



## London's air in flux

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# Which air pollution management policies are working?

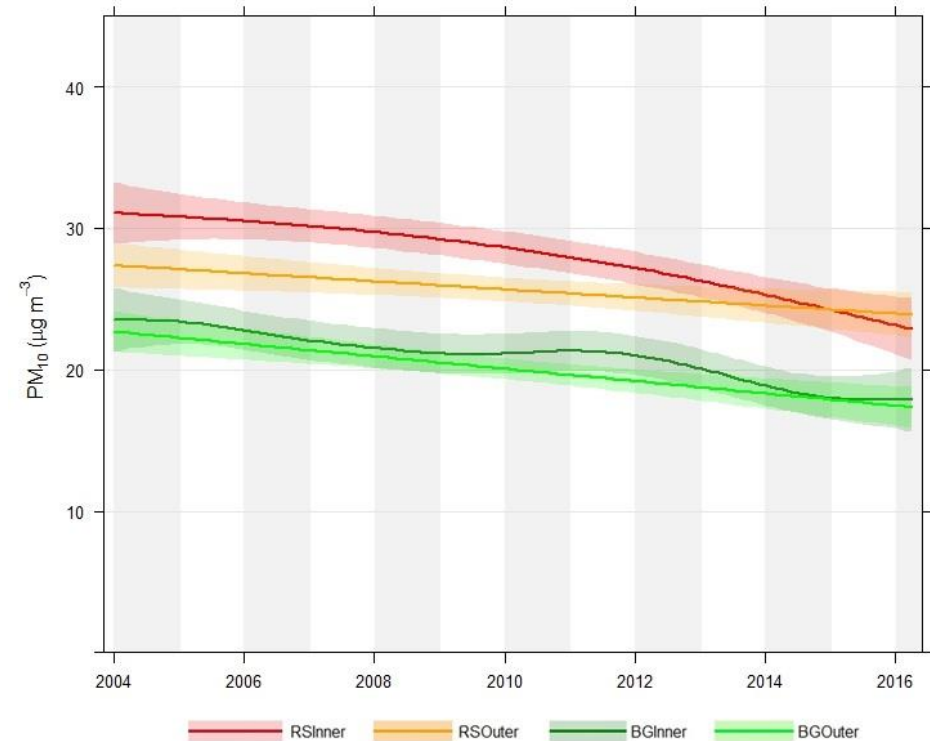
- A large number of policy initiatives are being taken in London, the UK and the EU to improve air quality
  - TfL bus retrofit program, LEZ, EURO classes, etc.
- Difficult to evaluate which policy is working best / at all since we don't have intervention vs control.
- Why not look for the places where air pollution is improving fastest to find the best policy package?

EURO emission standards for passenger cars, g/km					
Tier	Date	CO	NOx	PM	P [# /km]
<b>Diesel</b>					
Euro 1†	Jul-92	2.72 (3.16)	-	0.14	-
Euro 2	Jan-96	1	-	0.08	-
Euro 3	Jan-00	0.64	0.5	0.05	-
Euro 4	Jan-05	0.5	0.25	0.025	-
Euro 5a	Sep-09	0.5	0.18	0.005	-
Euro 5b	Sep-11	0.5	0.18	0.005	6×10 <sup>11</sup>
Euro 6	Sep-14	0.5	0.08	0.005	6×10 <sup>11</sup>
<b>Petrol (Gasoline)</b>					
Euro 1†	Jul-92	2.72 (3.16)	-	-	-
Euro 2	Jan-96	2.2	-	-	-
Euro 3	Jan-00	2.3	0.15	-	-
Euro 4	Jan-05	1	0.08	-	-
Euro 5	Sep-09	1	0.06	0.005**	-
Euro 6	Sep-14	1	0.06	0.005**	6×10 <sup>11</sup> ***

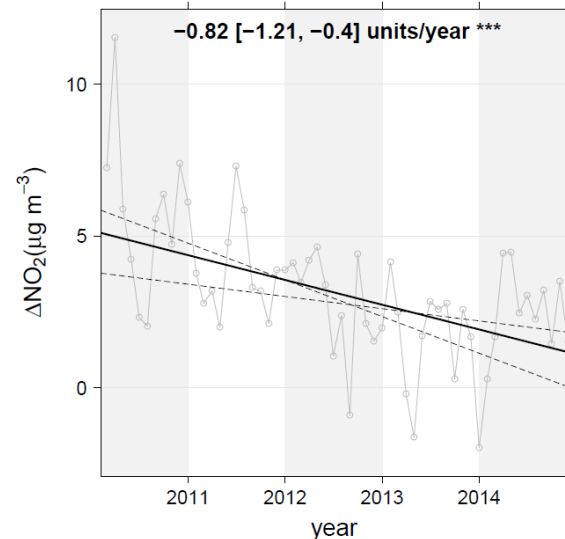


# Which air pollution management policies are working?

- Standard approaches look at single sites of aggregate metrics across an area.
- This is can be subject to preferential sampling and other bias
- Masks heterogeneity.



# Methods



- **65 traffic** locations in London
- **Trends in roadside increments** (background concentration removed) of air pollutants ( $\Delta$ )
- > 75% data capture
- **Trends** calculated between **2005-09** and **2010-14** (inc)
- $\Delta\text{NO}_x$ ,  $\Delta\text{NO}_2$ ,  $\Delta\text{PM}_{10}$ ,  $\Delta\text{PM}_{2.5}$ ,  $\Delta\text{BC}$ ,  $\Delta\text{CO}_2$
- Trends calculated using the **Theil-Sen estimator** adjusted for seasonality: trend +/- 95% confidence interval (R-Open-Air, Carslaw & Ropkins)
- Overall trend calculated by **meta-analysis** (linear **random-effects model**)
  - more weight is given to sites with less variance ( $v_i$ ) and more precision ( $w_i = 1/v_i$ )
- As a 2<sup>nd</sup> stage **k means** was used to cluster roads by behaviour

