UNIVERSITY OF BIRMINGHAM

Field Measurement and Data Analysis Approaches to Estimating Non-Exhaust Emissions from Road Traffic

Roy M. Harrison

University of Birmingham

and National Centre for Atmospheric Science

What are the non-exhaust emissions from road traffic?

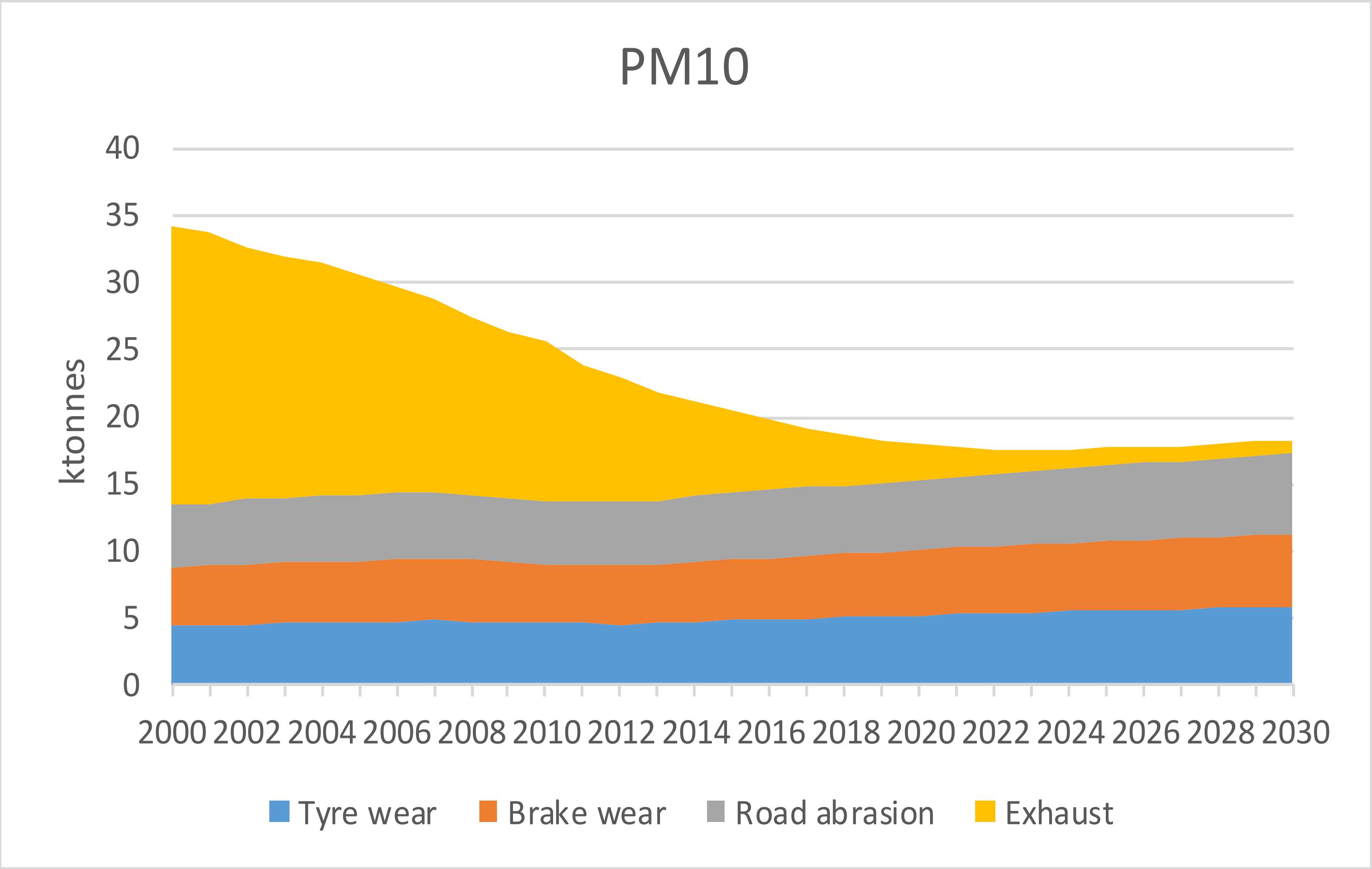
- brake dust (from disc and pad)
- tyre dust
- road abrasion particles
- resuspended road surface dusts

Sources of Air Pollutants from a Vehicle

Emissions dependent upon

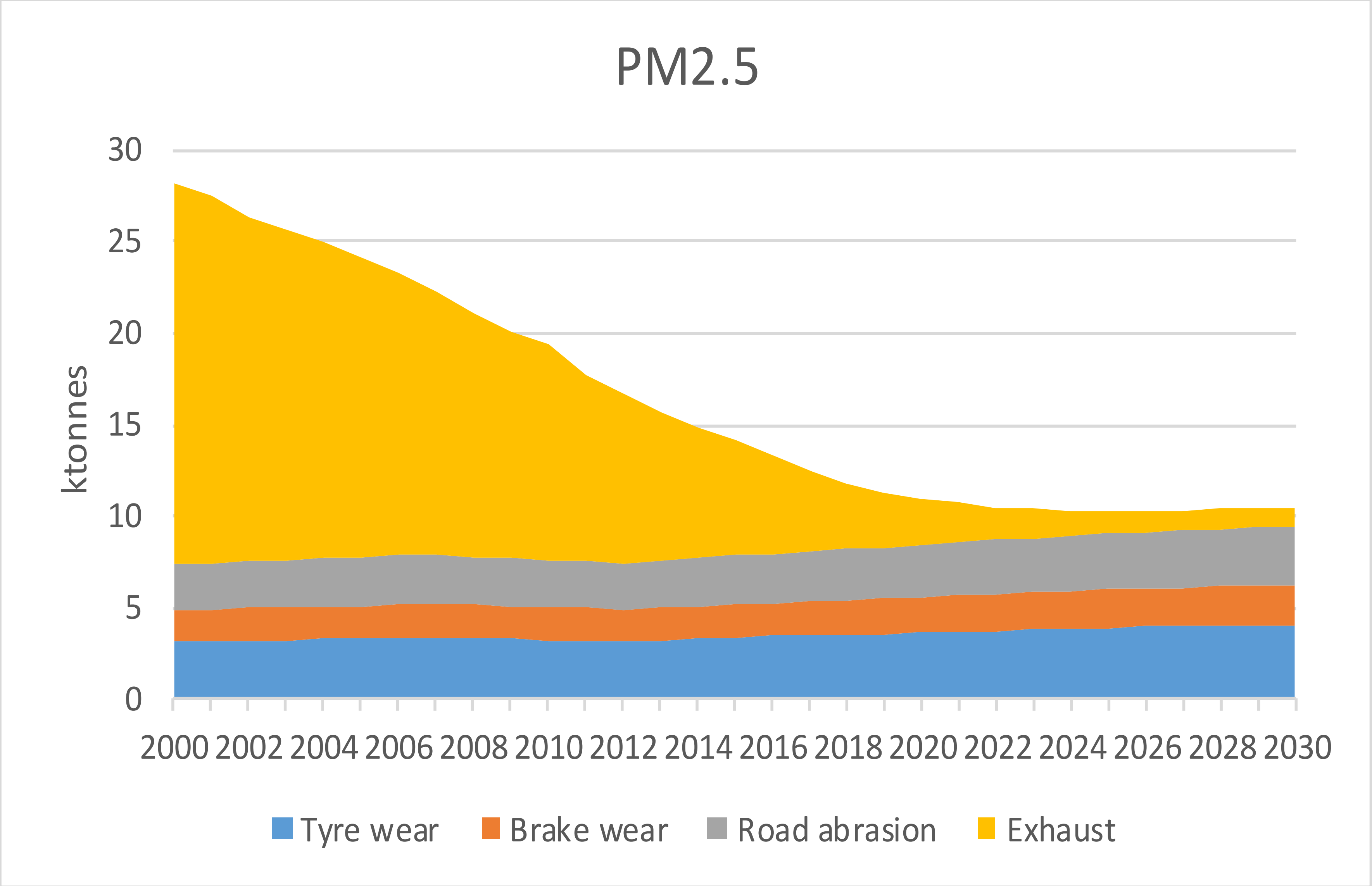
- vehicle speed (resuspension, tyre and road surface wear)
- engine revs and load (exhaust)
- driving mode (exhaust, brake, tyre, road surface)
- materials (brakes, tyres, road surface)
- fuel and lubricant (exhaust)
- vehicle weight and aerodynamics (resuspension)
- road surface silt loading (resuspension)

