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# Non Exhaust Emissions from Vehicles

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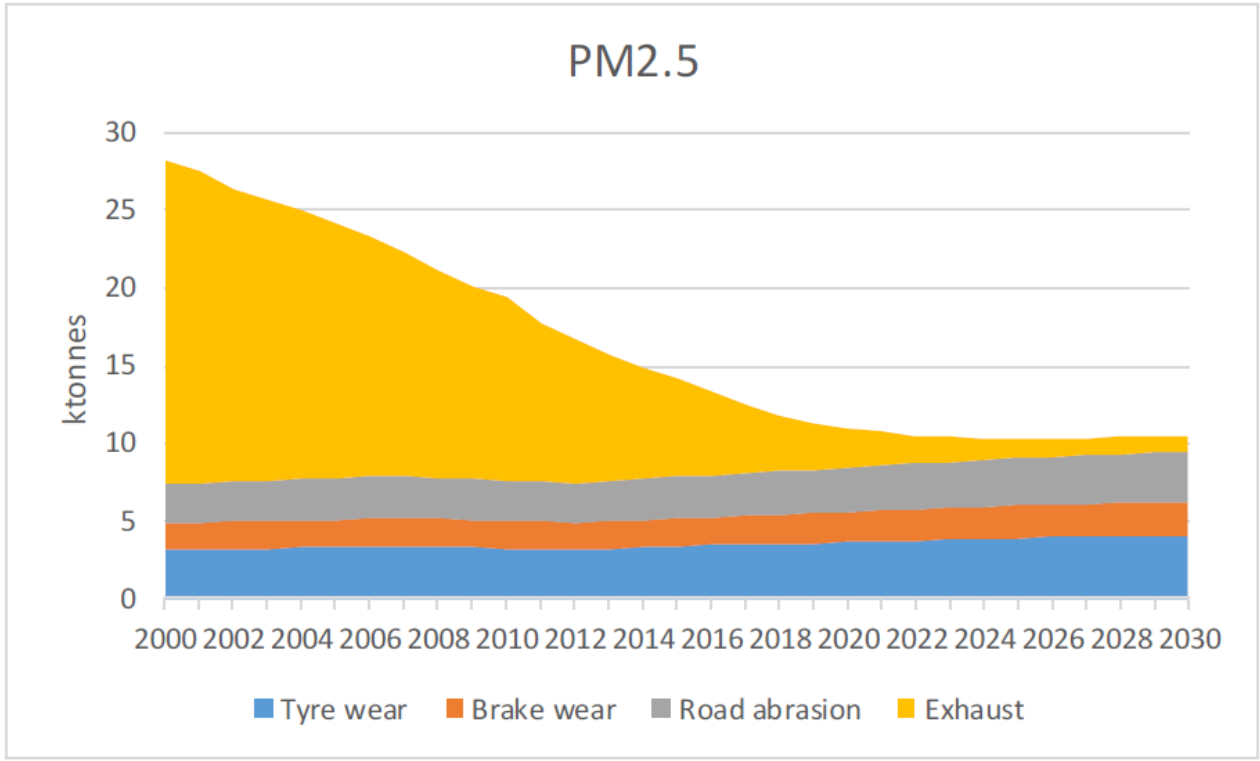
# Introduction

- Sources of non exhaust emissions
- Environmental evidence
- Possible effects
- Research questions
- Possible mitigation measures