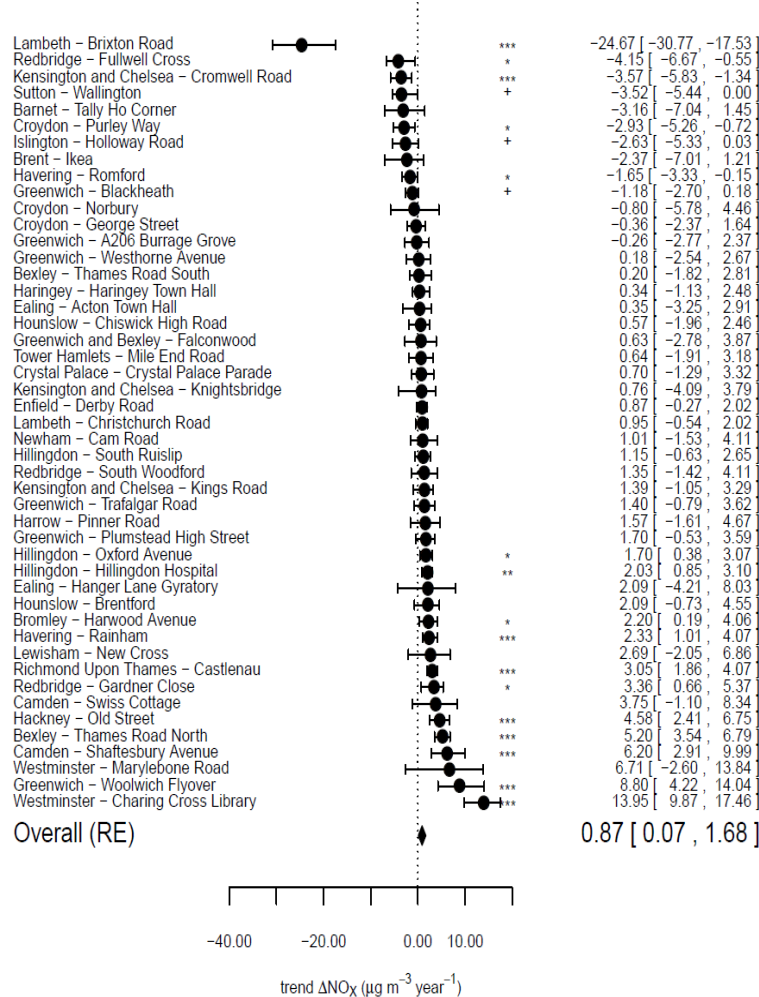
# Results: trends 2005 - 2009

## trends in $\Delta\text{NO}_x$

## trends in $\Delta\text{NO}_2$

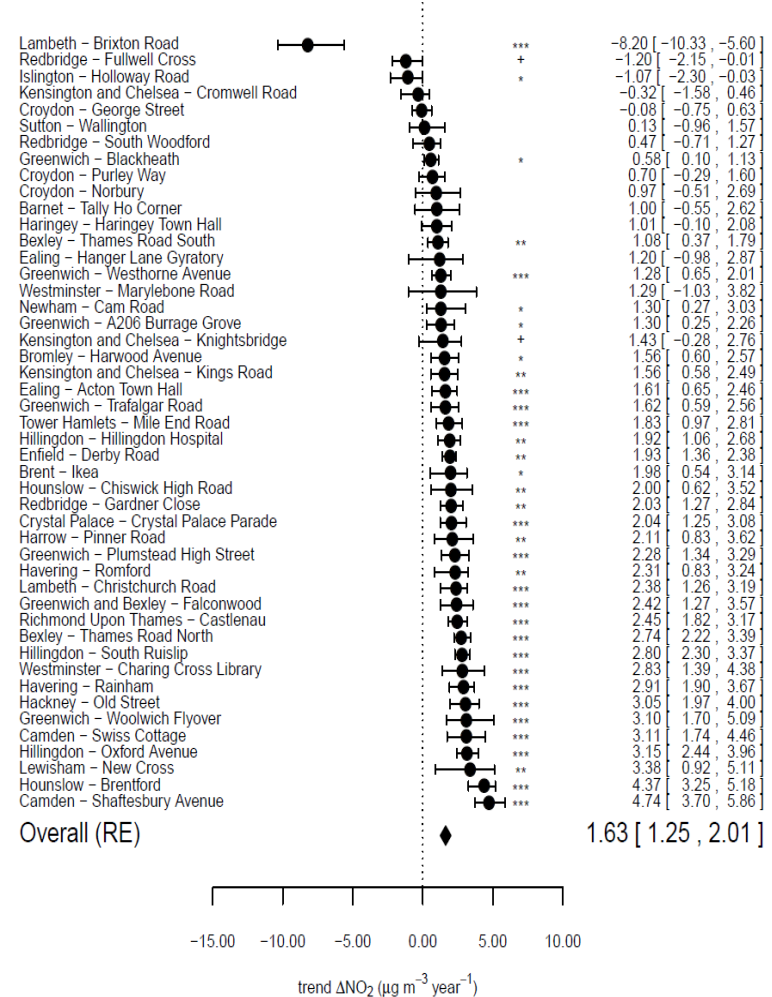
### A

Trends 2005 - 2009



### B

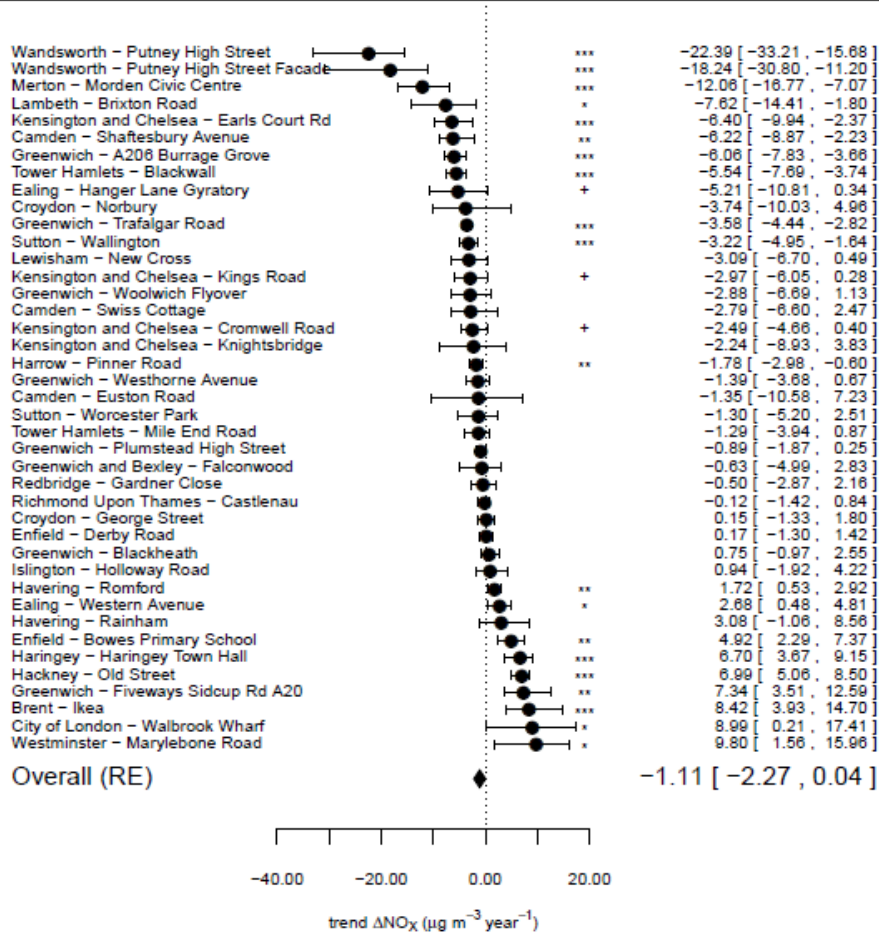
Trends 2005 - 2009



### C

# Results: trends 2010 - 2014

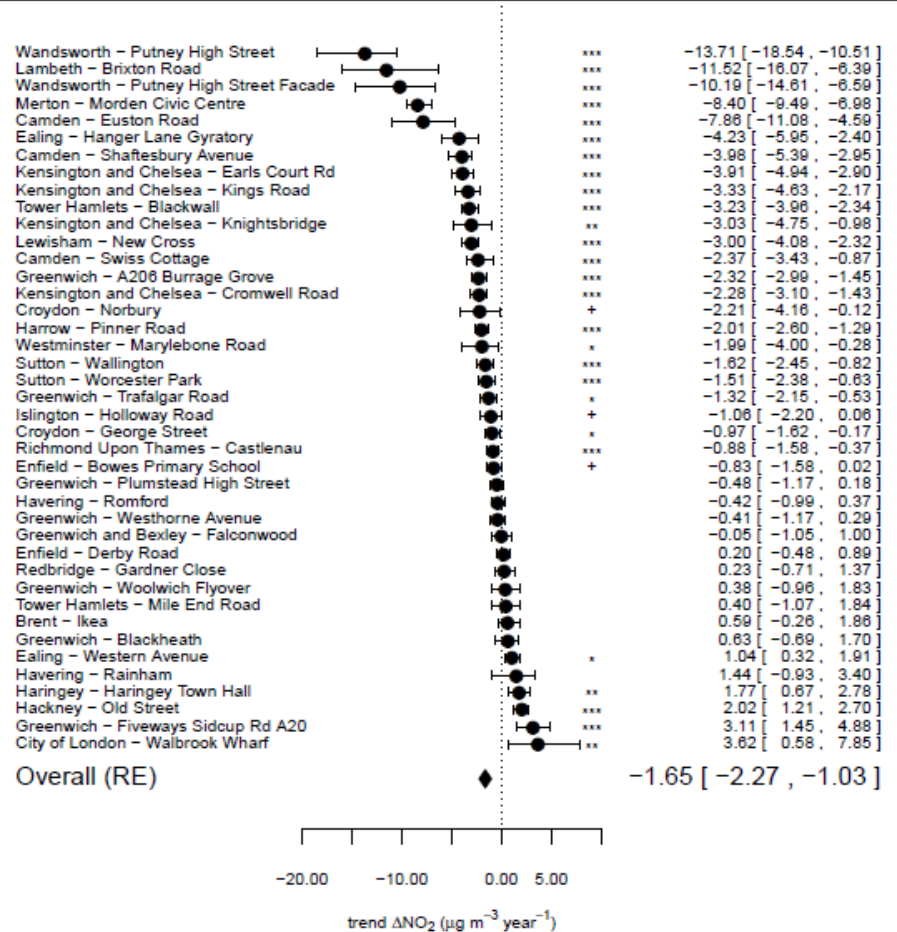
## trends in $\Delta\text{NO}_x$



Annual mean: 116.68 [ 106.34 , 127.02 ]

Overall trend  $\Delta\text{NO}_x$ : -0.95% year<sup>-1</sup>

## trends in $\Delta\text{NO}_2$



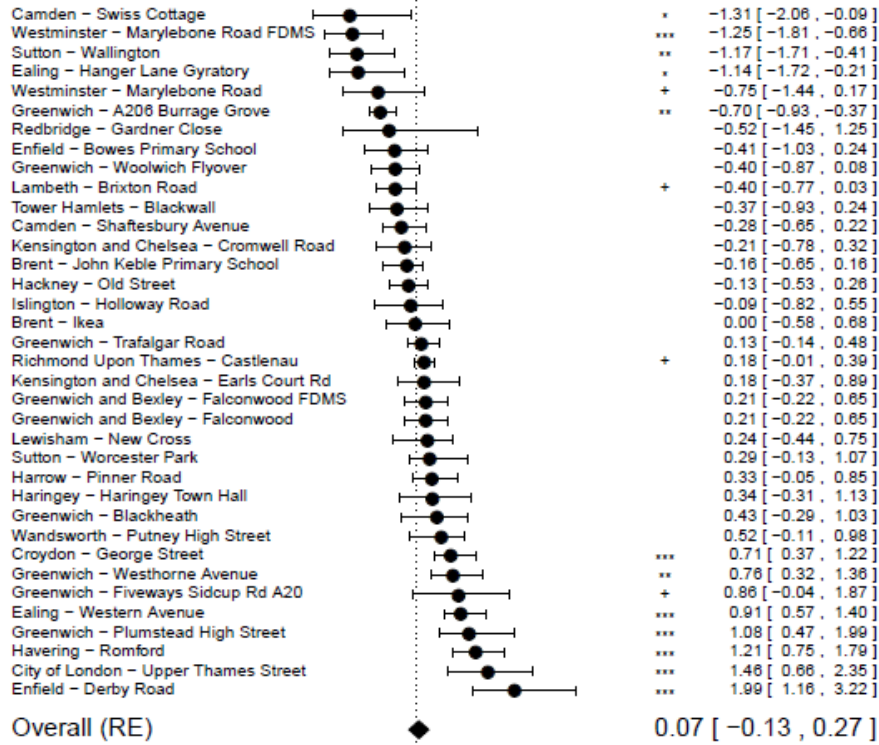
Annual mean: 34.12 [ 31.55 , 36.68 ]

Overall trend  $\Delta\text{NO}_2$ : -4.84% year<sup>-1</sup>

# Results: trends 2010 - 2014

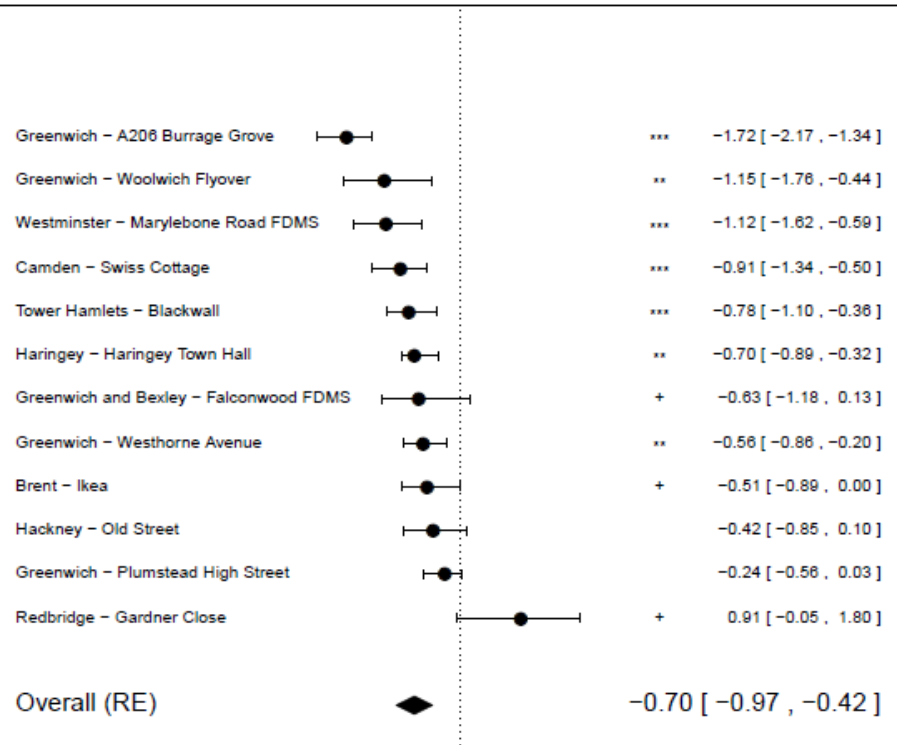
trends in  $\Delta PM_{10}$

trends in  $\Delta PM_{2.5}$



Annual mean: 6.33 [ 5.72 , 6.95 ]

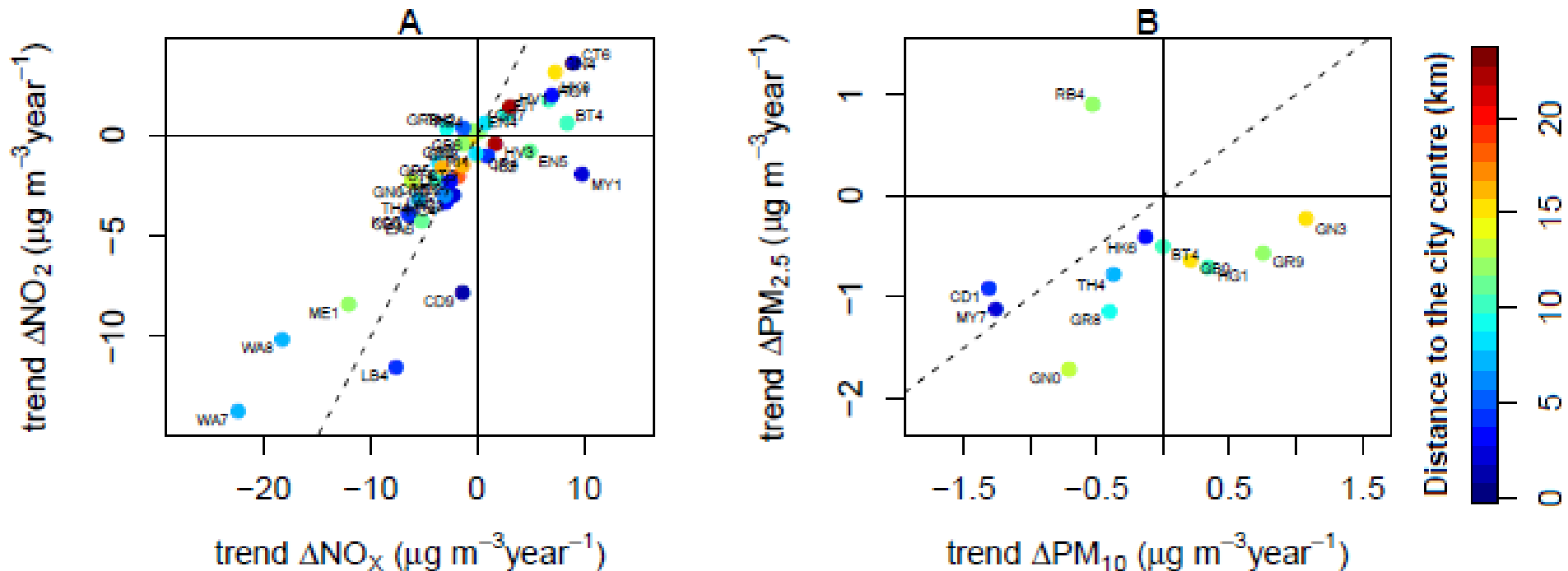
Overall trend  $PM_{10}$ : 1.11% year<sup>-1</sup>



Annual mean: 2.47 [ 1.78 , 3.17 ]