UK emissions of PM_{10} from road transport



Source: NAEI

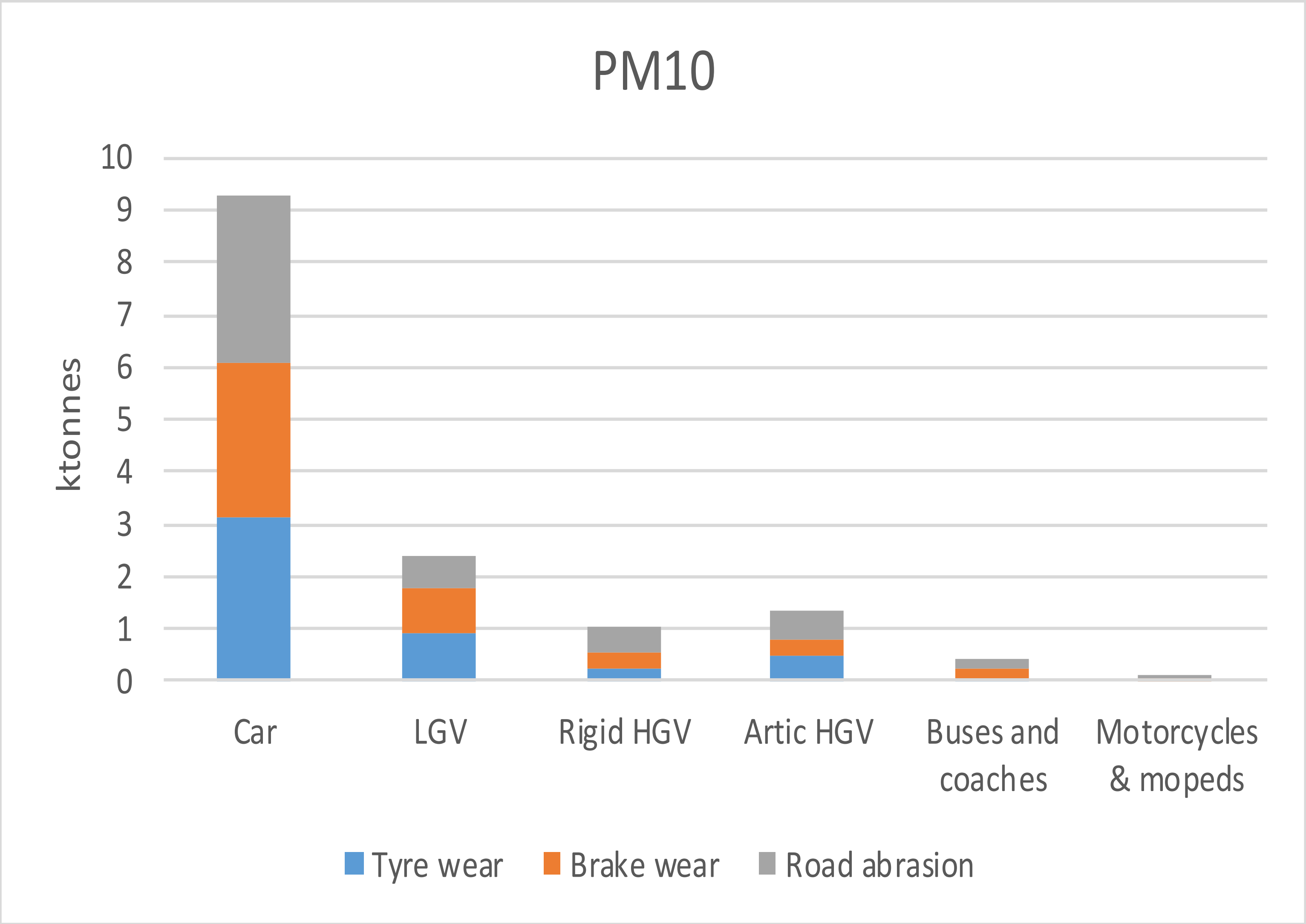
UK emissions of $PM_{2.5}$ from road transport



Source: NAEI

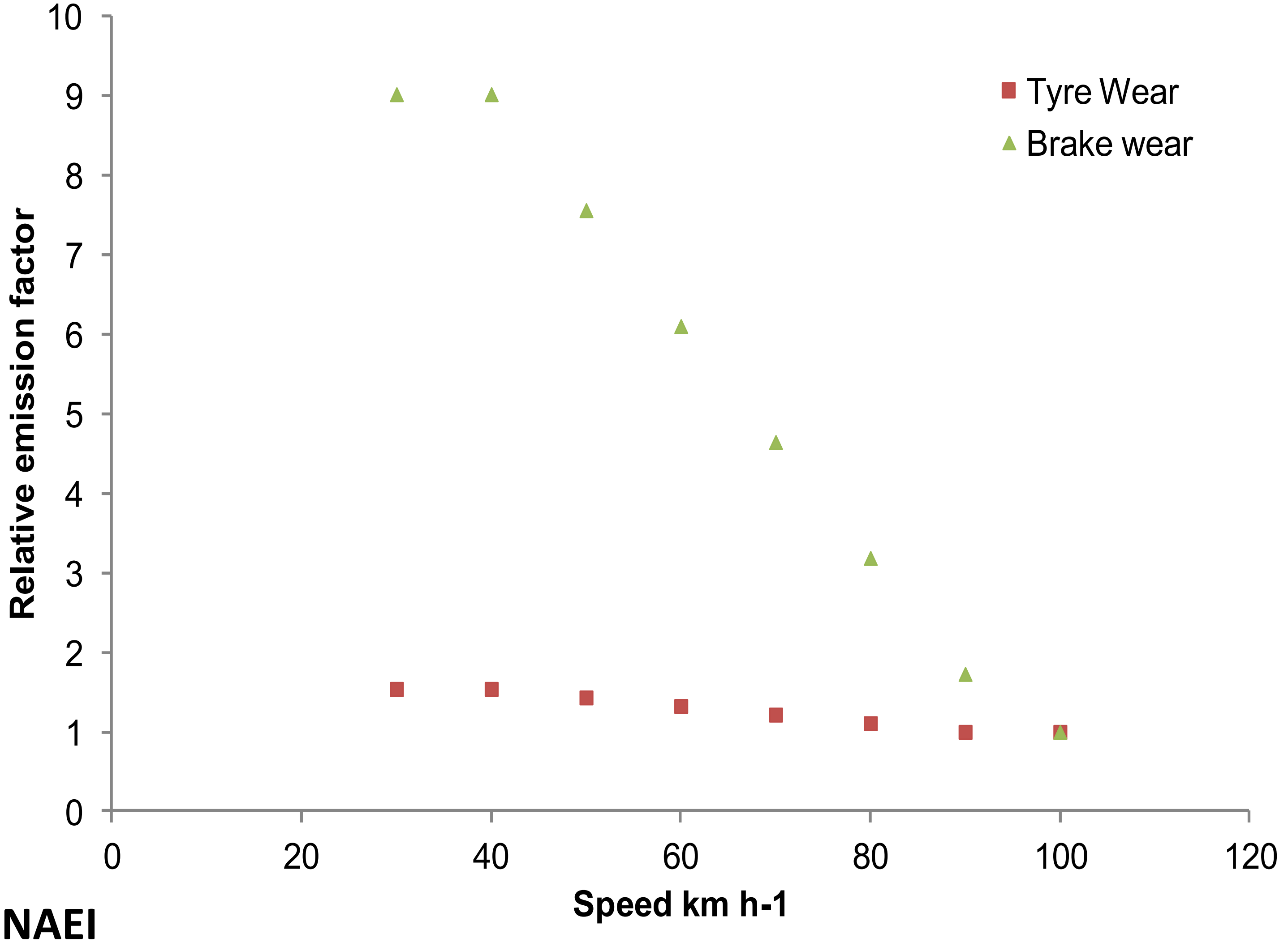
UNIVERSITY OF BIRMINGHAM

UK emissions of PM_{10} from road transport in 2016 by vehicle type



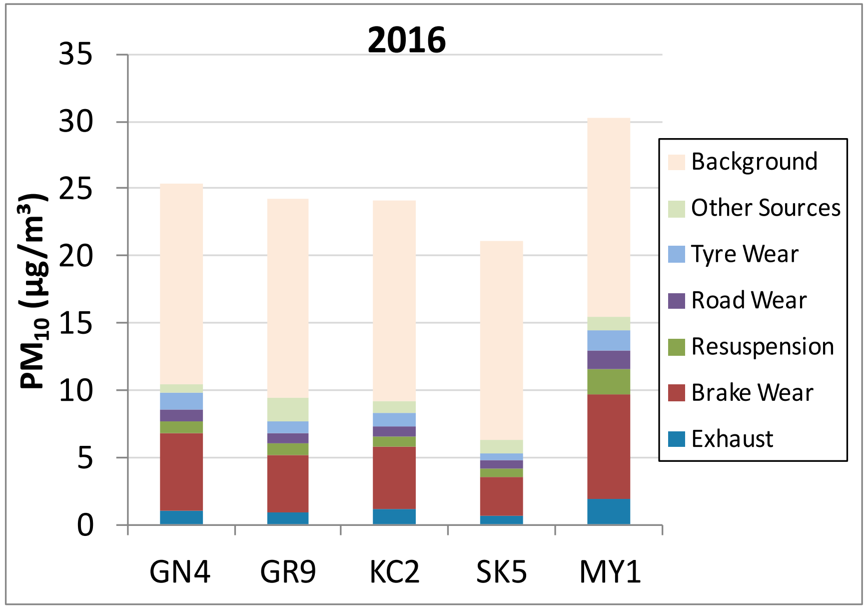
Source: NAEI

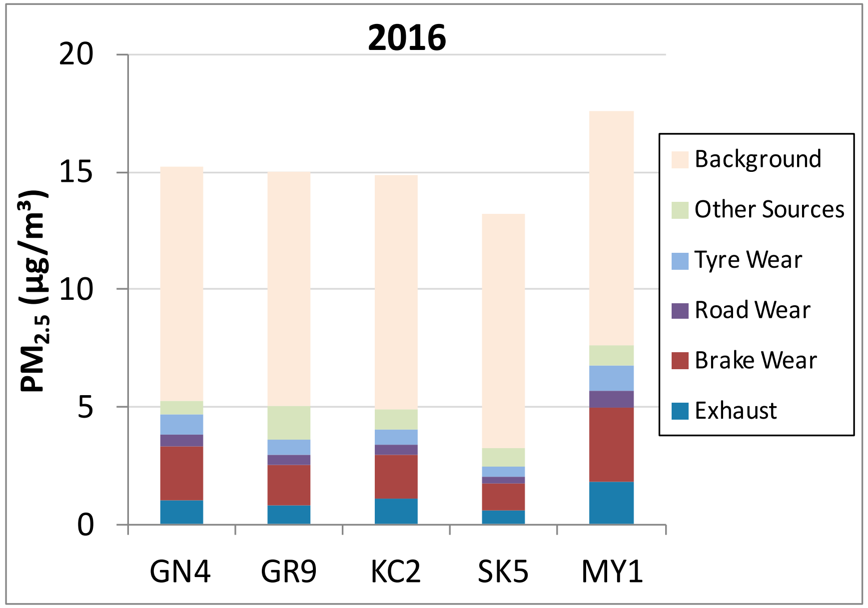
Speed dependence of emissions factors for brake and tyre wear. Each are normalised to their respective emissions rate at 100 km h^{-1}. In this plot speed refers to the average traffic speed and not the instantaneous speed of any vehicle



Source: NAEI

PM_{10} and $PM_{2.5}$ concentrations modelled using ADMS-Urban at five major roads in London apportioned by emission type (µg m^{-3}) for 2016 and 2020. 'Other' represents the contribution of non-traffic sources in the LAEI.