# Zero emission?

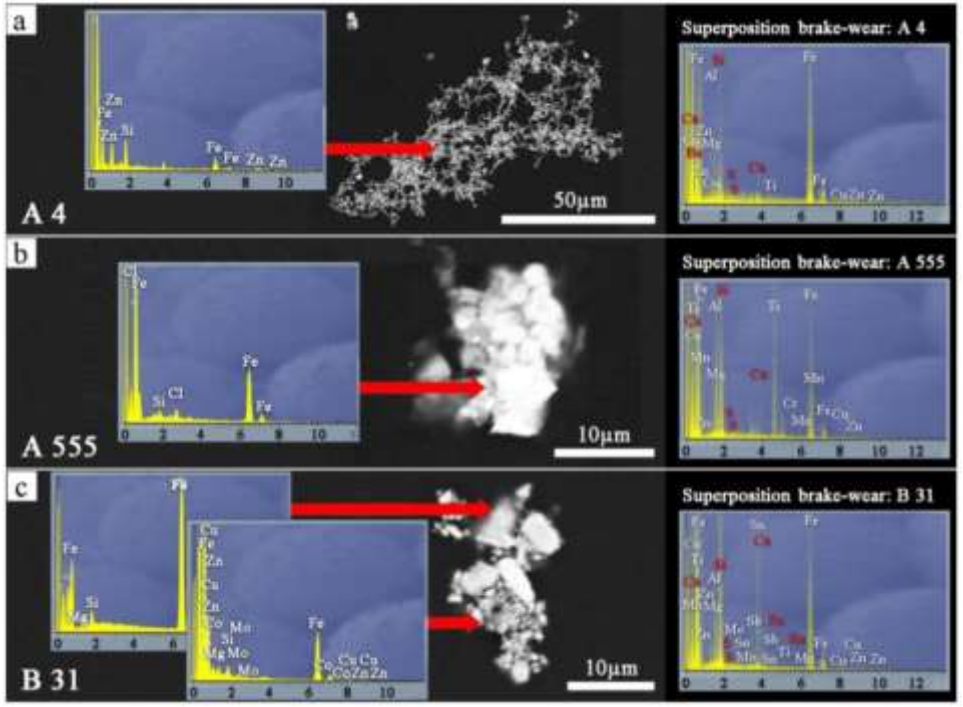
- A more correct term would be ‘zero exhaust emission’
- Since the introduction of filtration, most new diesel and gasoline vehicles emit little mass of particulate anyway
- Going forward, non exhaust emissions are predicted to be the dominant source of primary particulate matter from vehicles




AQEG, *Non Exhaust Emissions from Road Traffic*, DEFRA, 2019

# Brake wear

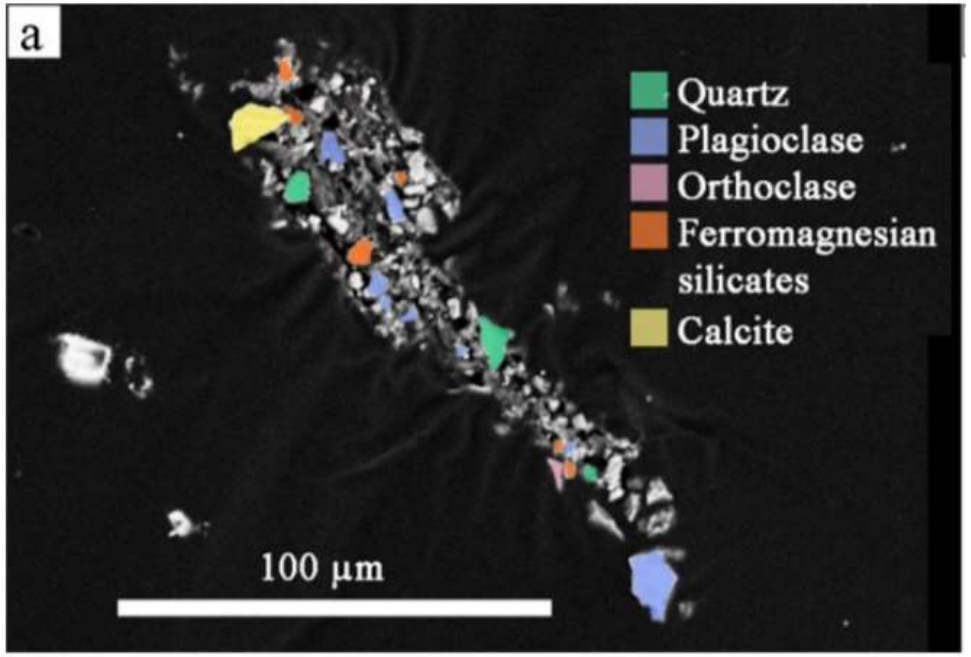
- Through routine action, brakes produce particulate through abrasion and material being ‘burned’ off
- Composition of the particles reflective of the composition of the disc and pads
  - Pad composition varies greatly according to local legislation and intended characteristics
  - In addition to carbonaceous material, contains a large amount of metals