Overall trend  $\Delta PM_{2.5}$ : -28.4% year<sup>-1</sup>

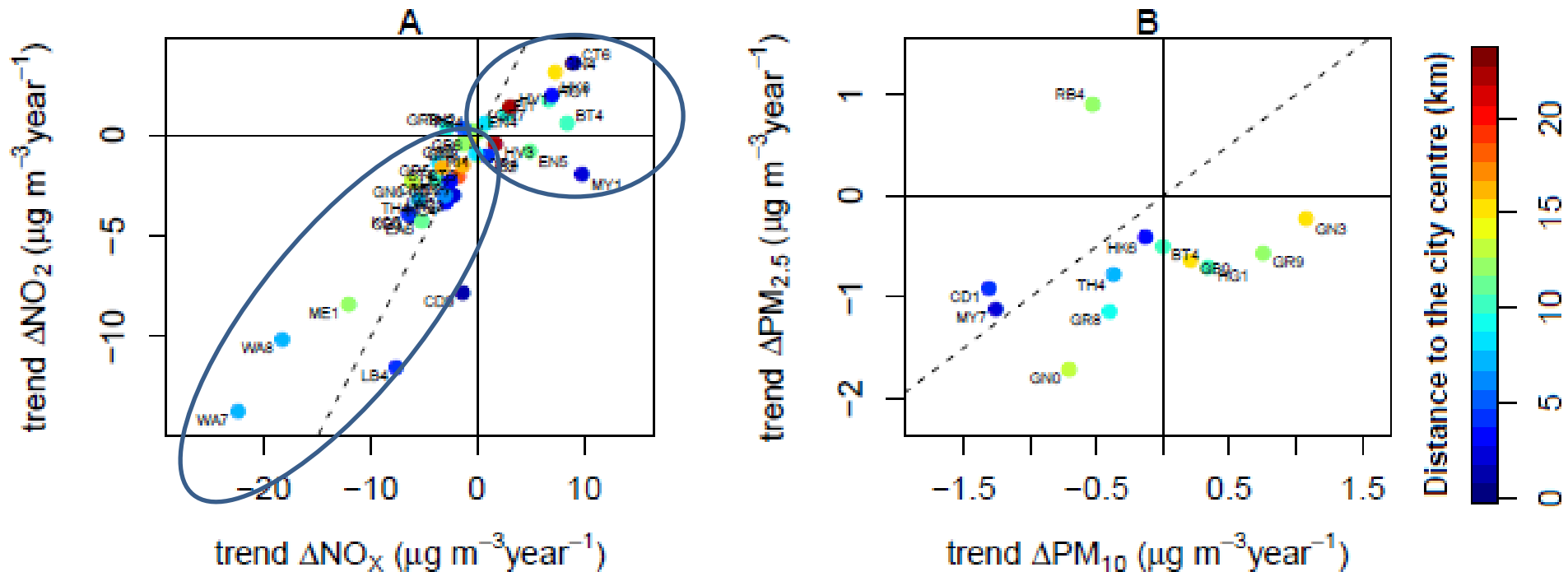
# Comparing pollutant trends 2010 - 2014



MRC-PHE  
Centre for Environment & Health

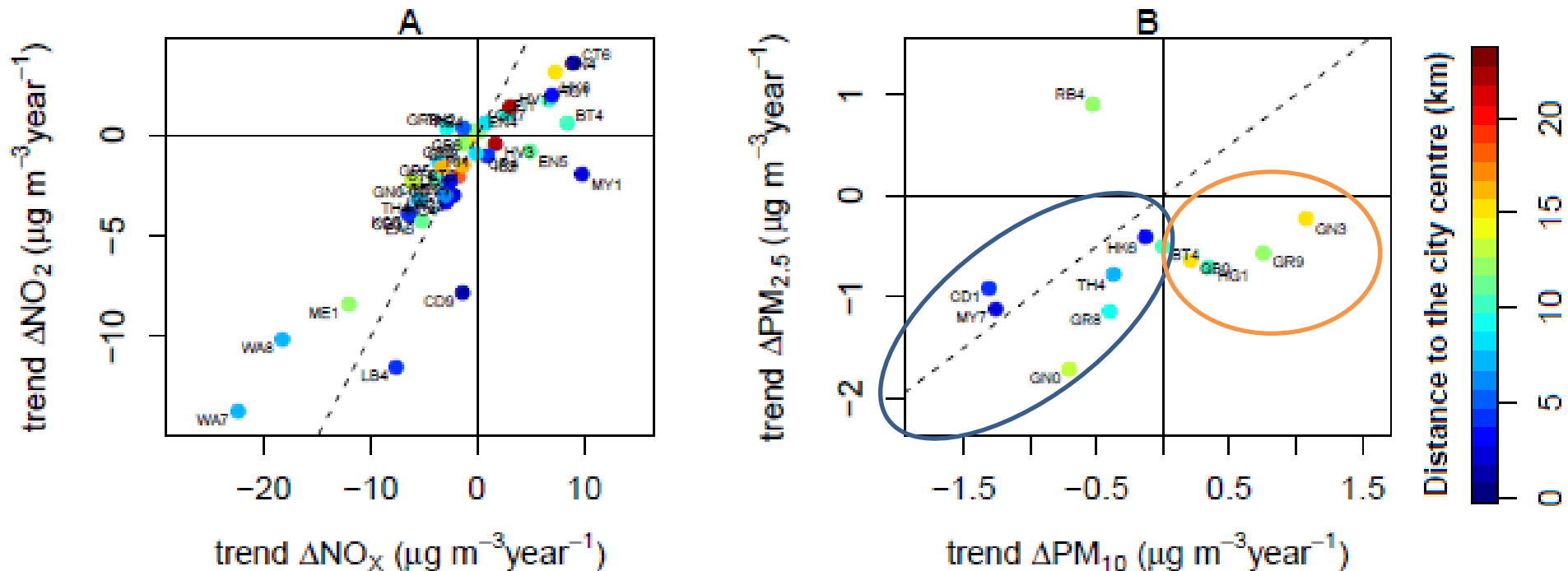


# Comparing pollutant trends 2010 - 2014



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# Comparing pollutant trends 2010 - 2014

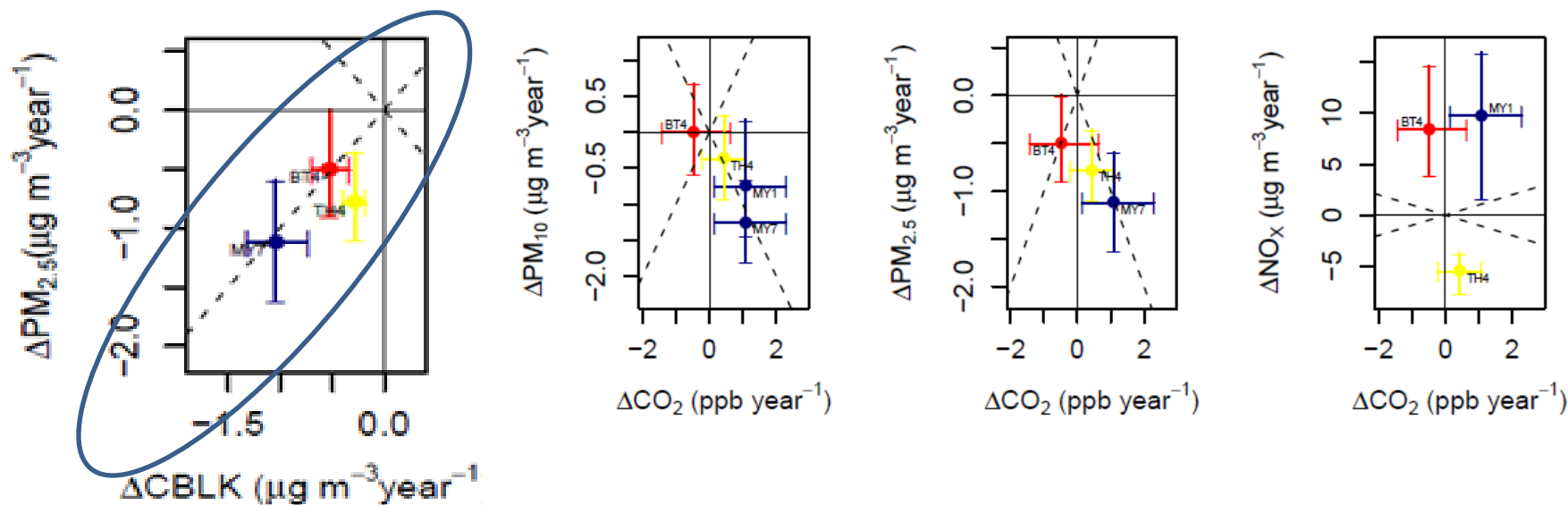


# Comparing pollutant trends 2010 - 2014

CO<sub>2</sub>

Black Carbon

	Westminster Marylebone Rd	Brent Ikea	Tower Hamlets Blackwall
$\Delta\text{CO}_2$ (ppm y <sup>-1</sup> )	1.08 (0.14, 2.29) <sup>*</sup>	-0.48 (-1.42, 0.64)	0.44 (-0.20, 1.08)
$\Delta\text{CBLK}$ (μg m <sup>-3</sup> y <sup>-1</sup> )	-1.04 (-1.32, -0.74) <sup>***</sup>	-0.53 (-0.70, -0.34) <sup>***</sup>	-0.28 (-0.39, -0.18) <sup>***</sup>

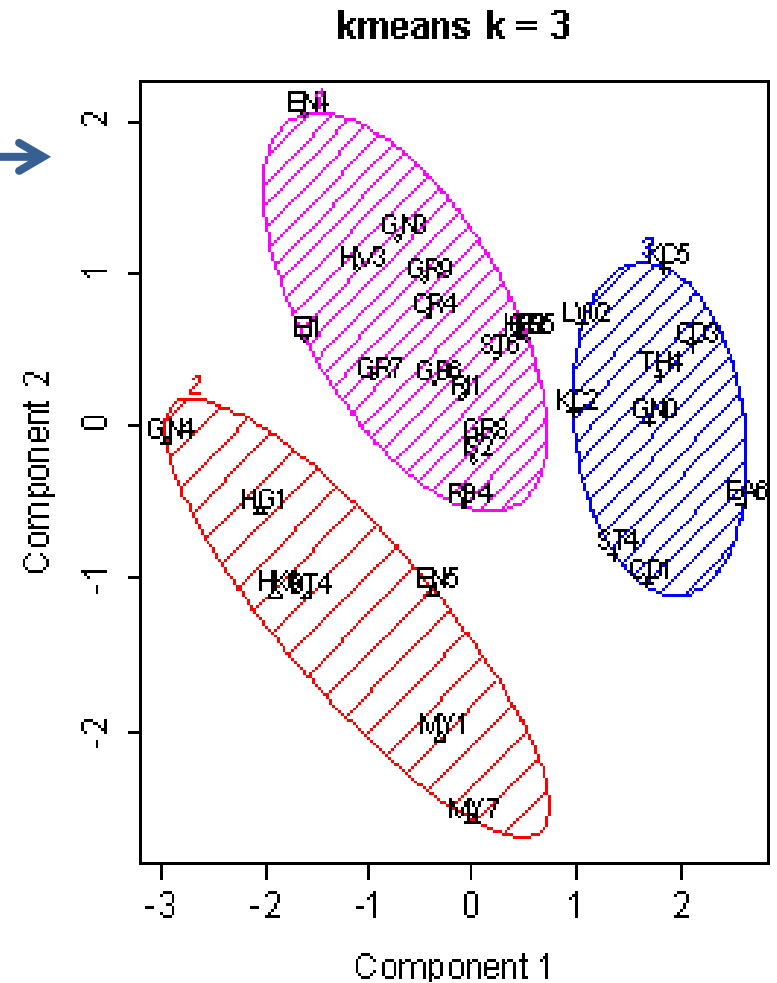
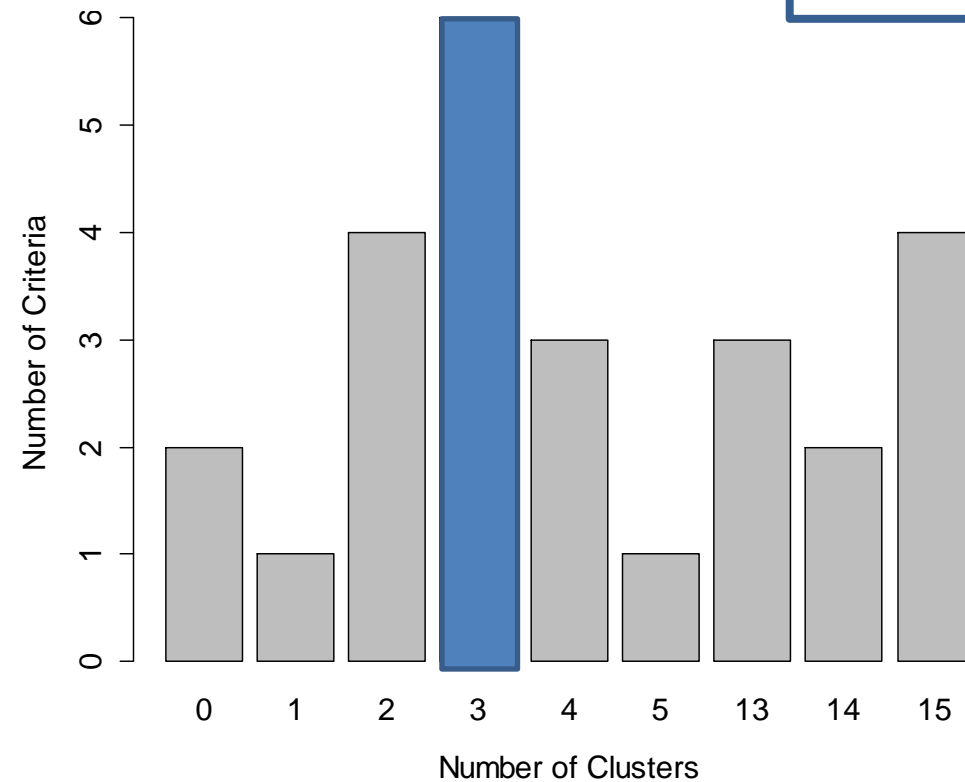
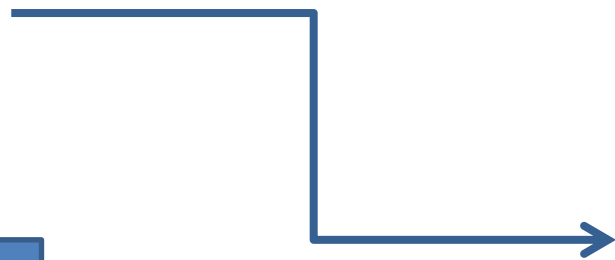


