2 than SCR



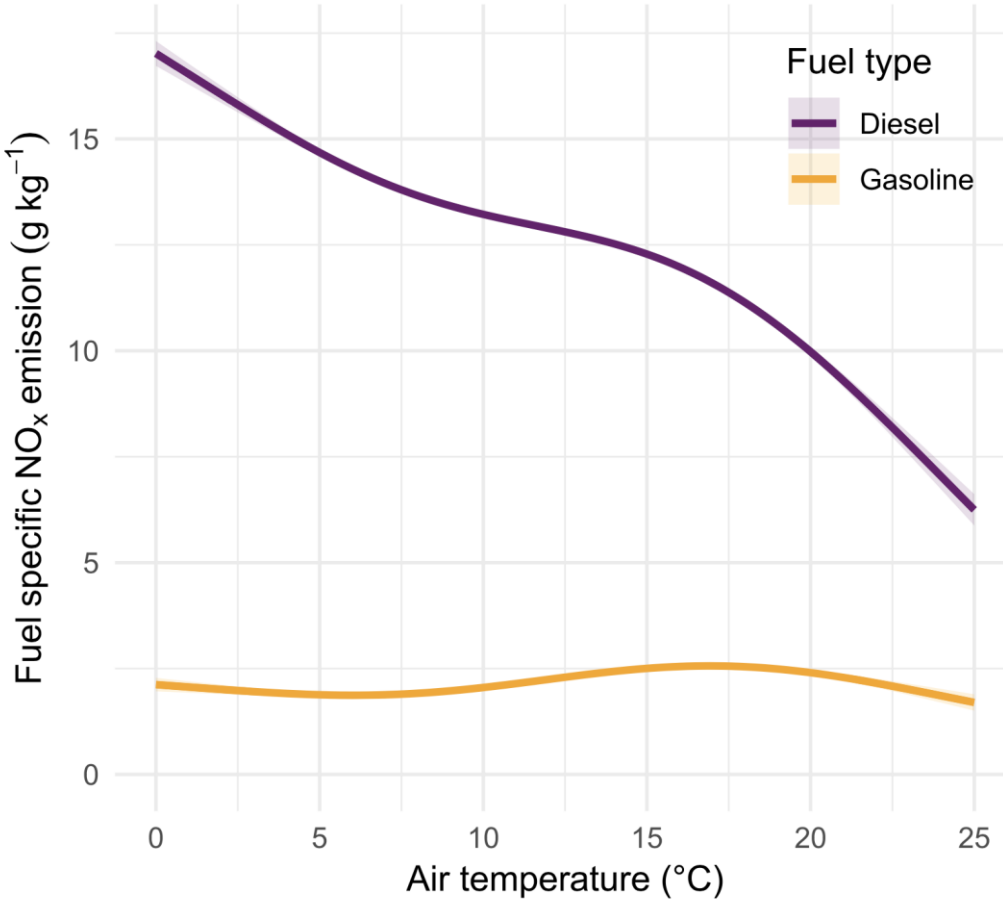
Diesel NO_x by main technology and vehicle make

- Where manufacturers produce LNT and SCR vehicles, LNT emissions re always higher
- Next step is to consider Euro 6d-temp that can have LNT + SCR