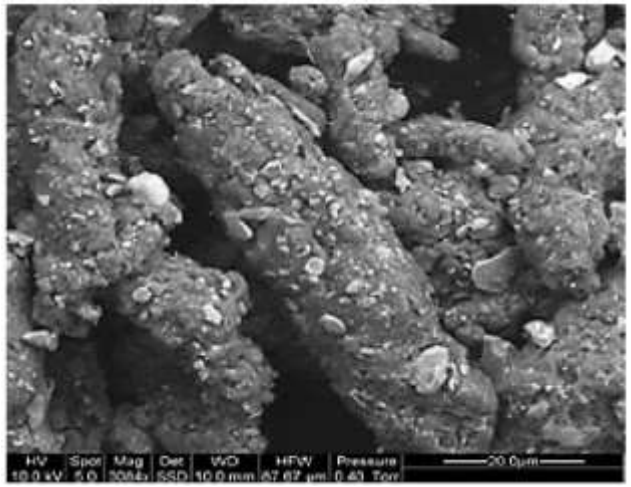

Sommer et al., *Aerosol and Air Quality Research*, 18: 2014–2028, 2018

# Tyre/road wear

- Formed through abrasion between tyres and road
- Tyre wear particles typically large carbonaceous particles containing embedded mineral particles
- Road wear can be enhanced by the use of studded tyres
- Modern tyres contain a large fraction of synthetic polymers, so are now considered a source of microplastics