# Methods: finding patterns

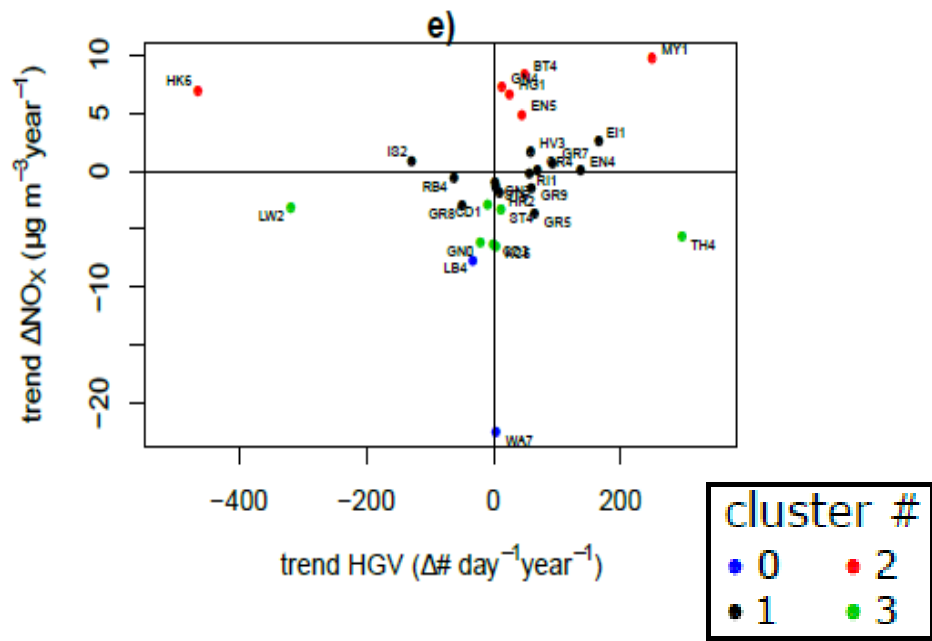
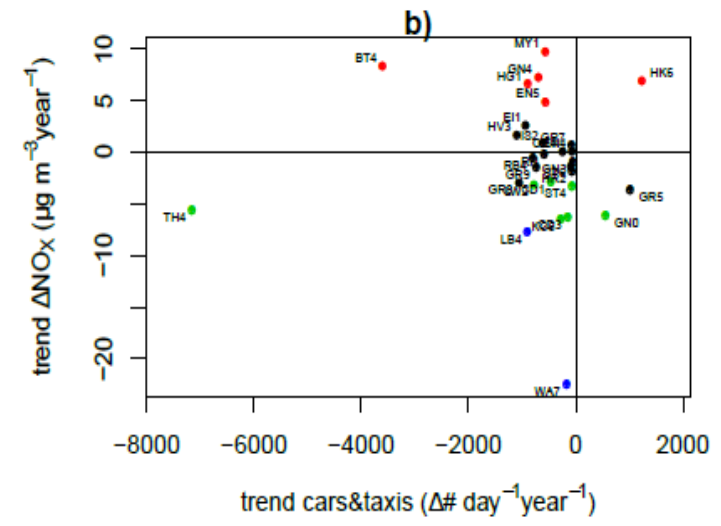
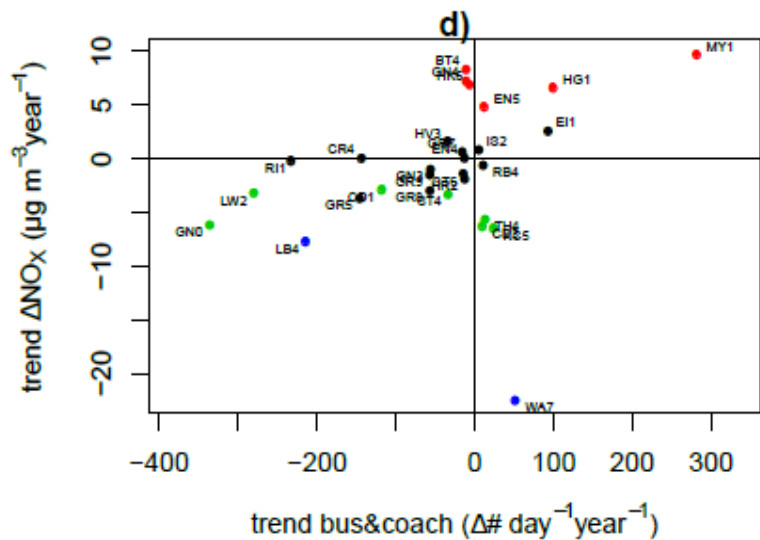
- *K-means* cluster analysis used to group sites with the most similar trends for the time period 2010-2014
- Variables: trends in  $\Delta\text{NO}_x$ ,  $\Delta\text{NO}_2$  and  $\Delta\text{PM}_{10}$
- Before clustering, each variable is normalized (mean = 0; variance = 1)
- Exclude Wandsworth – Putney High St and Lambeth – Brixton Road (outliers)

# Results: clustering sites

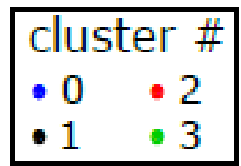
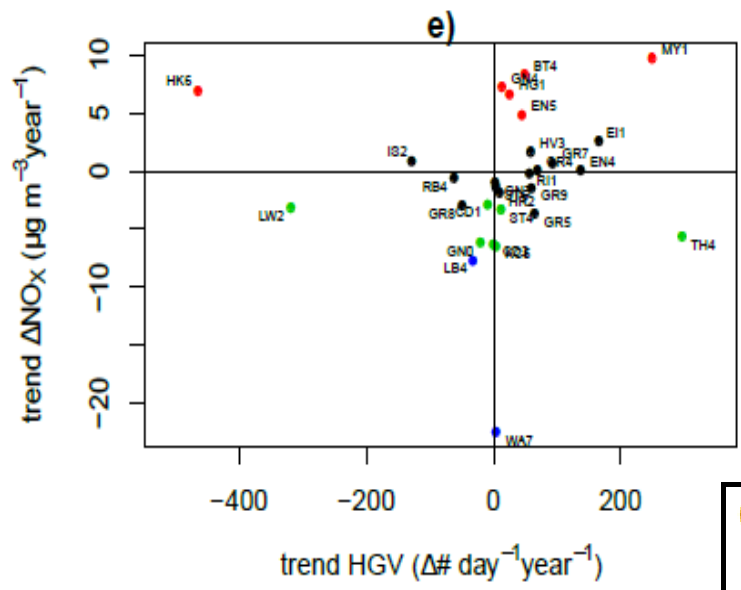
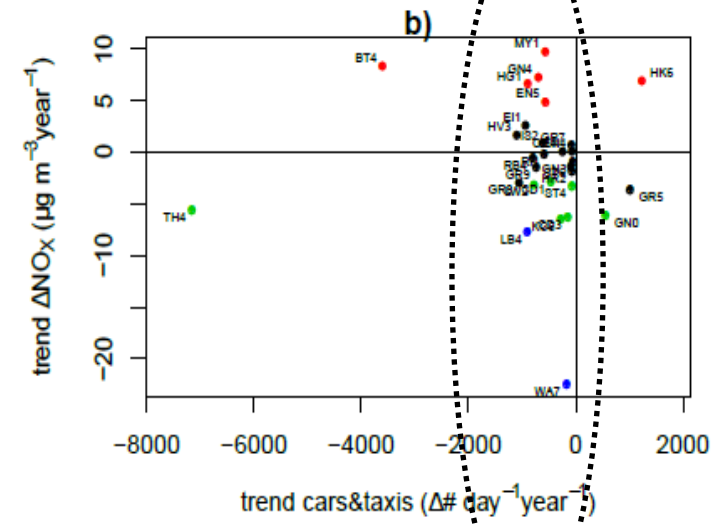
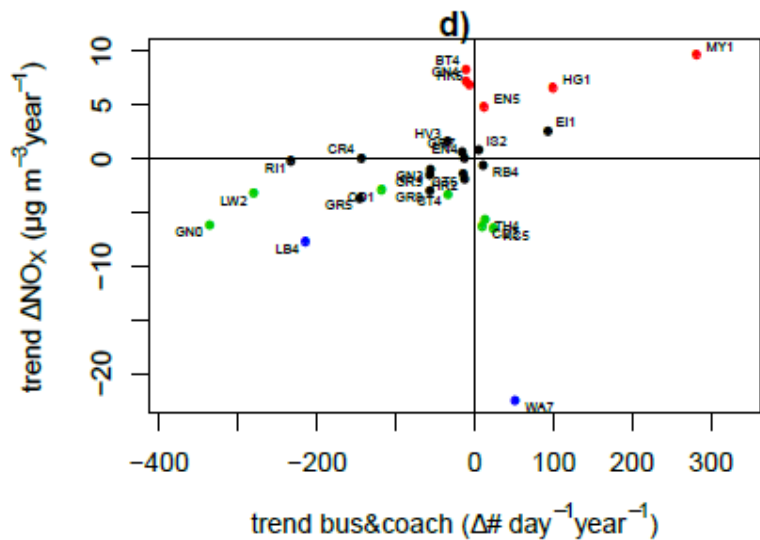
n = 31 sites