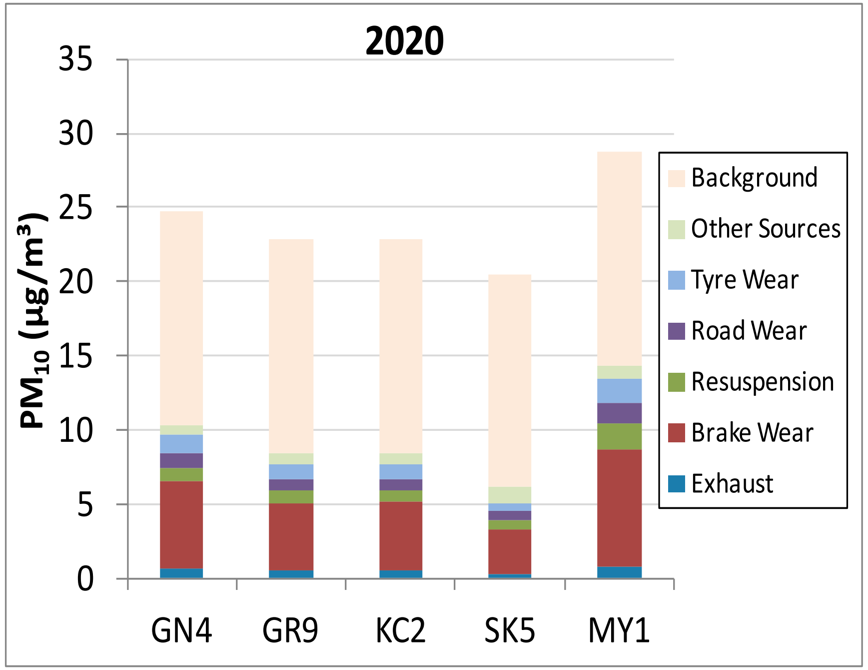


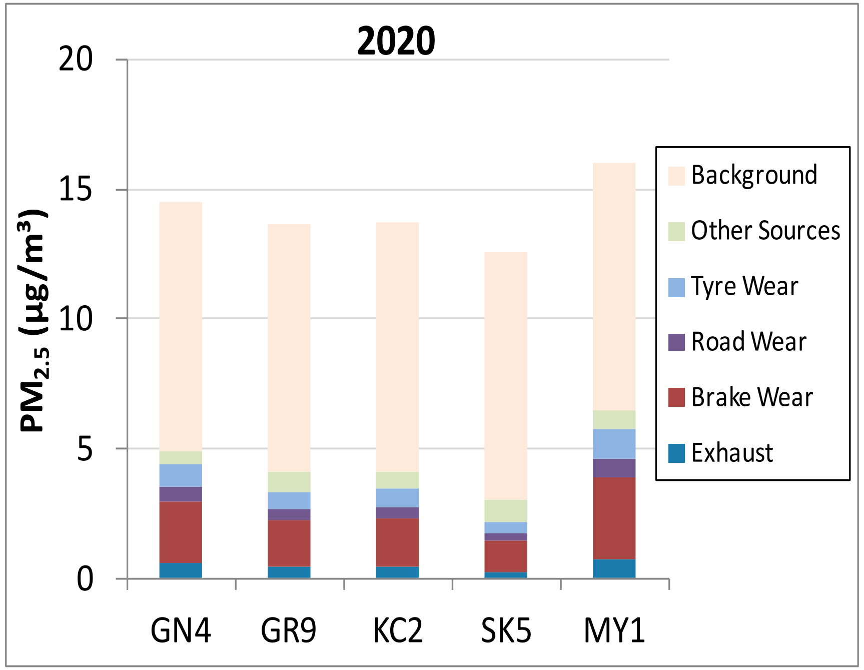


Source - AQEG Report: Non-Exhaust Emissions from Road Traffic

UNIVERSITY OF BIRMINGHAM

PM_{10} and $PM_{2.5}$ concentrations modelled using ADMS-Urban at five major roads in London apportioned by emission type (µg m^{-3}) for 2016 and 2020. 'Other' represents the contribution of non-traffic sources in the LAEI.

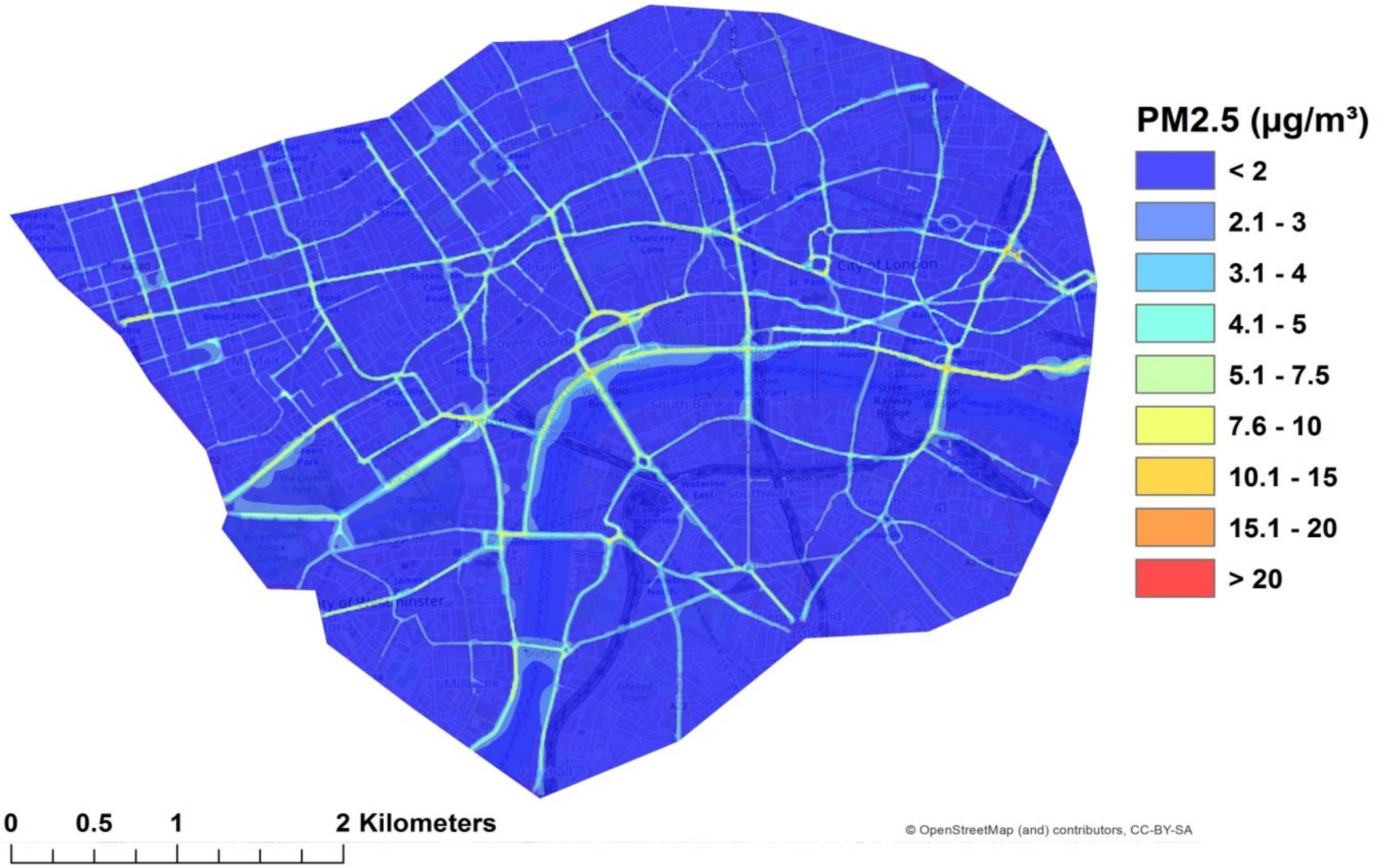




Source - AQEG Report: Non-Exhaust Emissions from Road Traffic

UNIVERSITY OF BIRMINGHAM

Modelled non-Exhaust $PM_{2.5}$ annual average concentration for 2016 within the London Congestion Charging Zone



Specific Sources: Non-exhaust Emissions from Road Traffic

- Emission inventories include tyre wear, brake wear and road surface wear. They do not include particle resuspension.

- Until recently, non-exhaust emissions of PM_{10} were of a similar magnitude to exhaust emissions. By 2020, non-exhaust emissions will be strongly dominant.

- This source contributes similar masses of particles to the fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) fractions.

- There are no current measures in place, or planned, to control emissions from this source.