Effect of ambient temperature – broad view

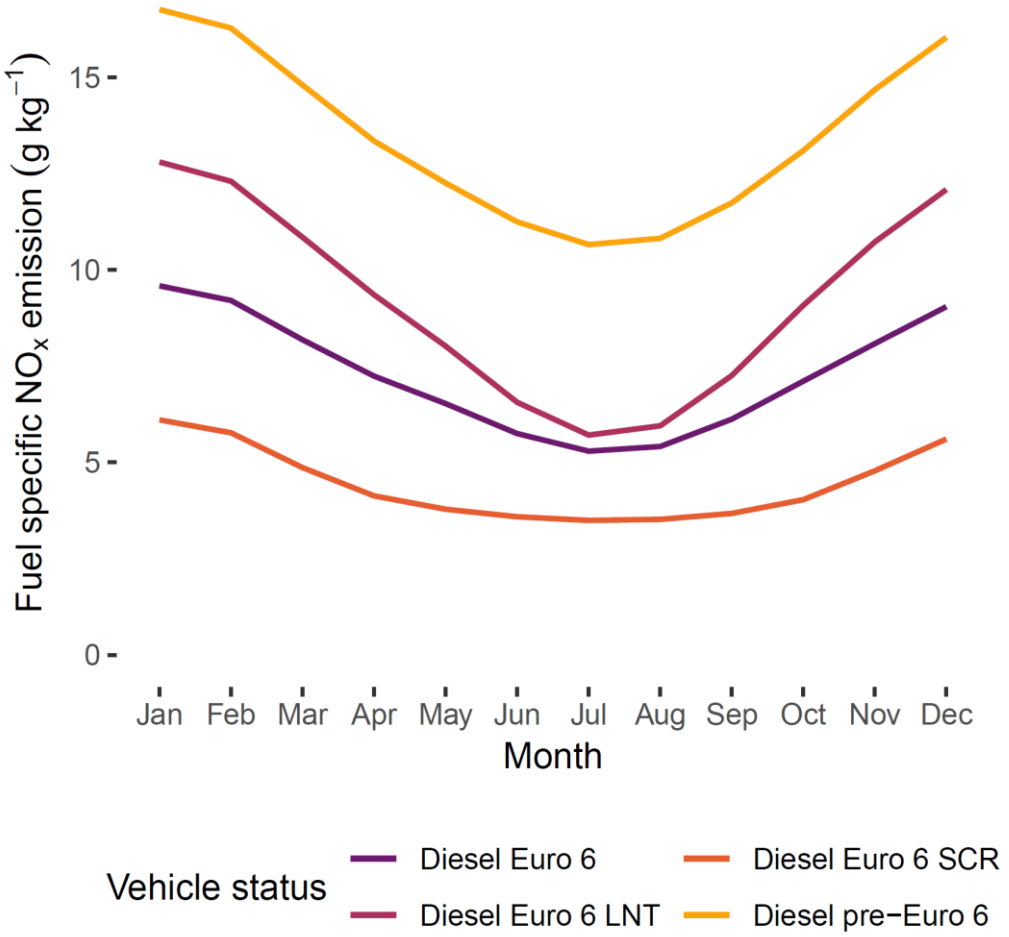
- Consider all light duty diesel vehicles
- Large range of site types, ambient temperatures, driving conditions
- Split between gasoline / diesel
- Strong temperature dependence for light duty diesel vehicles – separate from any cold start effects