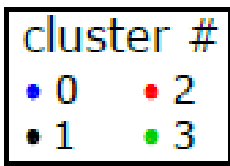
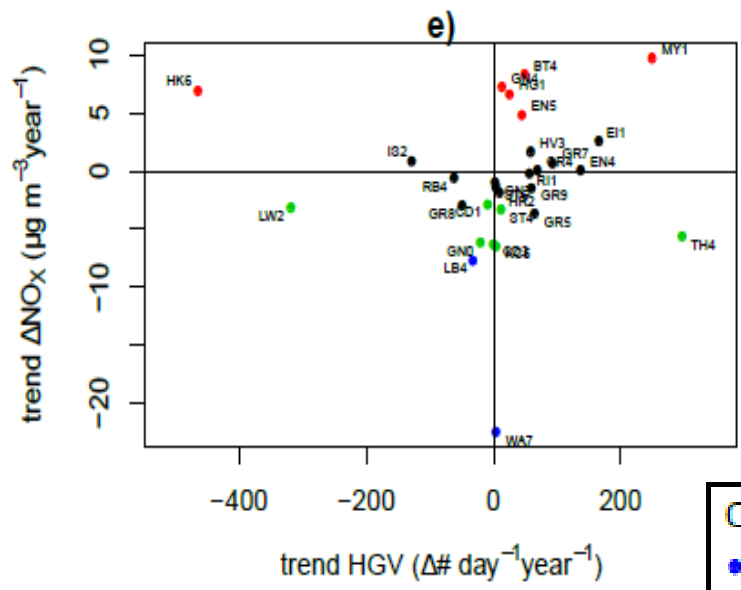
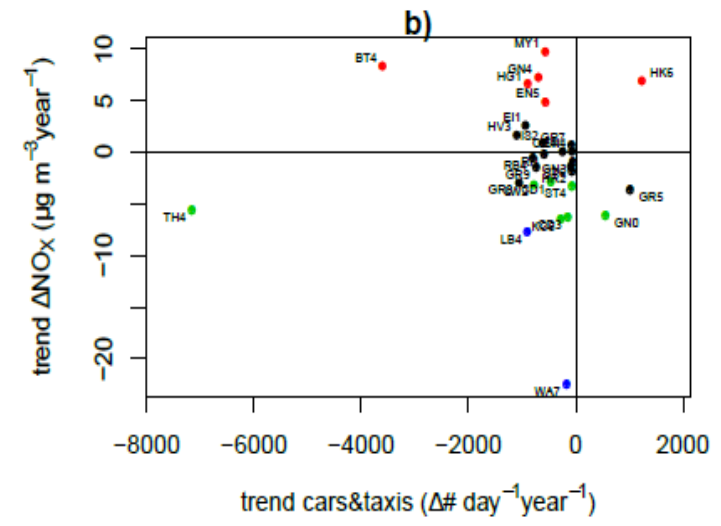
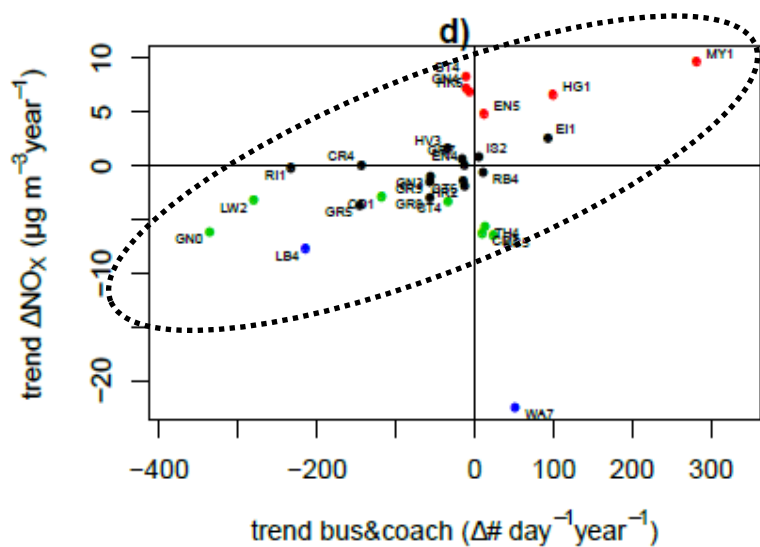
# Comparison to changes in traffic - NOX



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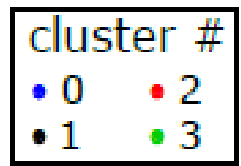
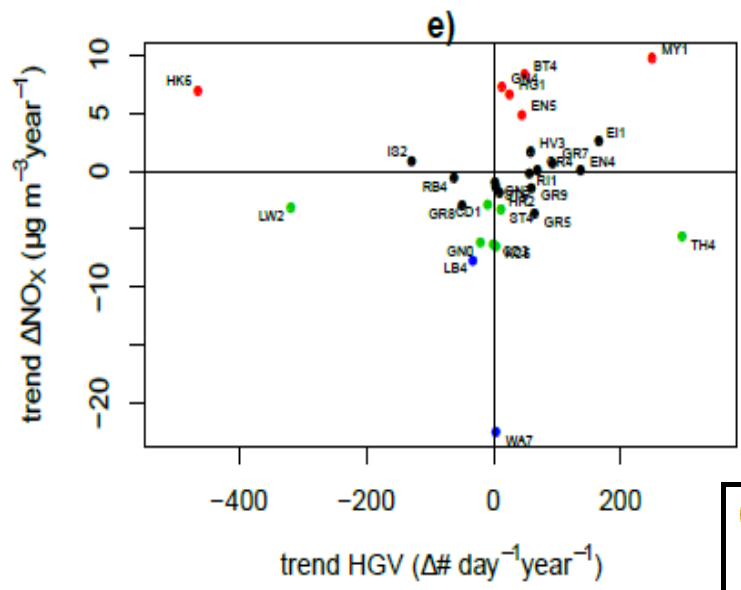
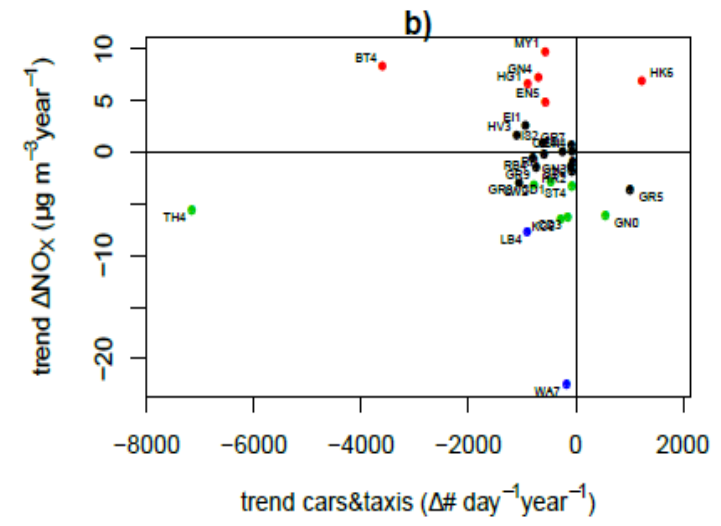
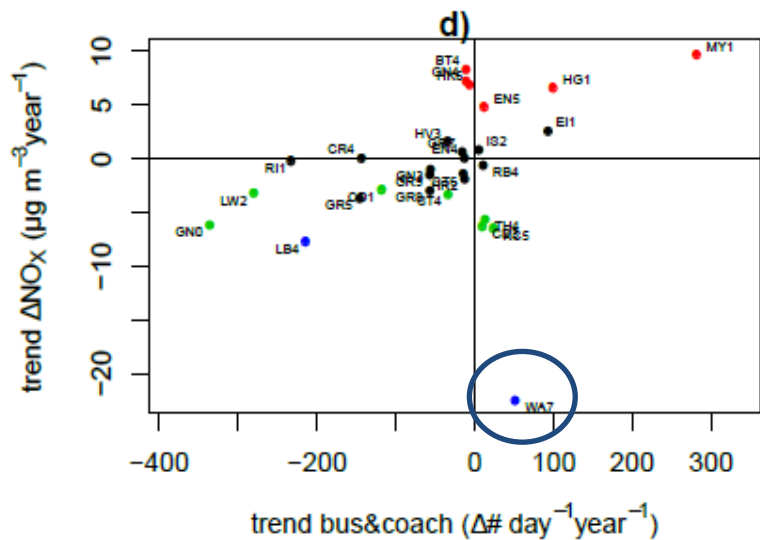


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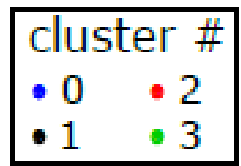
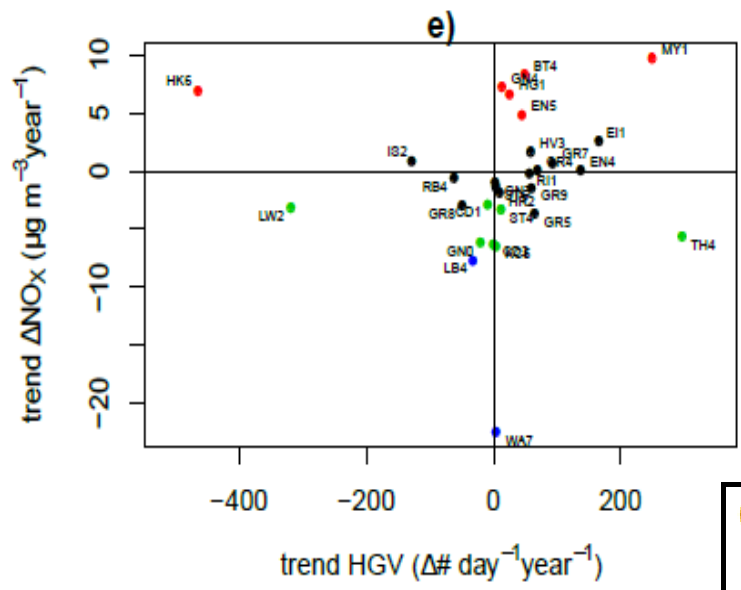
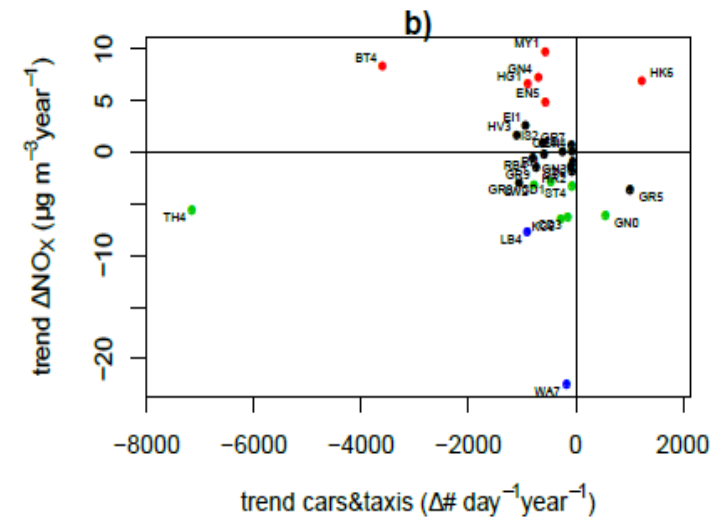
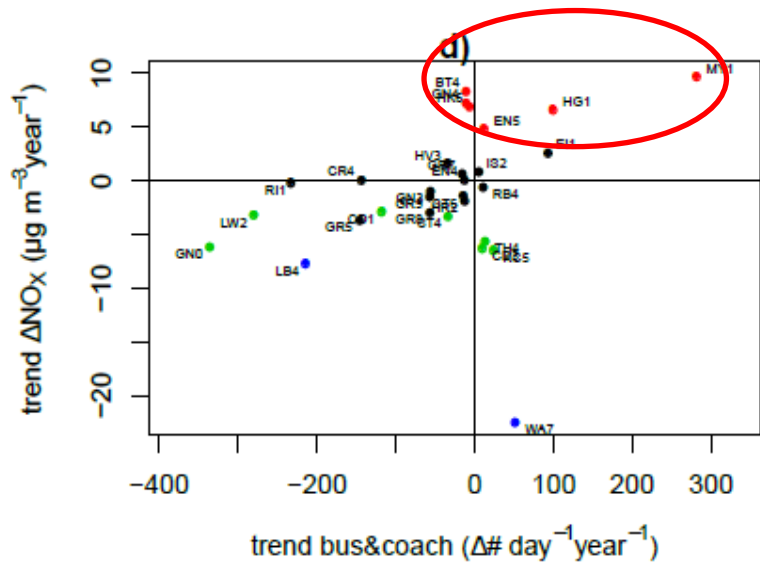