Contribution of tyre and brake wear sources from road transport of total UK emissions of metals in 2016

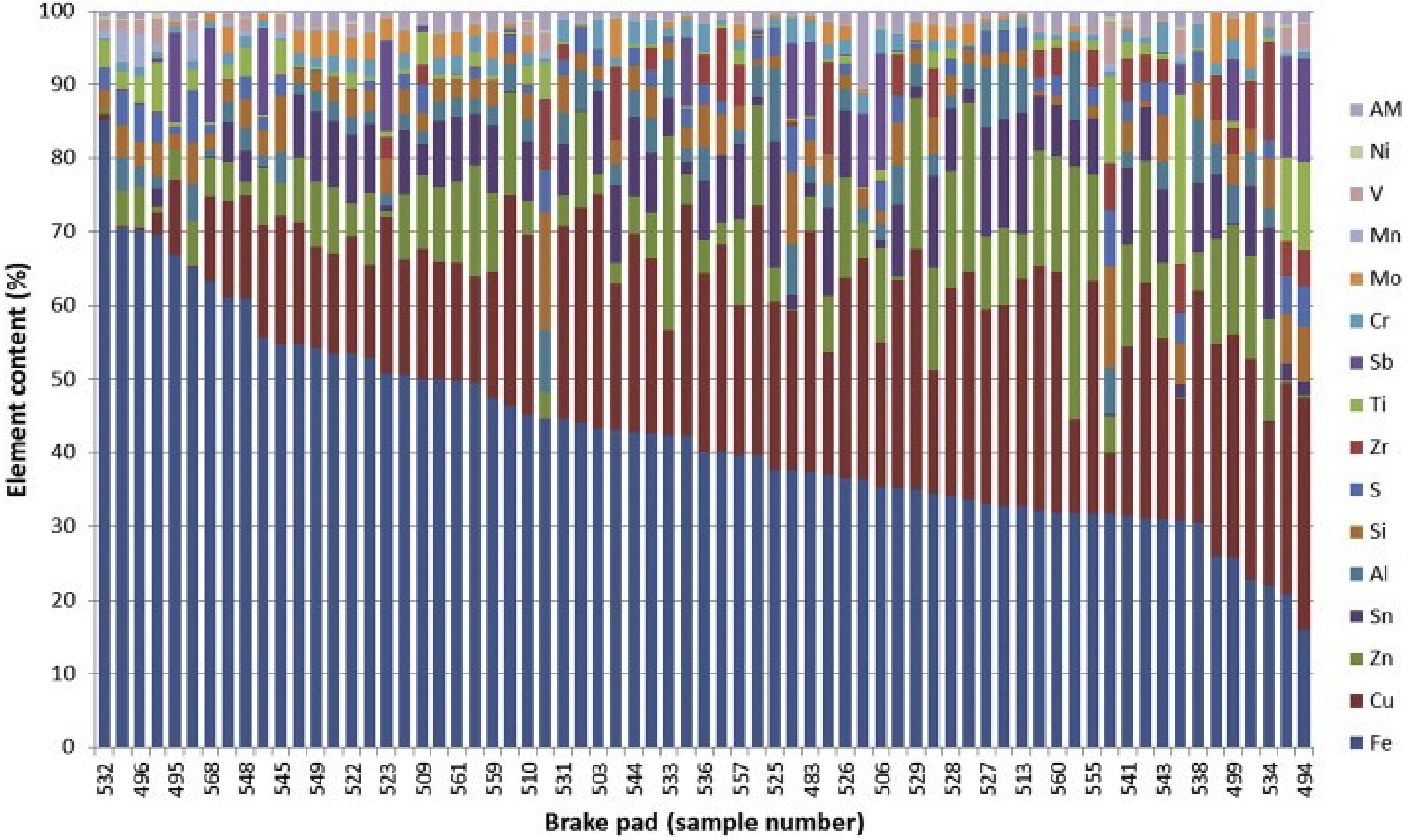
	Cd	Cr	Cu	Ni	Zn
% NEE	0.8%	3%	47%	0.8%	21%

Elemental Data as Tracers of Non-Exhaust Emissions

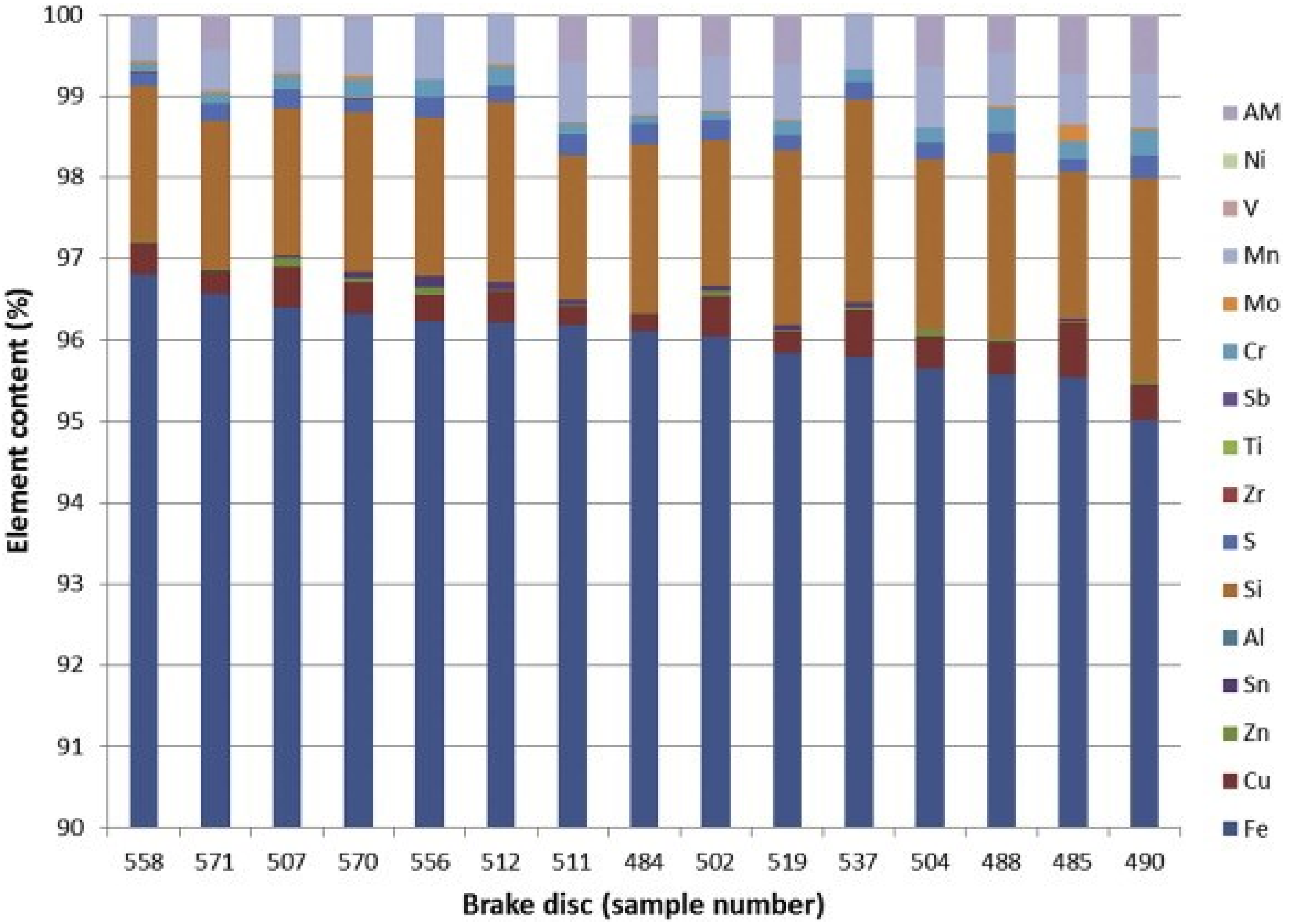
Examine:

- Relationship between metals to identify those with a common source
- Consider typical chemical origins of metals
- Fe, Cu, Sb and Ba characteristic of brake dust
- Al, Si, Ca, Ti are typically crustal and likely to arise from soil or resuspension
- Zn arises mainly from tyre dust
- Size distributions are indicative of source

UNIVERSITY OF BIRMINGHAM



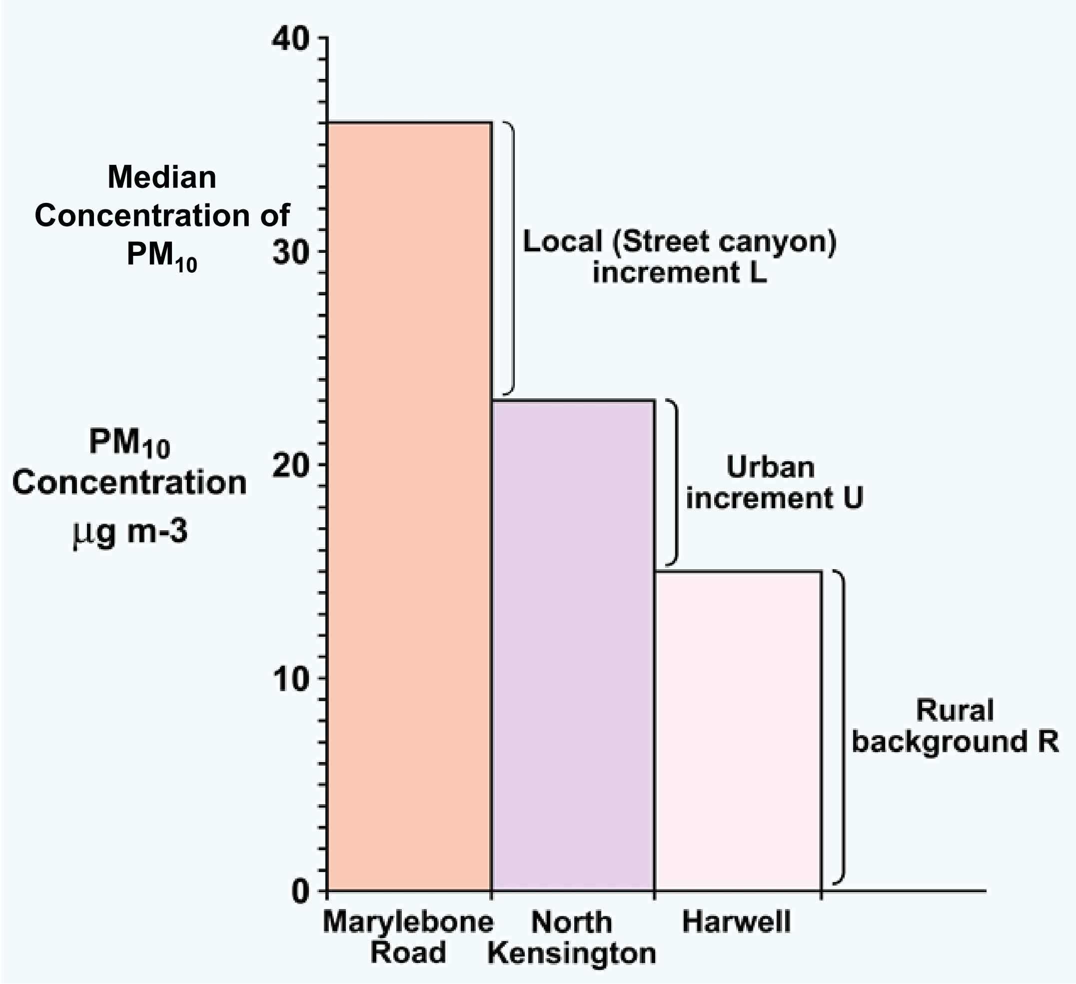
Measured metals as a fraction of total measured metals in brake pads by XRF (= 100%). Note that this excludes non- XRF measurable elements such as C, O and Mg. Additional Material (AM) consists of measured elements like (W, P, Pb, Co) with a minor contribution