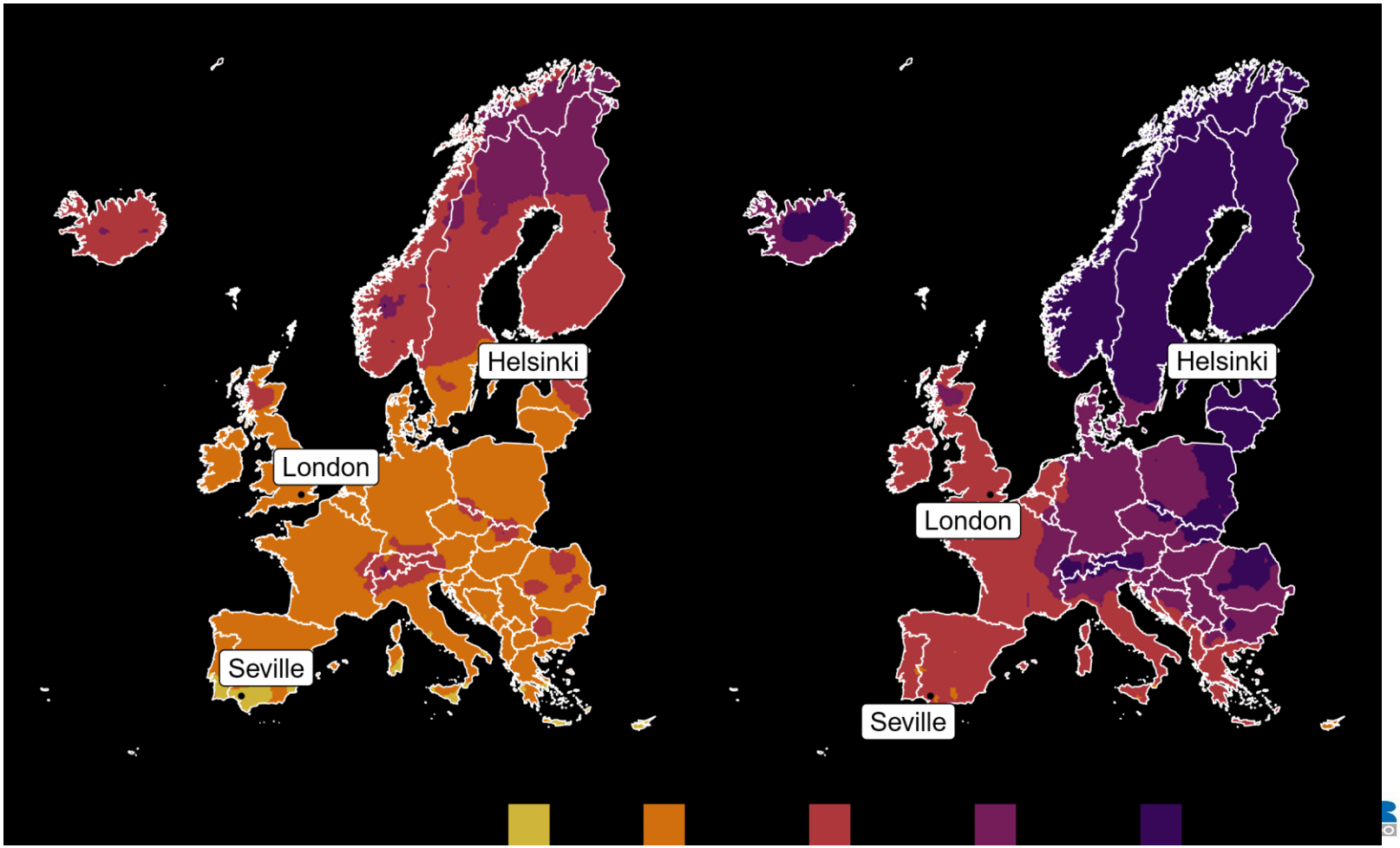
Grange, S.K., Farren, N.J., Vaughan, A.R., Rose, R.A. and D.C. Carslaw (2019). Strong temperature dependence for light-duty diesel vehicle NO_x emissions. *Environmental Science & Technology*. 53, 6587–6596. https://doi.org/10.1021/acs.est.9b01024.