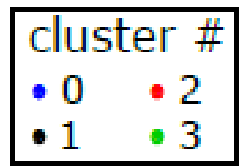
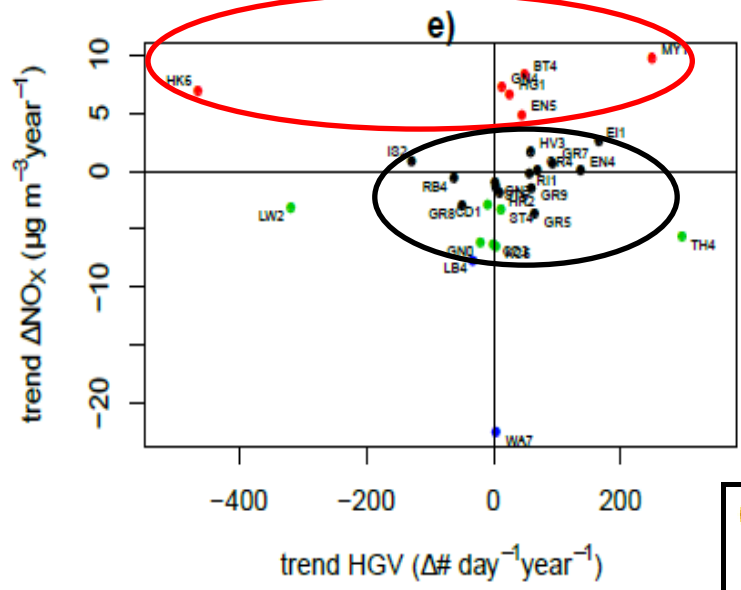
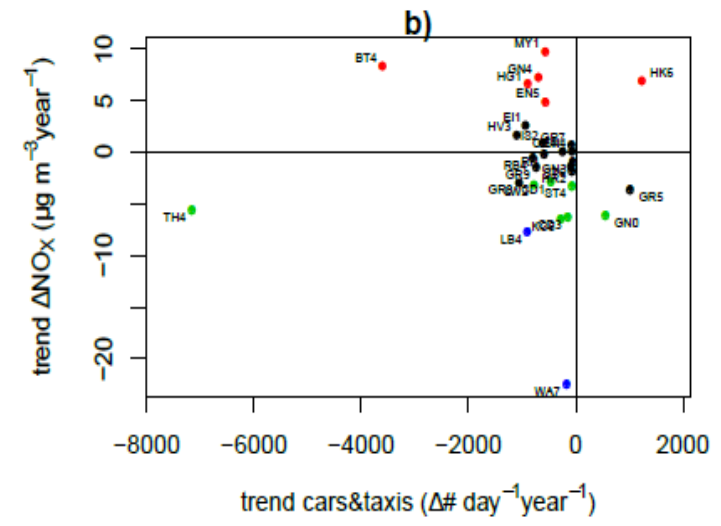
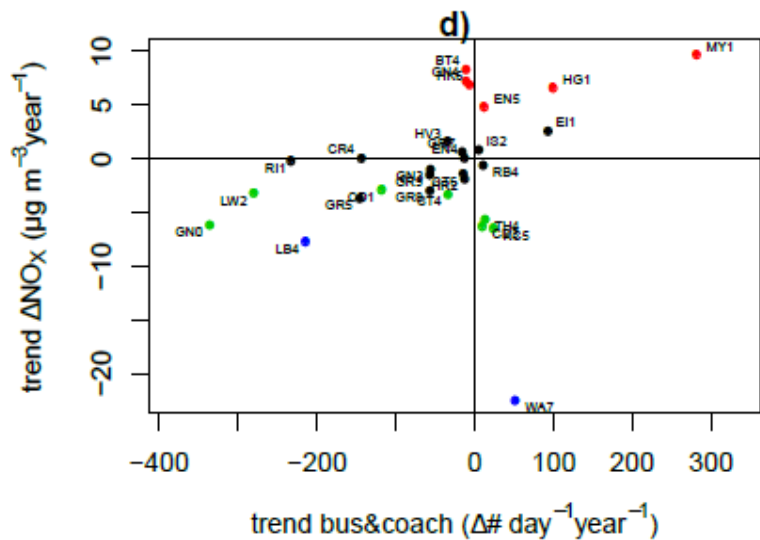
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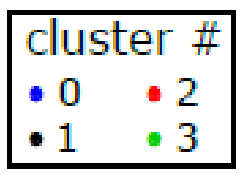
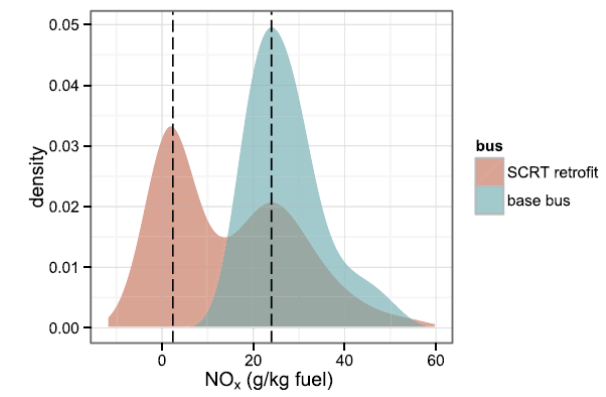
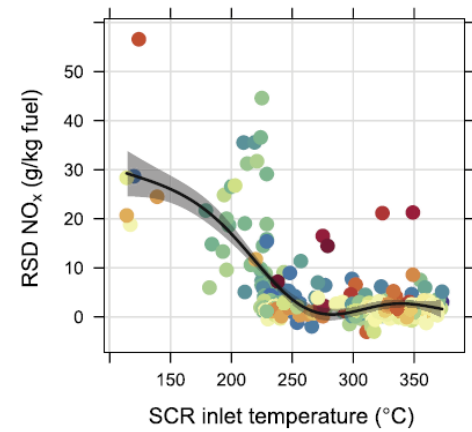
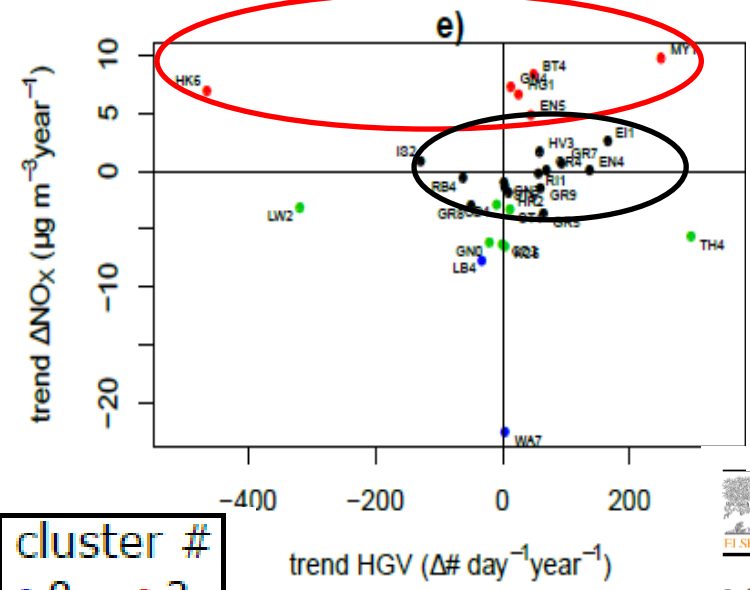
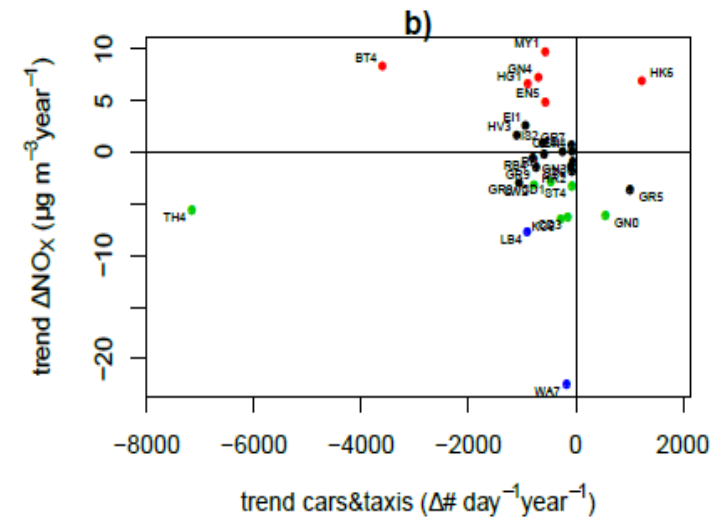
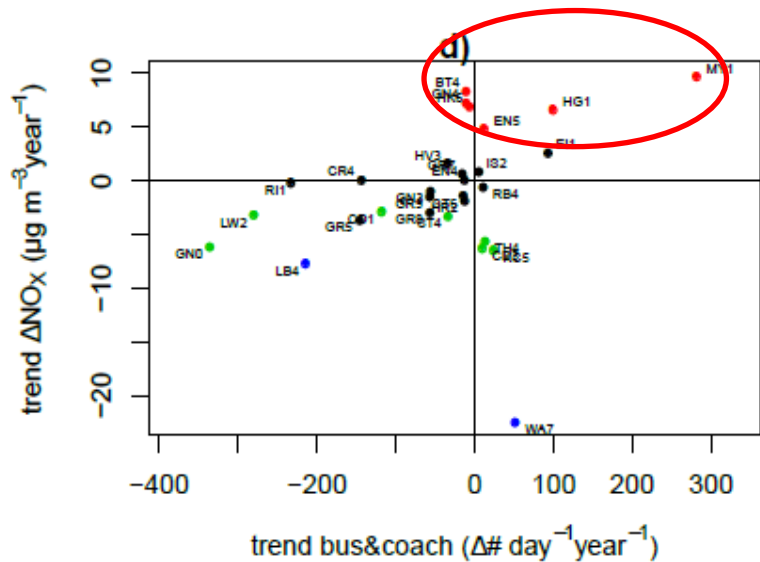
# Comparison to changes in traffic - NOX



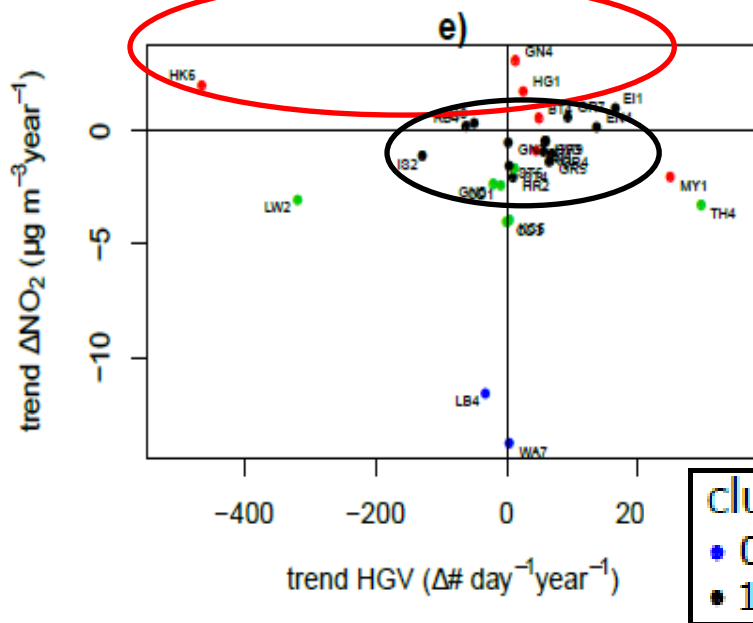
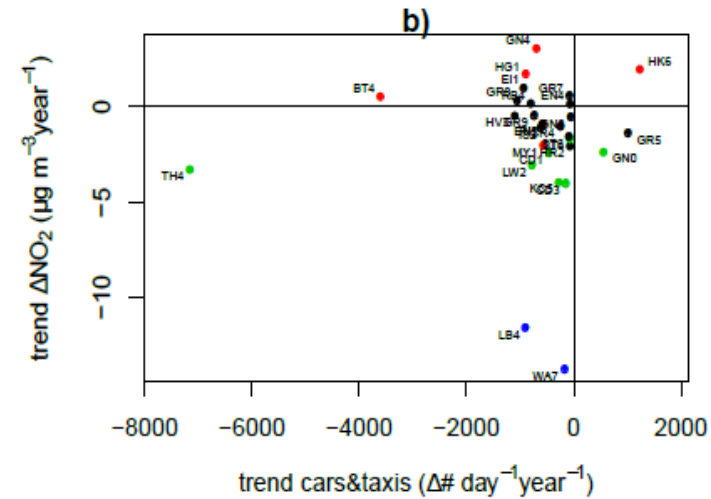
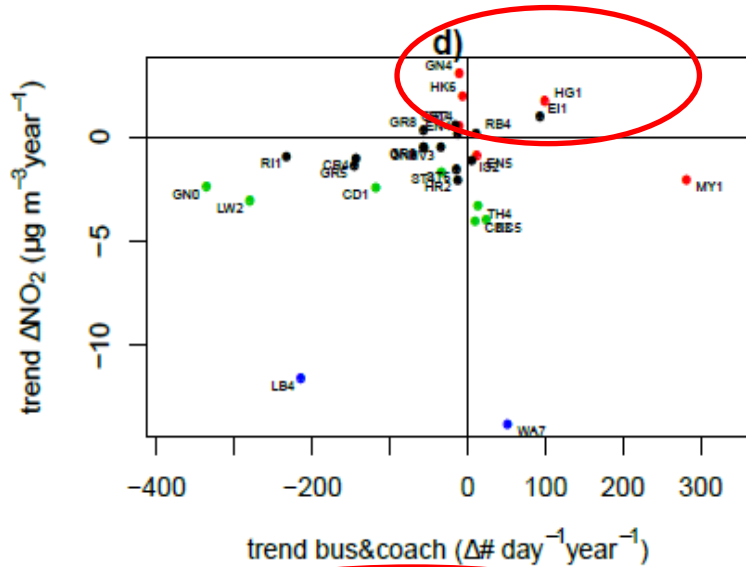
# Comparison to changes in traffic - NOX