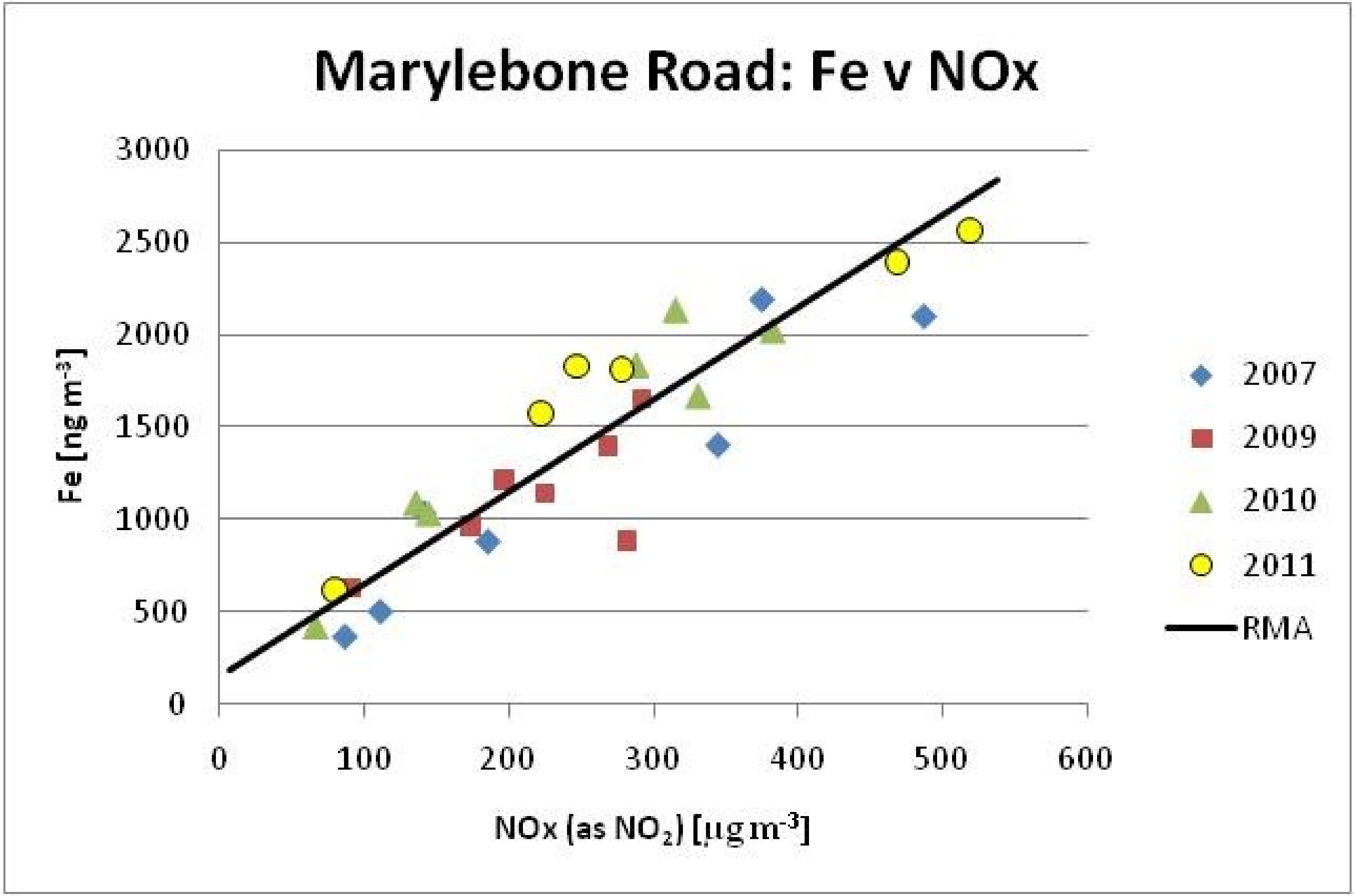
Element content in brake discs measured by XRF. Percentages are the fraction of total measured metals. Additional Material (AM) consists of measured elements like (W, P, Pb, Co) and excludes non-measured elements such as C, O and Mg. Note start of the *Y*-axis at 90%

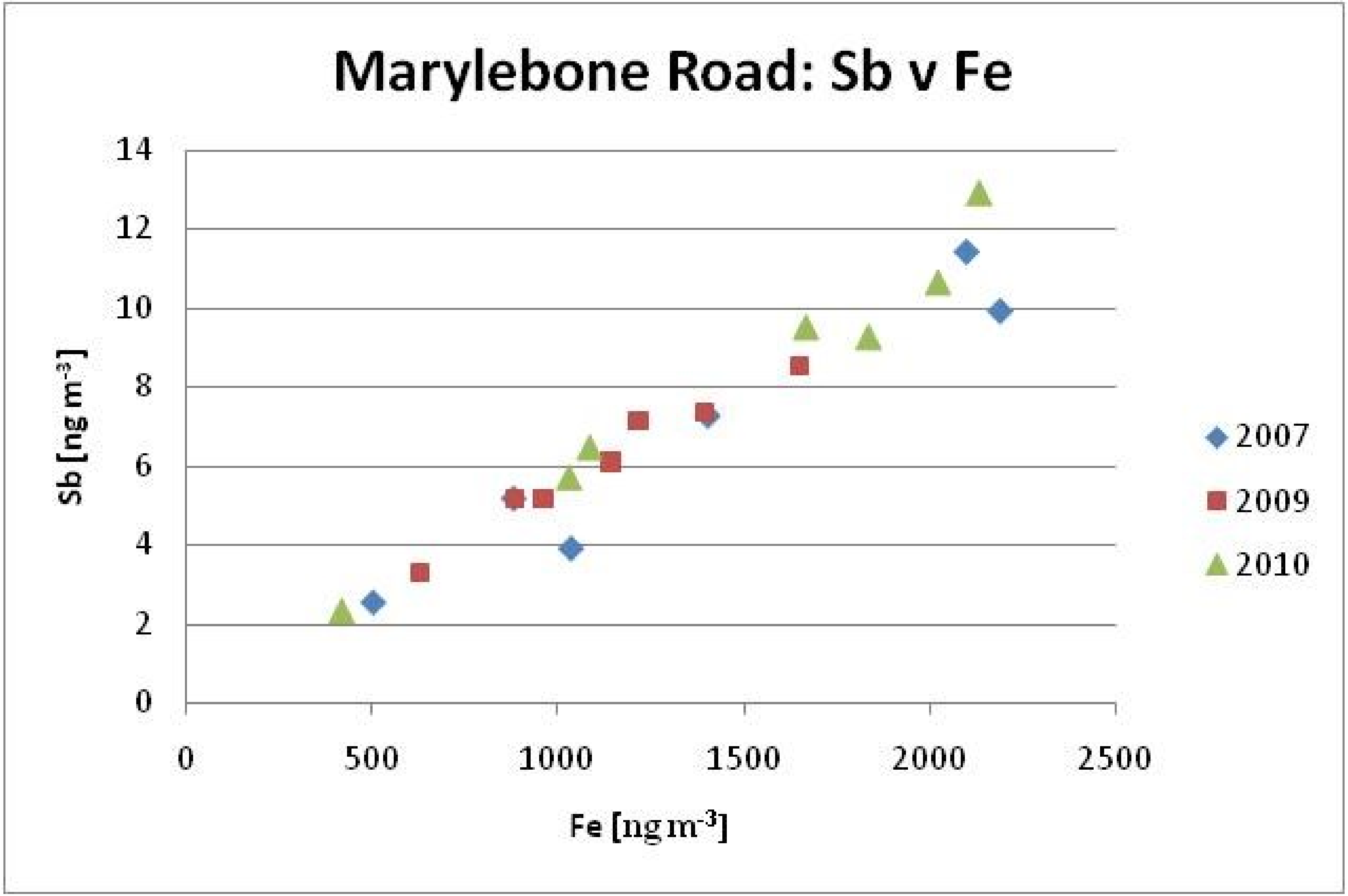
From Hulskotte et al., Atmos. Environ., 99, 436-445 (2014)