Effect of ambient temperature

- Increased use of Euro 6 SCR diesels could have important implications
- Important for air quality …
  - Low temperatures can lead to less efficient dispersion (stable atmosphere)
  - Increased emissions and less efficient dispersion → increased concentrations
  - Should lead to a more rapid decrease in NO_x than we currently think – and especially under winter episode conditions

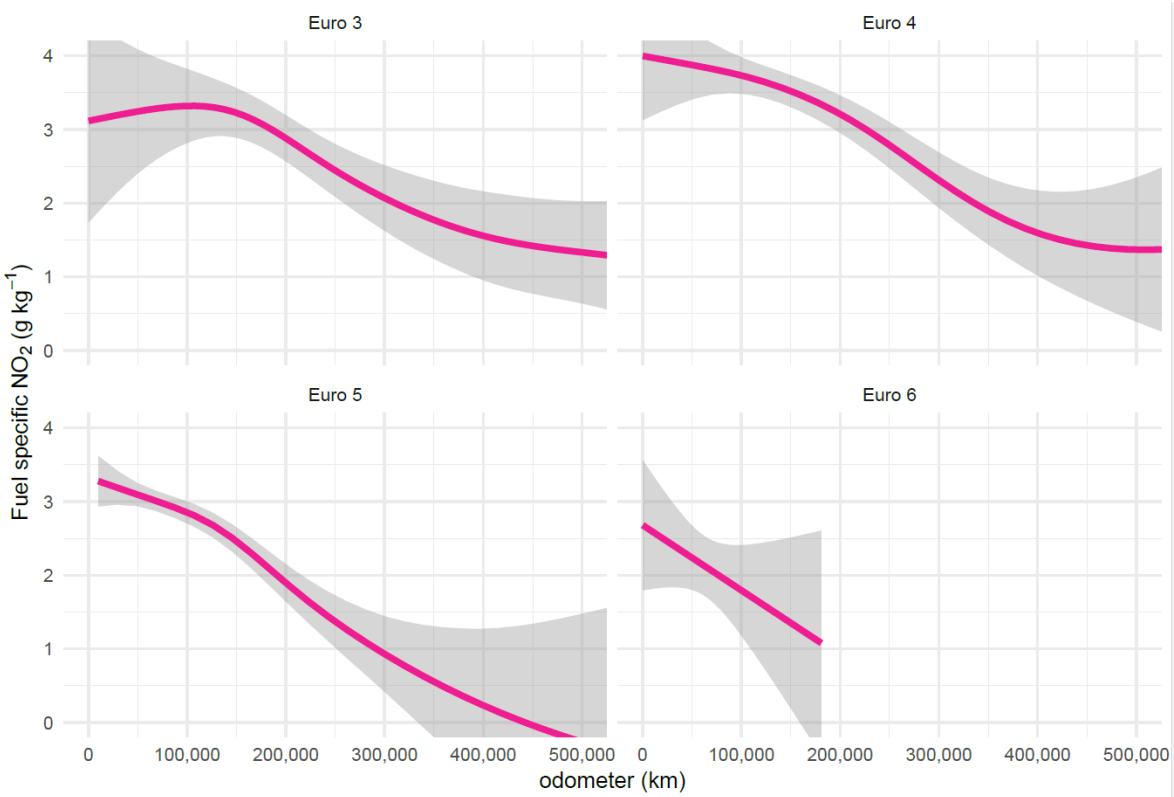


Ambient temperature 'penalty' across Europe – annual and winter



Effect of vehicle mileage on emissions of NO_2 from diesel cars

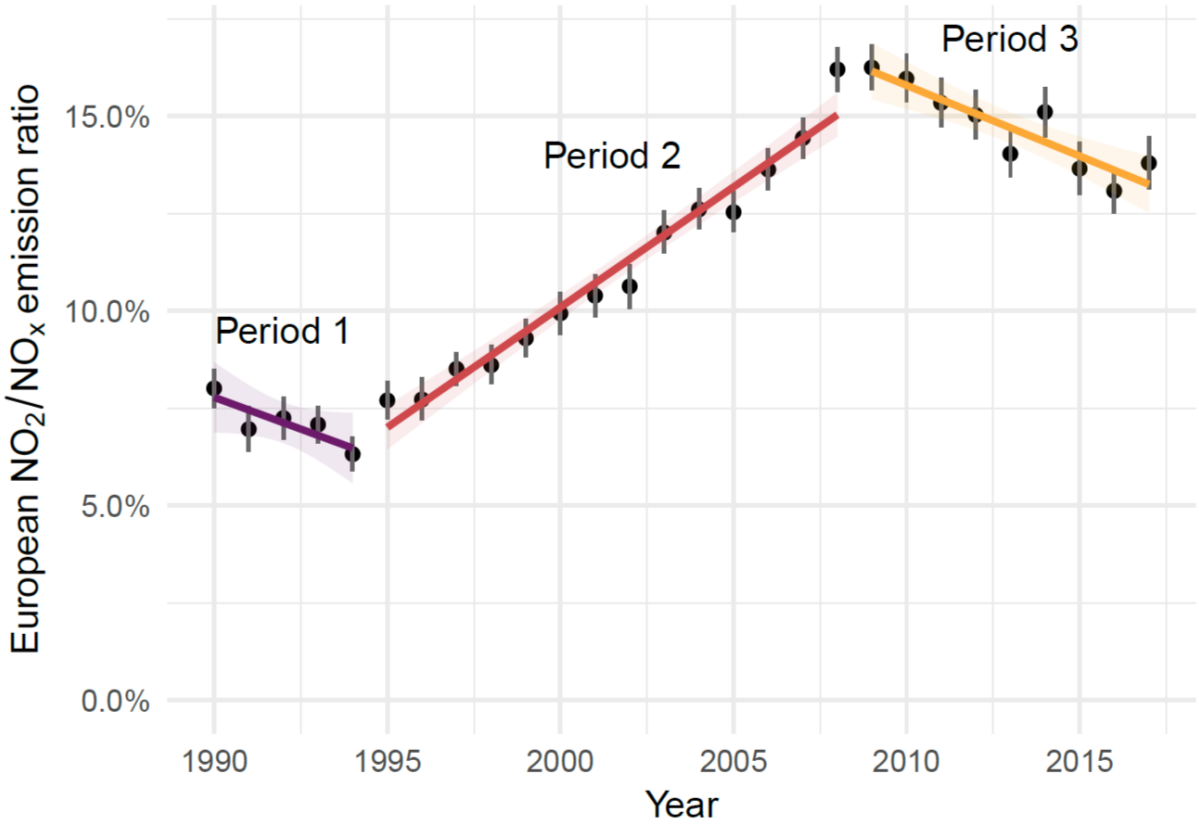
- Emissions of NO_2 decrease with increasing vehicle mileage*
  - Catalyst deactivation, other factors
- Emission factors do not account for this effect
- Could lead to pessimistic future projections of ambient NO_2 concentrations (f-NO_2 assumed to be too high)
  - … where it is most important i.e. close to roads



*Carslaw, D.C., Farren, N.J., Vaughan, A.R., Drysdale, W. S., Young, S. and J. D. Lee The diminishing importance of nitrogen dioxide emissions from road vehicle exhaust (2019), *Atmospheric Environment: X*. Vol. 1, 100002.