# Comparison to changes in traffic - NOX



# Comparison to changes in traffic – NO2



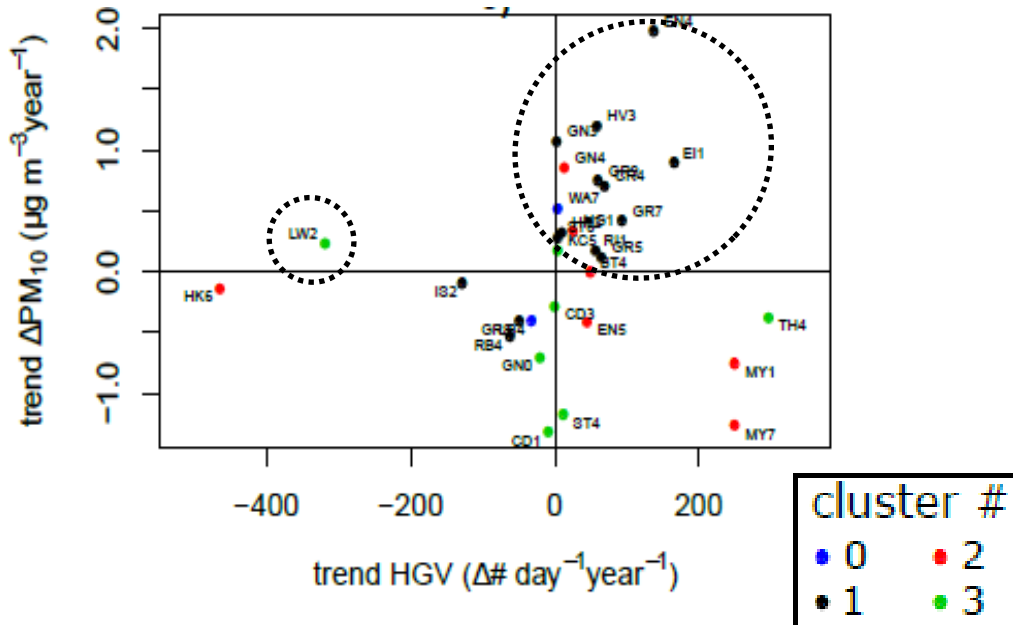
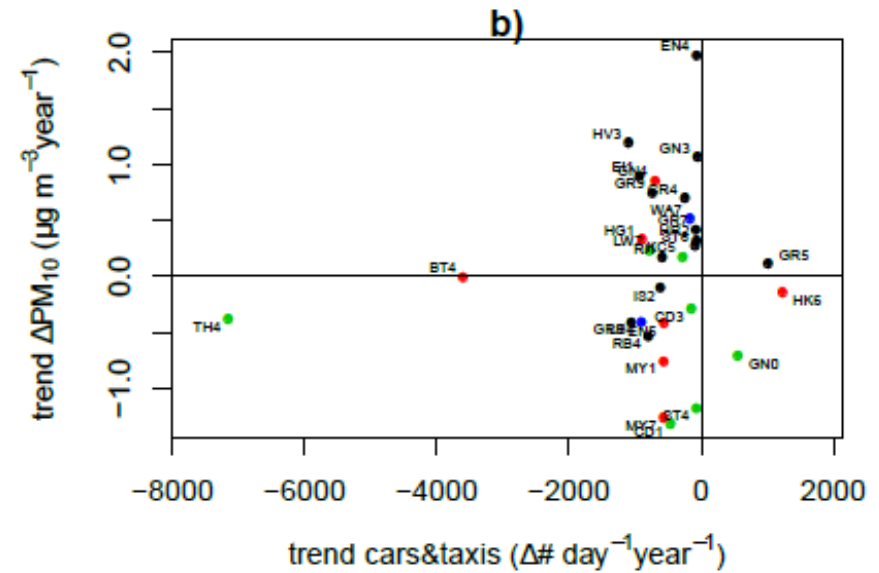
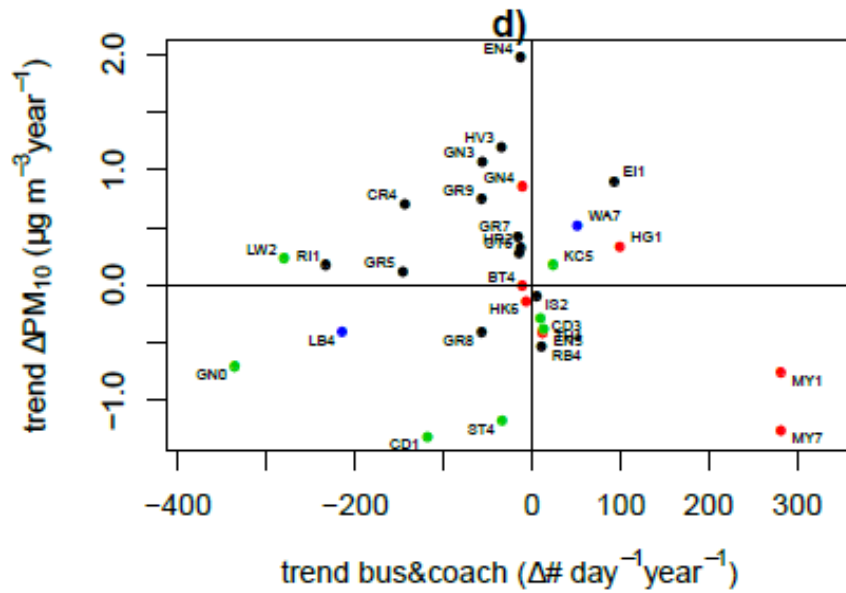
# NO<sub>2</sub> - Time to compliance at 2010-2014 rate?

Previous performance is not necessarily a predictor of future performance...

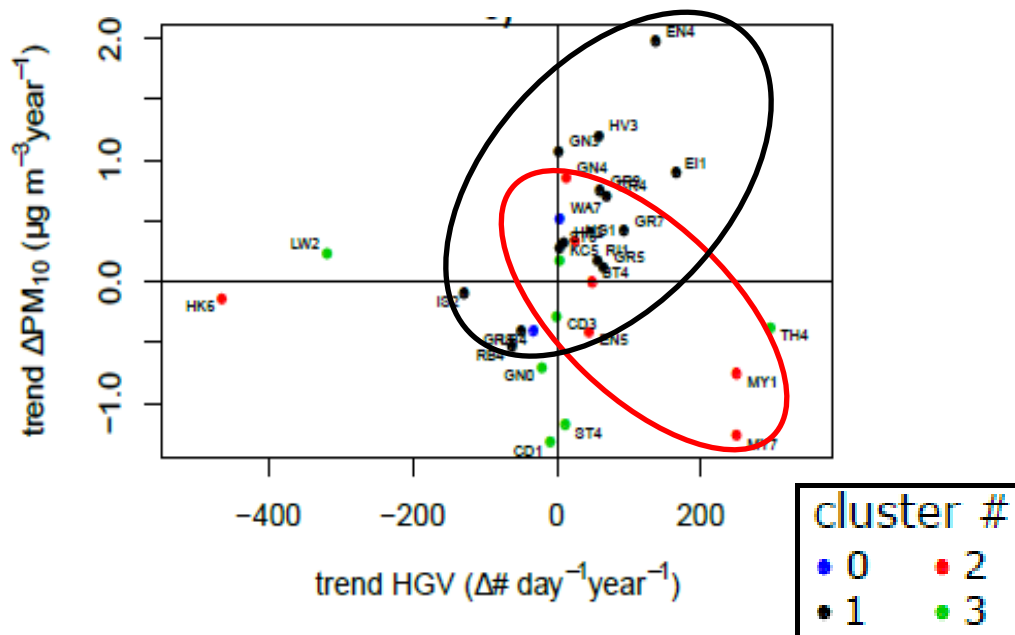
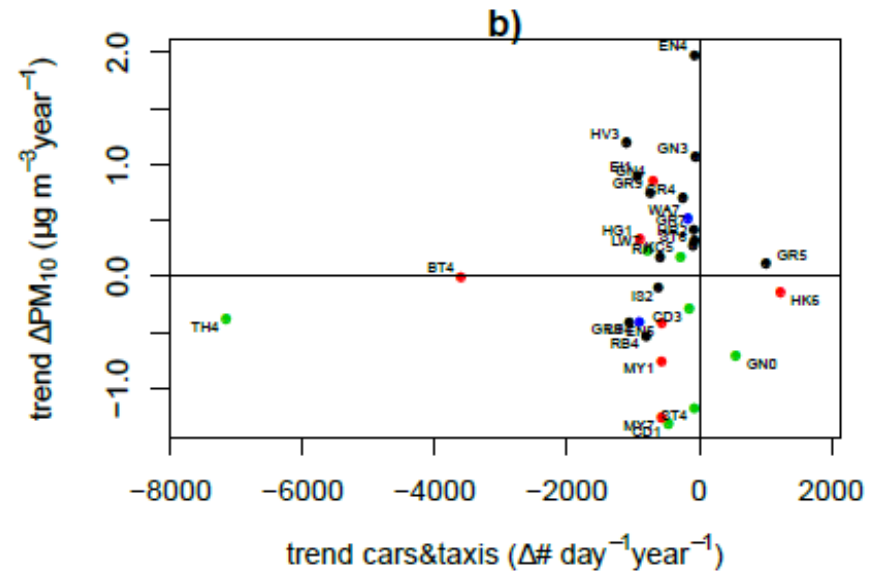
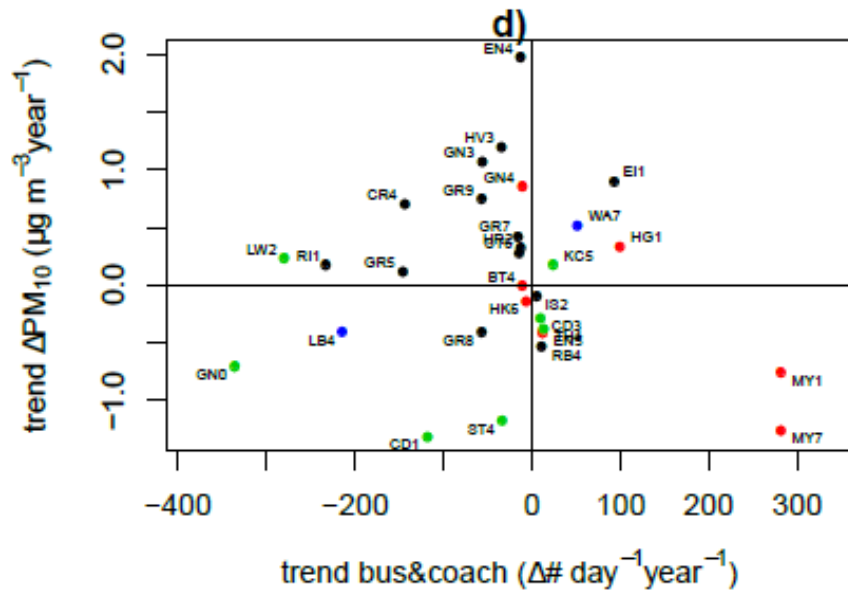
These are roadside increment only – see background trend too