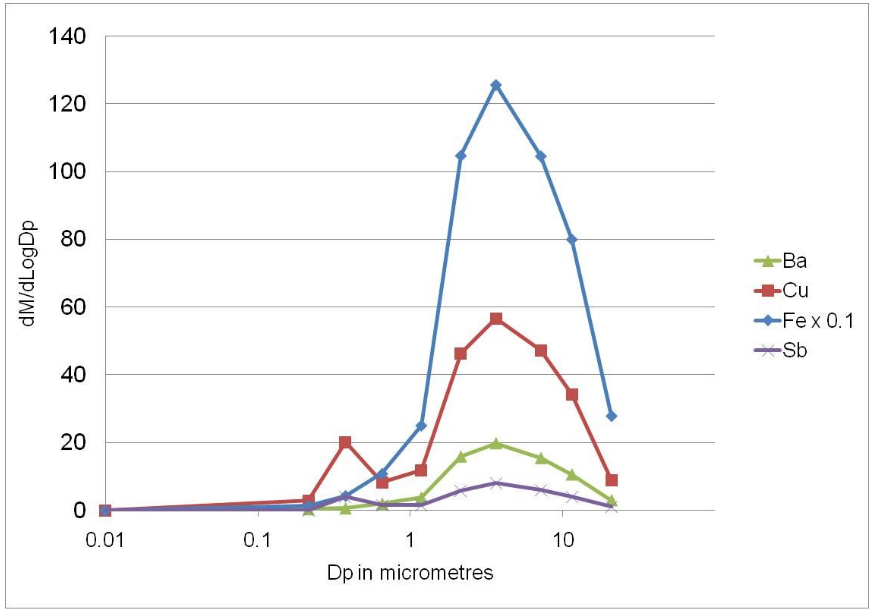
Median concentrations of PM_{10}



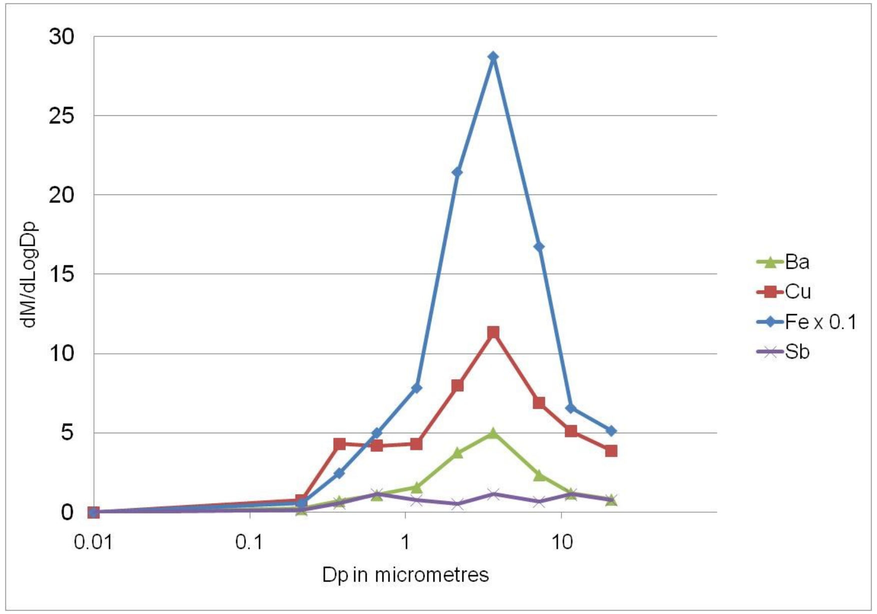
Marylebone Road


Marylebone Road: Fe v NOx
Fe [ng m-3]
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
NOx (as NO2) [µg m-3]
2007
2009
2010
2011
RMA


Marylebone Road: Sb v Fe
Sb [ng m-3]
Fe [ng m-3]
0
2
4
6
8
10
12
14
0
500
1000
1500
2000
2500
2007
2009
2010



a



b

Size Distribution of Ba, Cu, Fe, and Sb at (a) Marylebone Road and (b) Regent's Park

From Gietl et al., Atmos. Environ., 44, 141-146 (2010)

Elemental Data as Tracers of Non-Exhaust Emissions

Examine:

- Relationship between metals to identify those with a common source.
- Consider typical chemical origins of metals.
- Fe, Cu, Sb and Ba characteristic of brake dust.
- Al, Si, Ca, Ti are typically crustal and likely to arise from soil or resuspension.
- Zn arises mainly from tyre dust.
- Size distributions are indicative of source.

Mass Reconstruction

- **Assumes**

  Brake dust = Ba x 91

  Tyre dust = Zn x 50

  Resuspension = Si x 3.6

- **Gives contributions to mass of 0.9 – 11.5 µm particles**

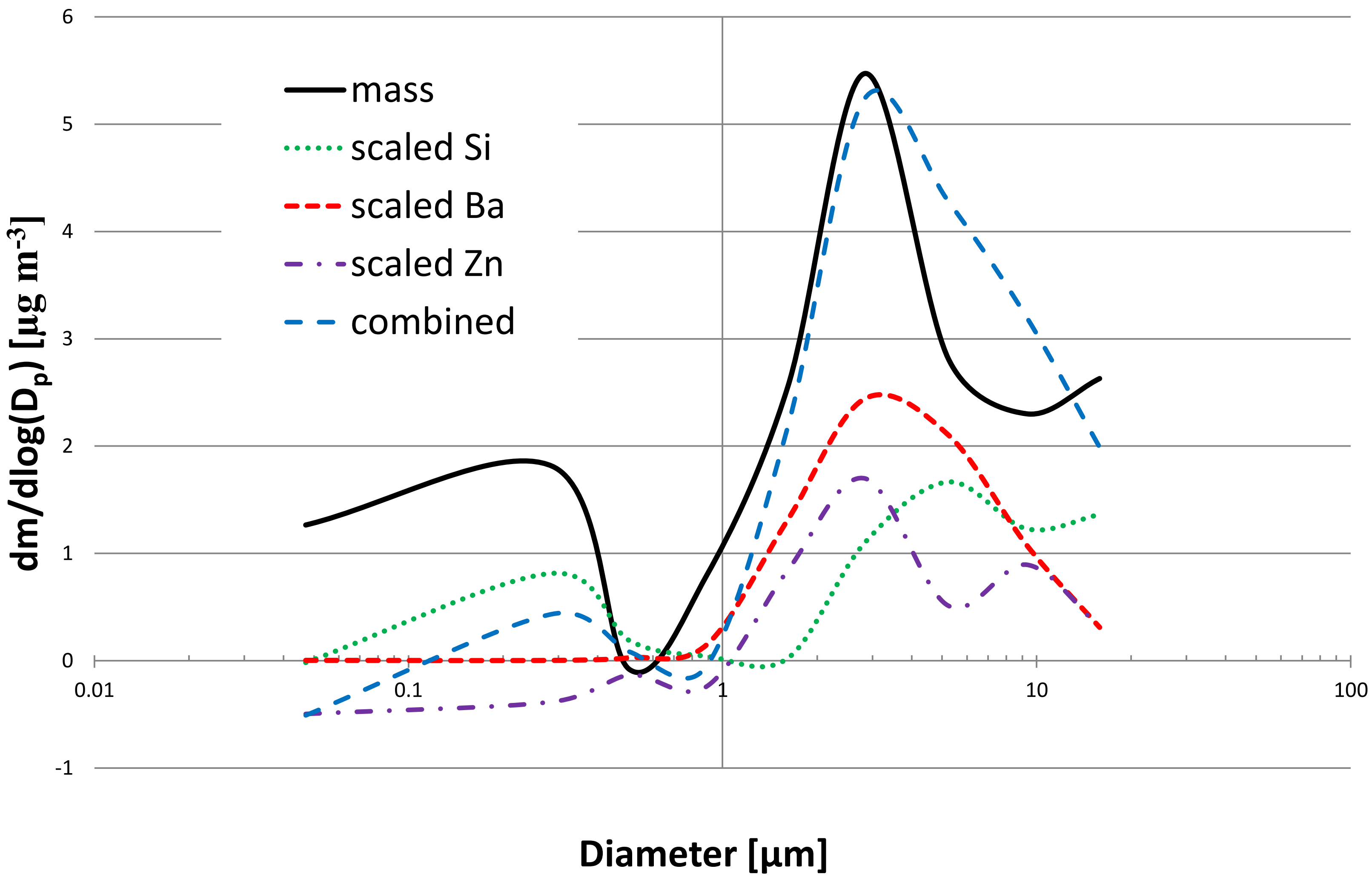
  Brake dust = 55.3 ± 7.9%

  Tyre dust = 10.7 ± 2.3%

  Resuspension = 38.1 ± 7%

Estimation of the Contribution of Brake Dust, Tire Wear and Resuspension to Nonexhaust Traffic Particles Derived from Atmospheric Measurements, R.M. Harrison, A. Jones, J. Gietl, J. Yin and D. Green, Environ. Sci. Technol., 46, 6523-6529 (2012)

Mass reconstruction - difference (all available data)



Receptor Modelling

- Use of air quality data to infer the sources responsible for measured pollution levels (opposite of dispersion modelling!)
- Receptor modelling of airborne particles depends upon an assumption of mass conservation