Decreasing primary NO_2 across Europe

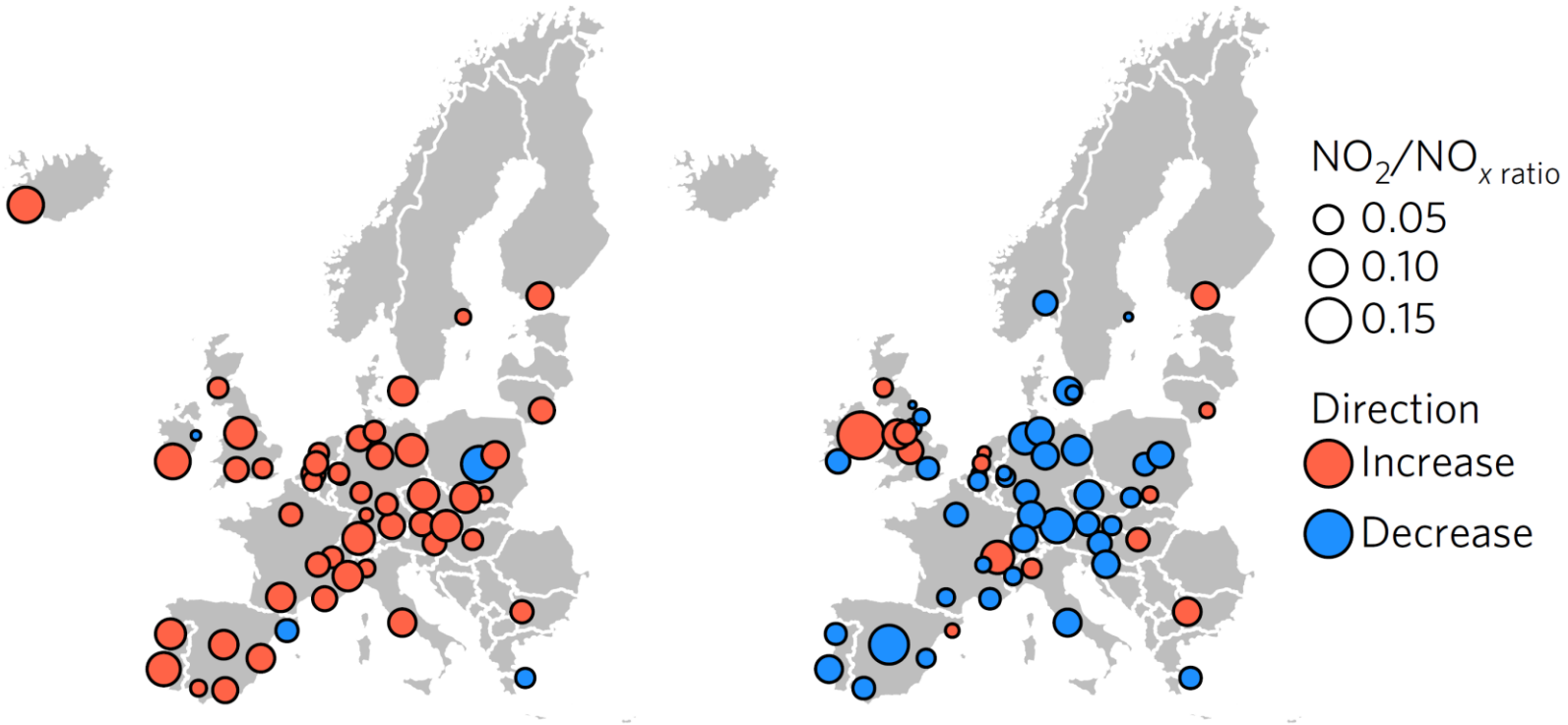
- Consider ambient roadside measurements in 61 urban areas
  - > 300 million hourly measurements
- Estimate mean traffic f-NO_2
- Clear decrease around 2009/2010



*Grange, S. K. Lewis, A. C., Moller, S. J. and D. C. Carslaw (2017) 'Lower vehicular primary emissions of NO_2 in Europe than assumed in policy projections', *Nature Geoscience*, 10(12), pp. 914–918.