cluster #	0	1	2	3
N	2	15	7	9
trend $\Delta\text{NO}_x$ ( $\mu\text{g m}^{-3} \text{ year}^{-1}$ )	-14.70 [-29.16, -0.23]	-0.41 [-1.45, 0.64]	6.66 [5.51, 7.81]	-4.52 [-5.62, -3.43]
mean $\Delta\text{NO}_x$ 1 <sup>st</sup> year ( $\mu\text{g m}^{-3}$ )	385.74 [279.09, 492.39]	58.98 [47.81, 70.16]	118.51 [77.97, 159.05]	135.86 [103.36, 168.36]
trend $\Delta\text{NO}_2$ ( $\mu\text{g m}^{-3} \text{ year}^{-1}$ )	-12.82 [-15.85, -9.79]	-0.48 [-0.92, -0.05]	0.81 [-0.52, 2.13]	-2.89 [-3.45, -2.33]
mean $\Delta\text{NO}_2$ 1 <sup>st</sup> year ( $\mu\text{g m}^{-3}$ )	133.68 [ 127.67, 139.68]	14.06 [ 10.82, 17.30]	29.95 [ 18.35, 41.54]	40.91 [ 31.02, 50.80]
List of AQMSs	WA7, LB4	CR4, E11, EN4, GB6, GN3, GR5, GR7, GR8, GR9, HR2, HV3, IS2, RB4, RI1, ST6	BT4, EN5, GN4, HG1, HK6, MY1, MY7	CD1, CD3, EA6, GN0, KC2, KC5, LW2, ST4, TH4

# Comparison to changes in traffic – PM10



# Comparison to changes in traffic – PM10





# Conclusions – NO<sub>2</sub>

- Roadside sites in London experienced a **significant downward trend in  $\Delta\text{NO}_x$  and  $\Delta\text{NO}_2$**  between 2010 and 2014 (-1% and -5% y<sup>-1</sup>).
- but **not all places improved.**
- SCR retrofits on Euro 3 buses effective when used intensively
- SCR might not be effective everywhere.
- Changes in  $\Delta\text{NO}_x$  and to a lesser extent  $\Delta\text{NO}_2$  have some linkage to changes in buses and HGV flows.  
**Are policies strong enough?**
- **Current trends show ~10 to >20 years to LV compliance.**
- Hopefully Euro 6 / VI will help.

# Conclusion - PM

- **$\Delta\text{PM}_{2.5}$  decreased** in 2010-14 (-28%) while  **$\text{PM}_{10}$  remained constant** (~1%) → **increase/stabilization of  $\Delta\text{PM}_{\text{coarse}}$**
- **$\Delta\text{PM}_{\text{coarse}}$**  comes from non-exhaust traffic (resuspension from the road, brake and tyre-wear).
- **$\Delta\text{PM}_{\text{coarse}}$  increasing on faster flowing roads**
- We have no policies to control resuspension from the road, brake and tyre-wear apart from vehicle number.
- Comparison with black carbon suggests that the **decrease in  $\Delta\text{PM}_{2.5}$**  was largely explained by a **decrease in traffic exhaust emissions**
- (but care needs to be taken with the black carbon trend since only three sites and Davy et al (in prep) shows no trend for two locations in central London).

# Conclusions

- New approaches to analysis of the whole population of monitoring sites revealed a clear **intra-city variability in trends. We need to check if our policies are working as intended and everywhere**
- **UK-wide? EU-wide?**
- **In places the decreased emissions from tailpipe abatement is being undone by increases in bus and HGV flow. Are policies strong enough?**
- **CO<sub>2</sub> from traffic is not going down as we would hope from policy.**
- **We need to look in future to see if Euro 6 / VI / CAZ / LEZ is working**



# Thanks for your attention

Thanks to Transport for London and Greater London Authority for part funding

Part of trends report is available at <http://content.tfl.gov.uk/roadside-air-quality-trends-in-london-identifying-outliers-part-1.pdf>



The full study is in review for *Environmental Pollution*.

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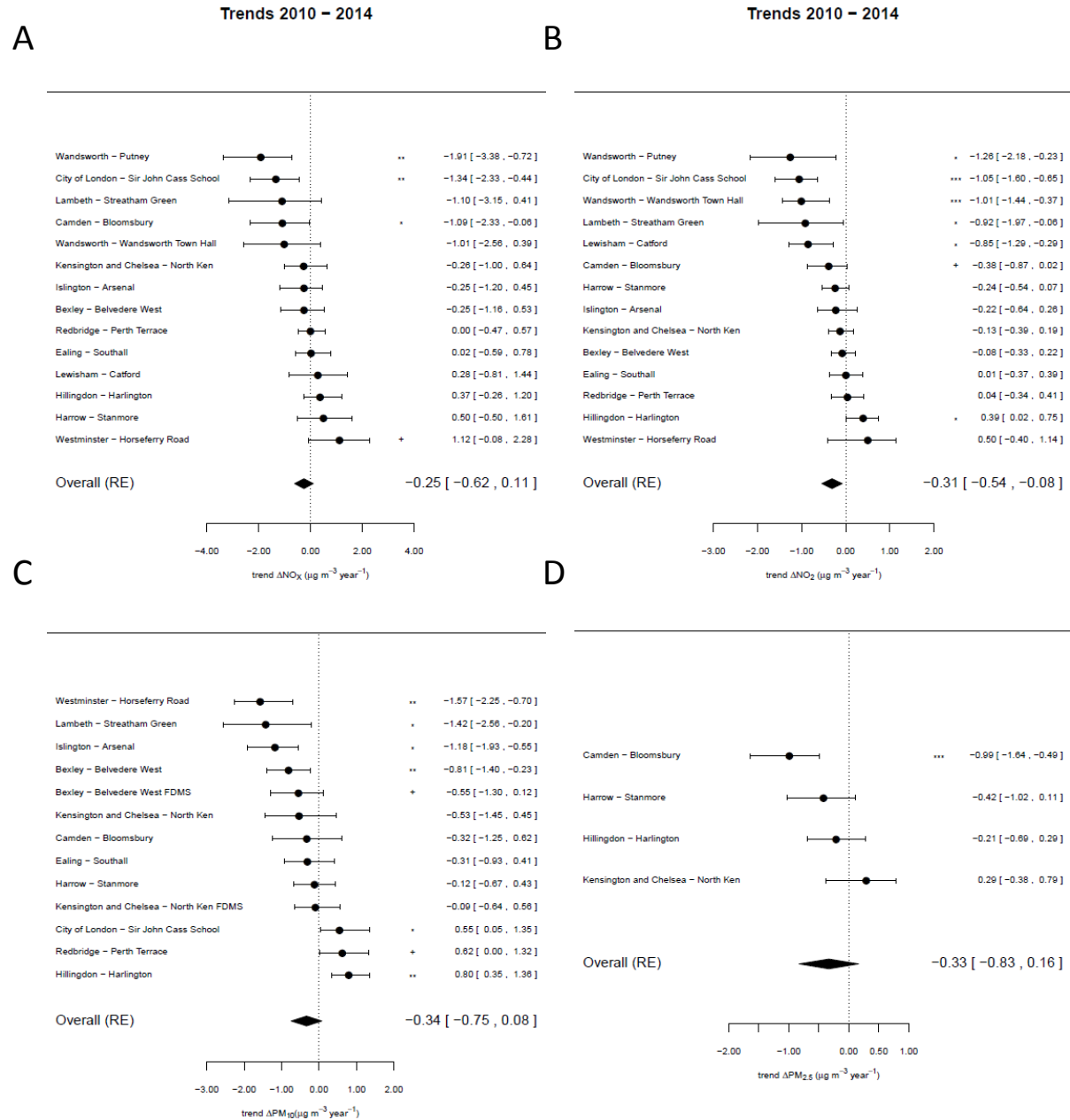


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[anna.font\\_font@kcl.ac.uk](mailto:anna.font_font@kcl.ac.uk)

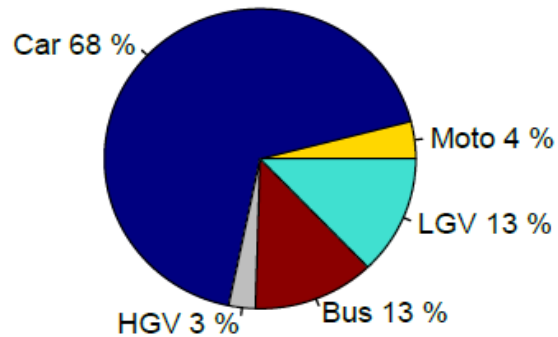
[www.environment-health.ac.uk](http://www.environment-health.ac.uk)

# Results: trends 2010 – 2014 - background

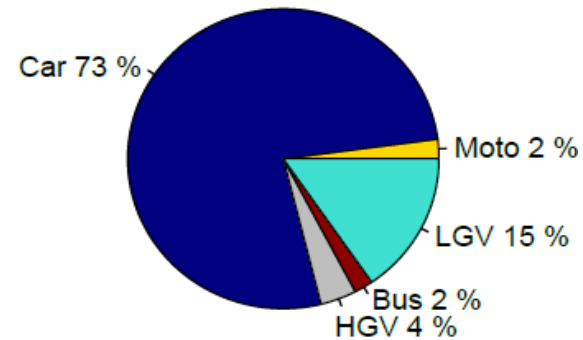


# But how can we explain the increases?

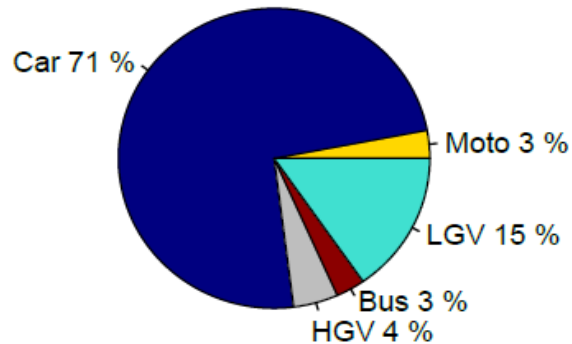
Cluster # 0



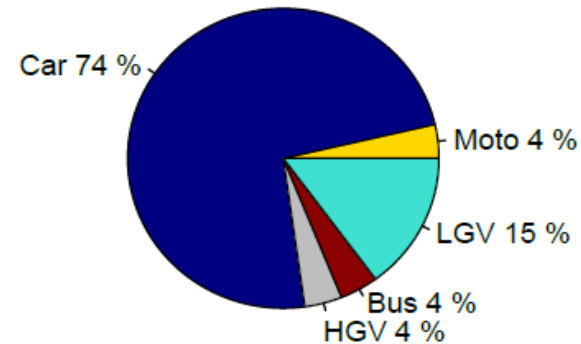
Cluster # 1



Cluster # 2



Cluster # 3



# Results: clustering sites

- **# 0:** sites in inner London, high streets with lots of buses. Reduction in  $\Delta\text{NO}_x$  and  $\Delta\text{NO}_2$
- **#1:** major roads in outer London with a reduction in  $\Delta\text{NO}_2$  and  $\Delta\text{PM}_{2.5}$  while  $\Delta\text{PM}_{10}$  increased therefore coarse PM increased
- **#2:** major multi-lane roads in inner and outer London. Clear increase in their  $\Delta\text{NO}_x$  while  $\Delta\text{PM}_{2.5}$  clearly decreased; mixed responses in  $\Delta\text{NO}_2$  and  $\Delta\text{PM}_{10}$
- **#3:** mixture of busy roads in inner and outer London.  $\Delta\text{NO}_x$ ,  $\Delta\text{NO}_2$ ,  $\Delta\text{PM}_{10}$  and  $\Delta\text{PM}_{2.5}$  decreased