$$C_i = \sum^{j} f_{i,j}\, g_j$$

where C_i = airborne concentration of component, *i*

f_{ij} = mass fraction of component *i* in particles from source, *j*

g_j = mass of particles from source *j* in an air sample

- Analysis of many air samples for multiple chemical components is necessary

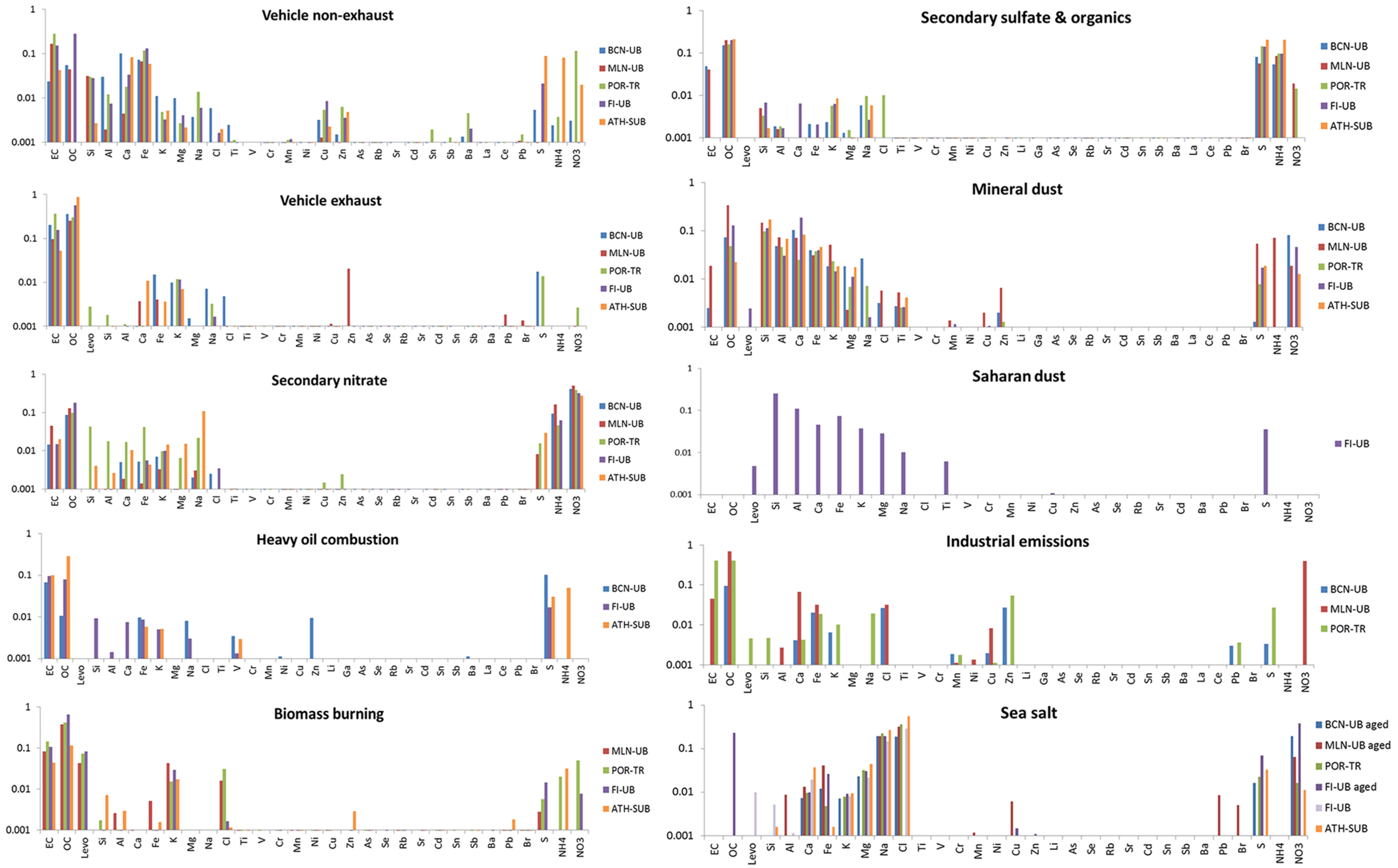
Types of Receptor Modelling of Particulate Matter

There are two main types

- **Chemical Mass Balance**
  - Requires only one air sample, although better results are obtained with more
  - Requires knowledge of chemical composition of particles from each source (f_{ij})
  - Varies g_j for all chemical components to obtain best fit to mass conservation equation

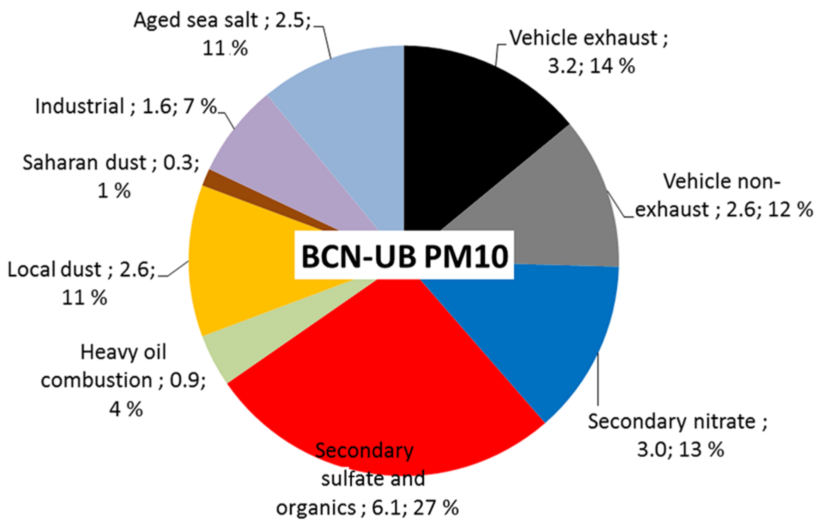
- **Multivariate Statistical**
  - Principal Component Analysis widely used, but Positive Matrix Factorization (PMF) has advantages and is more frequently utilised
  - Requires no advance knowledge of source chemical composition
  - Requires many separate samples, and identifies temporal correlations of components (e.g. Na and Cl in sea salt) in a multidimensional space.

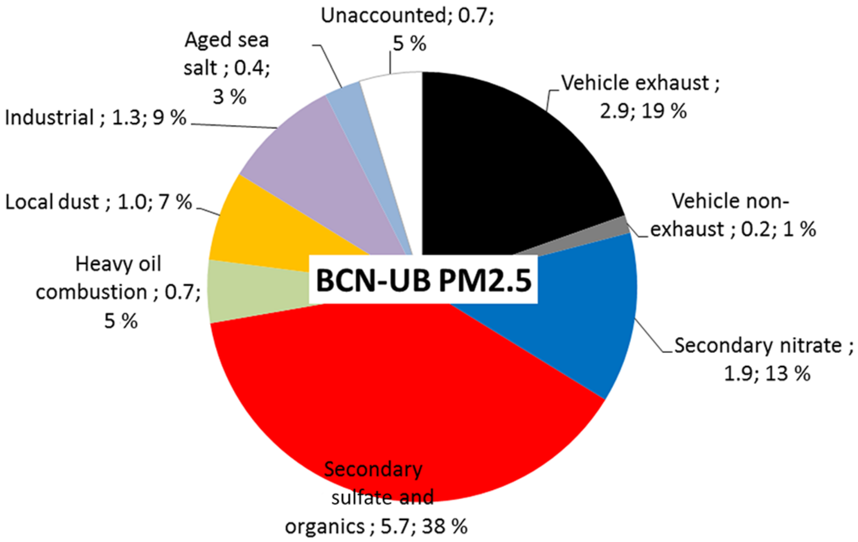
PMF factor profiles (μg μg^{-1}) for each monitoring site. At MLN-UB and POR-TR, the SSO factor includes heavy oil combustion

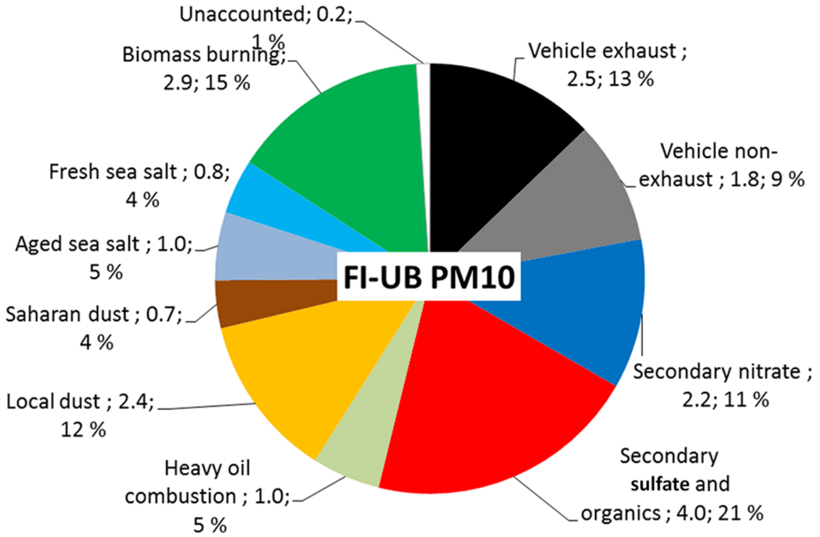


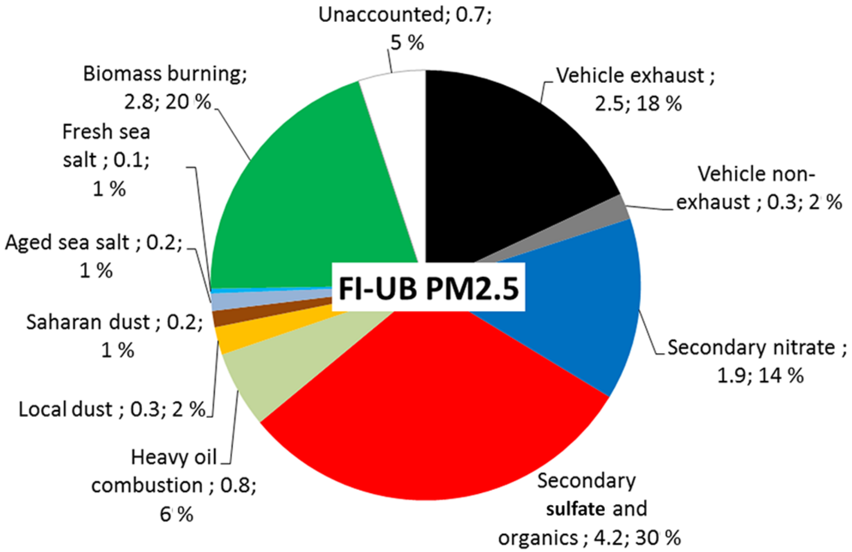
UNIVERSITY OF BIRMINGHAM

Average contribution (%) of PM_{10} and $PM_{2.5}$ sources for 12 months of study (1)