Primary NO_2 is *decreasing* across Europe

- Up to around 2010 primary NO_2 was increasing (left plot); post 2010 (right plot) there are clear decreases*
- Could lead to pessimistic future projections of ambient NO_2 concentrations



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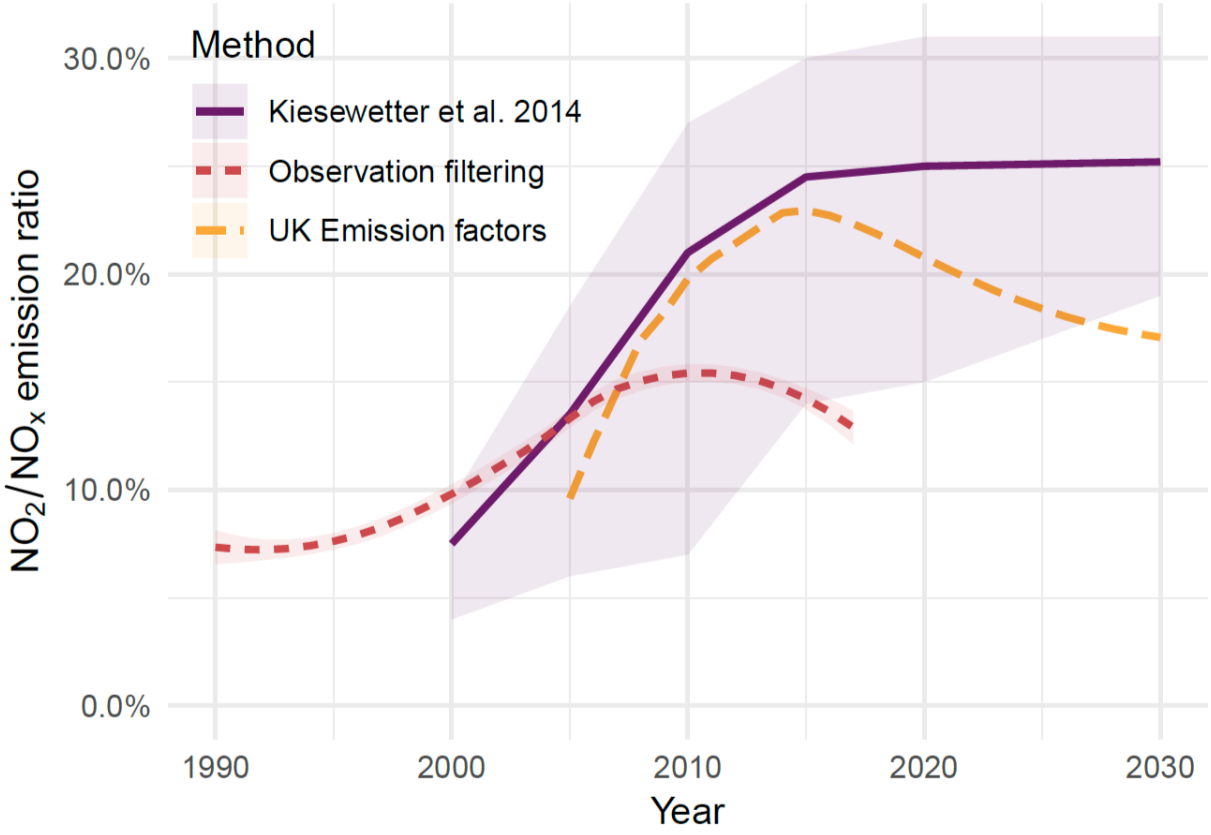
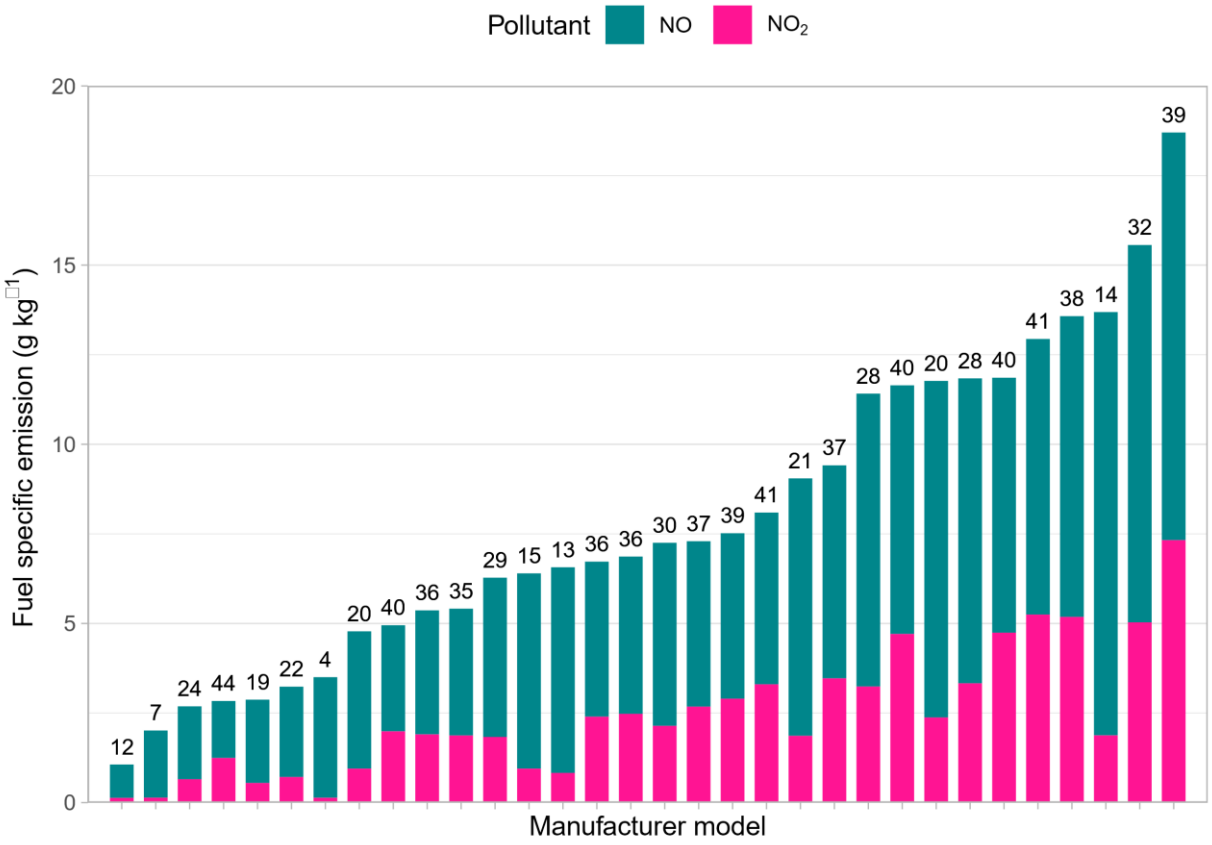
Comparison with emission factor models