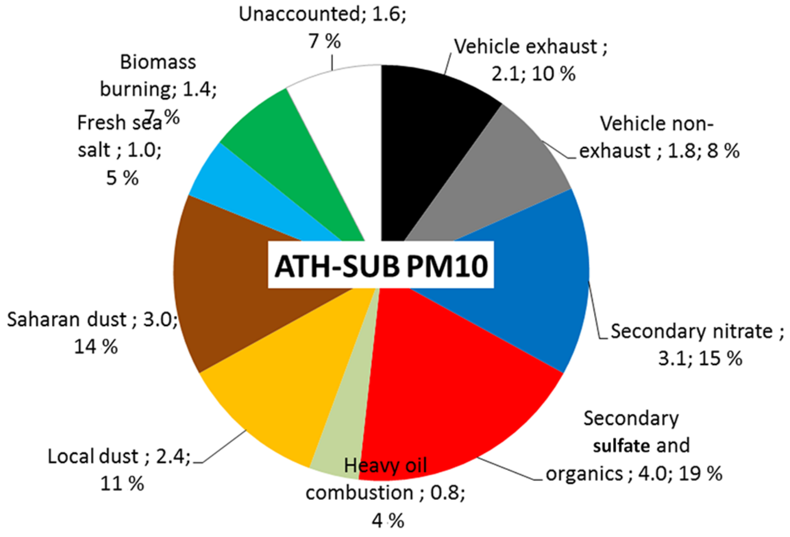


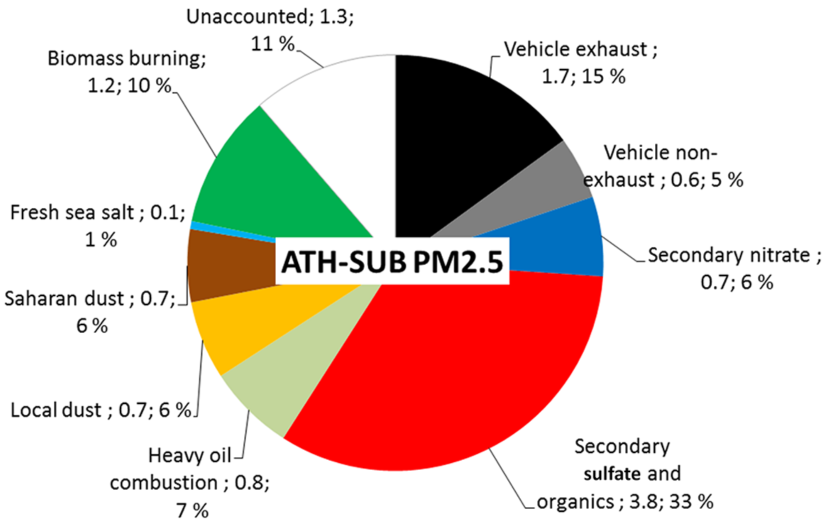


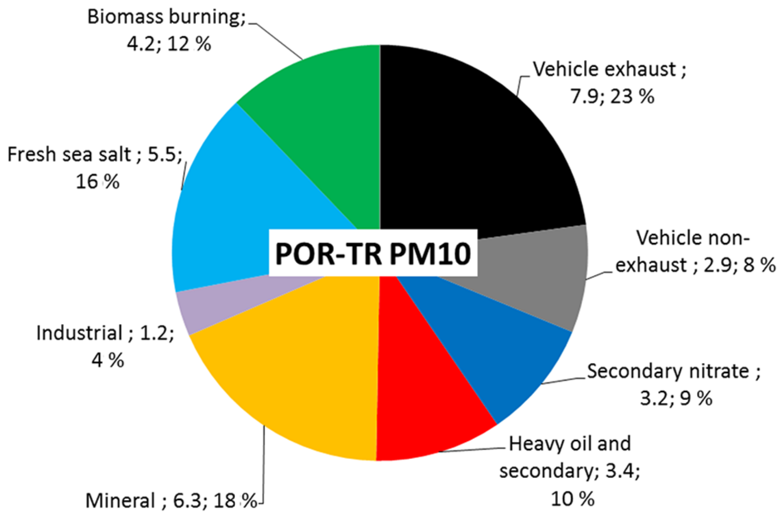


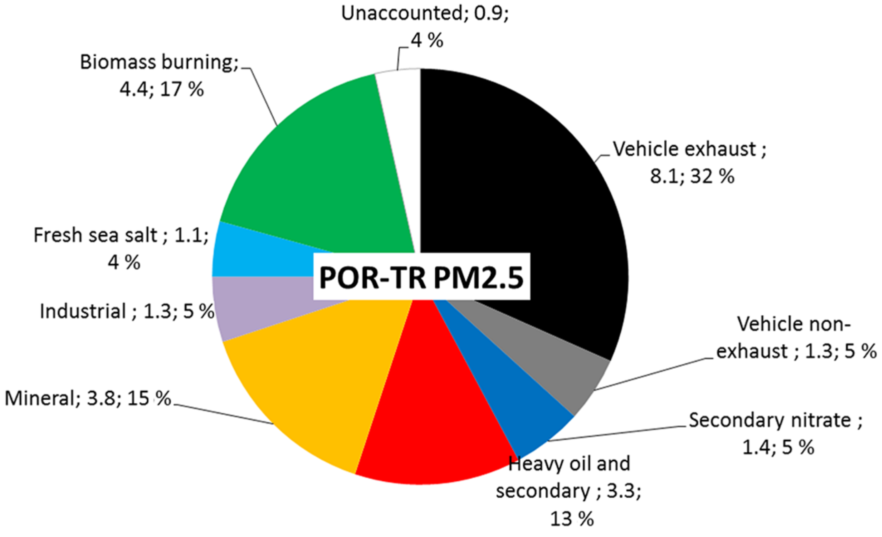
UNIVERSITY OF BIRMINGHAM

Average contribution (%) of PM_{10} and $PM_{2.5}$ sources for 12 months of study (2)

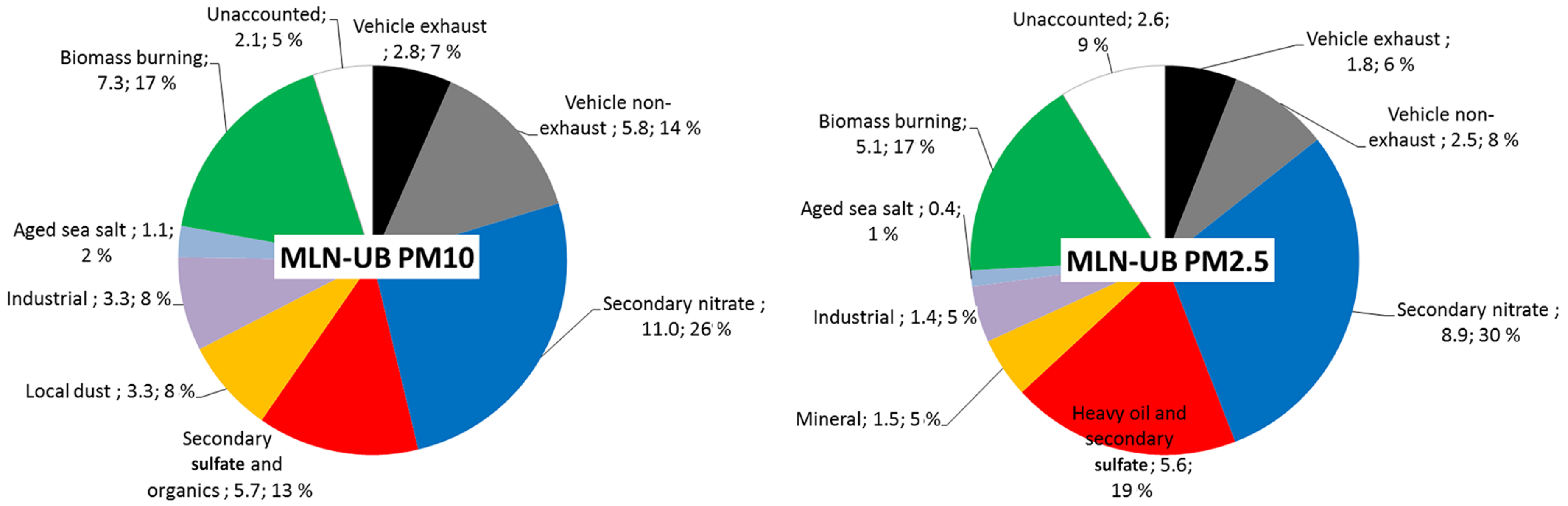








Average contribution (%) of PM_{10} and $PM_{2.5}$ sources for 12 months of study (3)



From Amato et al., ACP, 16, 3289-3309 (2016)

Empirical Model of Road Dust Resuspension

- Ef_i (mg VKT^{-1}) = $aMF10_i^b$
  where MF10 is the mobile road dust < 10 µm, and
  a and b are empirically determined coefficients

- MF10 can be predicted from
  CAM, a measure of road surface texture
  TR, traffic intensity, and
  DIST, the distance from the closest braking zone
  (from Padoan et al., Environ. Pollut., 237, 713-720, 2018)

Battery-electric vehicles (BEV)

- It has been suggested that BEV are heavier than their equivalent ICE vehicle.
- A greater vehicle weight implies greater abrasion emissions and dust resuspension.
- However, regenerative braking reduces brake wear.
- The net effect is uncertain

Electric Vehicles (EV): wear emissions

- EV have no exhaust emissions at point of use.
- EV have reduced brake wear emissions as much braking is regenerative rather than frictional.
- Timmers and Achten (2016) argued that EV would be heavier than equivalent ICE vehicles, and hence generate increased tyre wear/road abrasion and resuspension emissions.
- Independently analysed data suggest that on average a current EV passenger car is about 250 kg (18%) heavier than its ICE equivalent.
- Based upon laboratory-measured emission factors this would cause an increase in tyre and road wear emissions of 4-5%, although some studies suggest closer to 25%.

Electric Vehicles (EV): resuspension emissions

- The extent to which resuspension emissions are related to vehicle mass is uncertain.

- USEPA AP42, emission from paved roads:

  $E = k\,(sL)^{p}\,W^{b}$

  where sL is silt loading, W is vehicle weight and p = 0.91 and

  b = 1.02

- Using AP42, an 18% increase in vehicle weight leads to a 18% increase in resuspension emissions.

- It seems unlikely that total EV non-exhaust emissions will exceed that of an ICEV.

Conclusions

- According to the NAEI, non-exhaust emissions are now the dominant component of road traffic emissions.
- There are no wholly specific chemical tracers for non-exhaust sources.
- Trace elements such as Ba, Cu and Sb can be used as tracers for brake wear but none is wholly specific, and it is necessary to use a fleet average for quantification.
- Several tracers, including organic compounds, have been used for tyre wear.
- Road surface wear and resuspension are typically represented by crustal elements, also present in wind-blown soil and dust.
- Size distributions span the boundary at 2.5 µm between “fine” and “coarse” fractions.
- There are many uncertainties regarding the non-exhaust emissions from electric vehicles.


THANK YOU