- Observed f-NO_2 considerably less than EMISIA/ COPERT/ HBEFA factors
- Factors do not take account of mileage deterioration effects on emissions of NO_2
- Remote sensing data is useful in this respect



Amount of NO_x that is NO_2 for Euro 6b diesel cars

- Show by (anonymised) manufacturer
- Very large range in overall NO_X performance
- Can have low total NO_x ***and*** low proportion of NO_2
- Very low absolute emissions of NO_2 become irrelevant from an air quality perspective



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Concluding remarks

- The European NO_2 problem – two principal causes:
  - Total NO_x emissions from light duty vehicles have not reduced as expected
  - Increased emissions of direct NO_2 due to DOC / DPF
- Emissions of NO_x and NO_2 have peaked
  - Large differential performance by manufacturer in current fleet
- Effect of ambient temperature is (and has been) important and has implications for future projections of NO_x
- As diesel car mileage increases, NO_2 emissions decrease and are now much lower than currently assumed in emission factor models
  - What about other vehicles?

Concluding remarks

- Need to think about other impacts
  - The wider impacts of NO_x
  - Emissions of ammonia – unlike agricultural sources, emitted with NO_x and a more effective route to secondary particulate?
  - Move away from diesel and consequences for CO_2

Acknowledgements

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Early 'remote sensing' measurements at the Warren Spring Laboratory (predecessor to Ricardo Energy & Environment) from the early 1960s

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