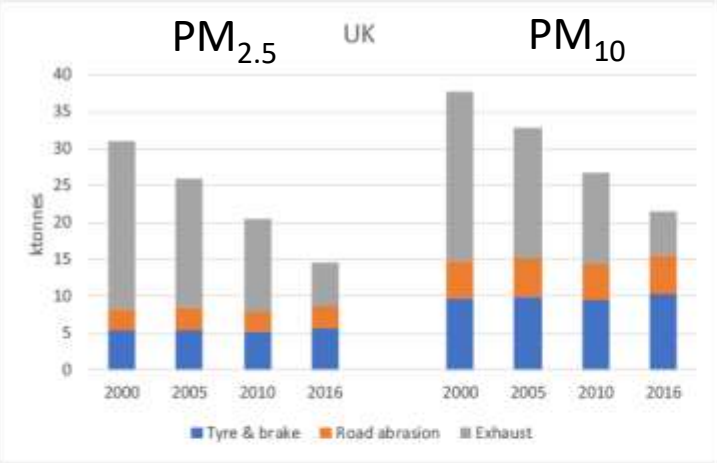


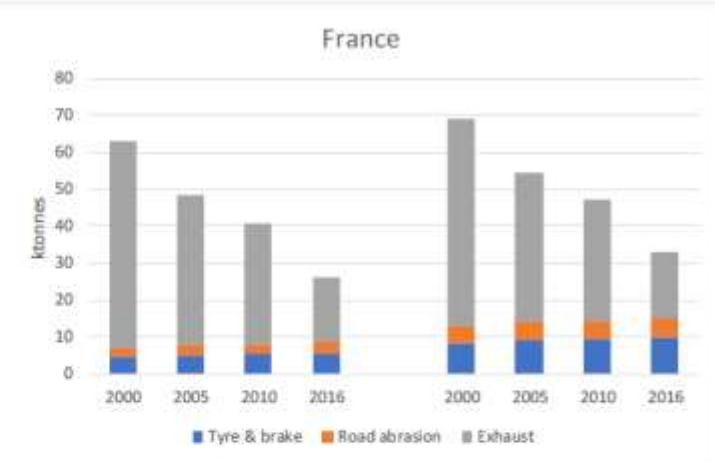

Sommer et al., *Aerosol and Air Quality Research*, 18: 2014–2028, 2018

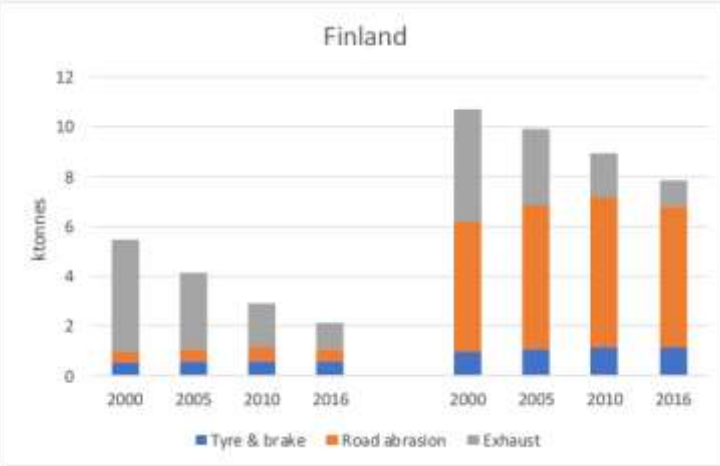


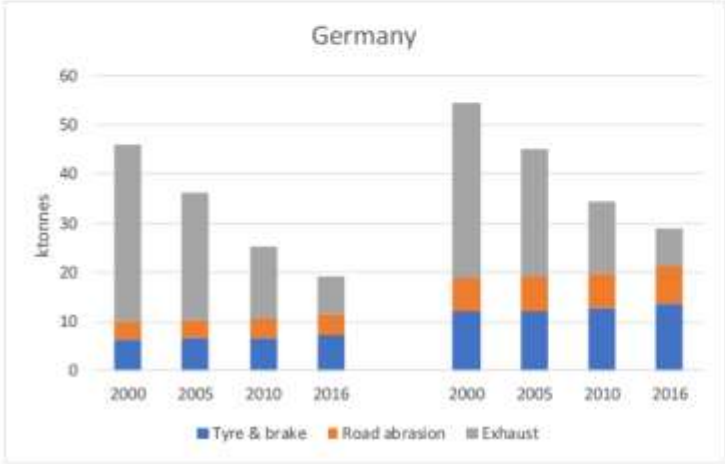
Panko et al., *Atmosphere* 10, 99, 2019.

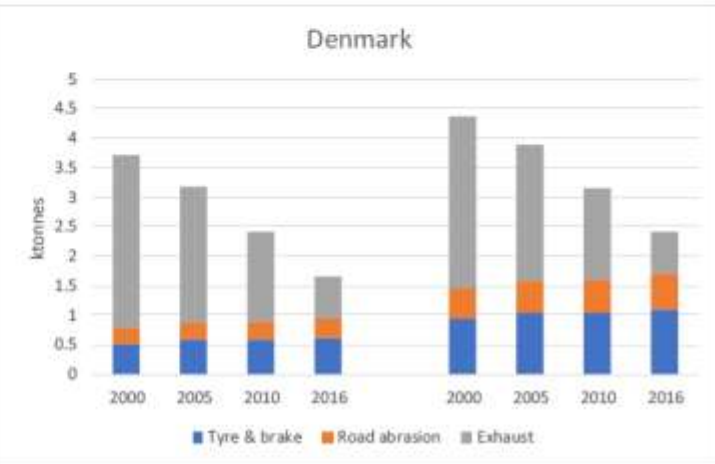
# Trends with country

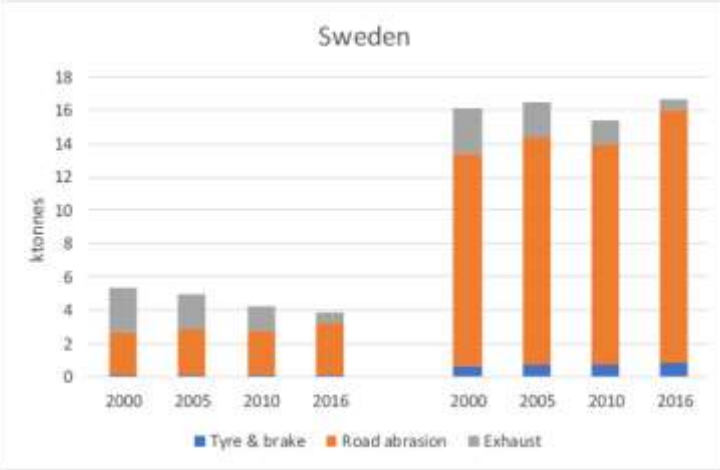



AQEG (2019)

# Resuspension

- Loose dust on the road, made airborne by tyre friction or air turbulence
- Can be a mixture of:
  - Minerals/soils
  - Construction/demolition debris
  - Grit/salt residue
  - Exhaust soot
  - Previously settled brake/tyre/road wear
- Enhanced in drier conditions

# Atmospheric measurements

- Particles are refractory and insoluble, so measurement of composition is difficult
  - Methods such as IC and AMS will not detect them
  - While they are light absorbing, urban Aethalometer measurements are typically dominated by soot
- Methods of study include:
  - Metals analysis by ICP-AES/MS or X-ray spectroscopy
  - Electron microscopy
  - Online size distribution data in conjunction with other metrics
  - Analysis of tyre wear polymers by pyrolysis or FTIR

Photo: University of Manchester

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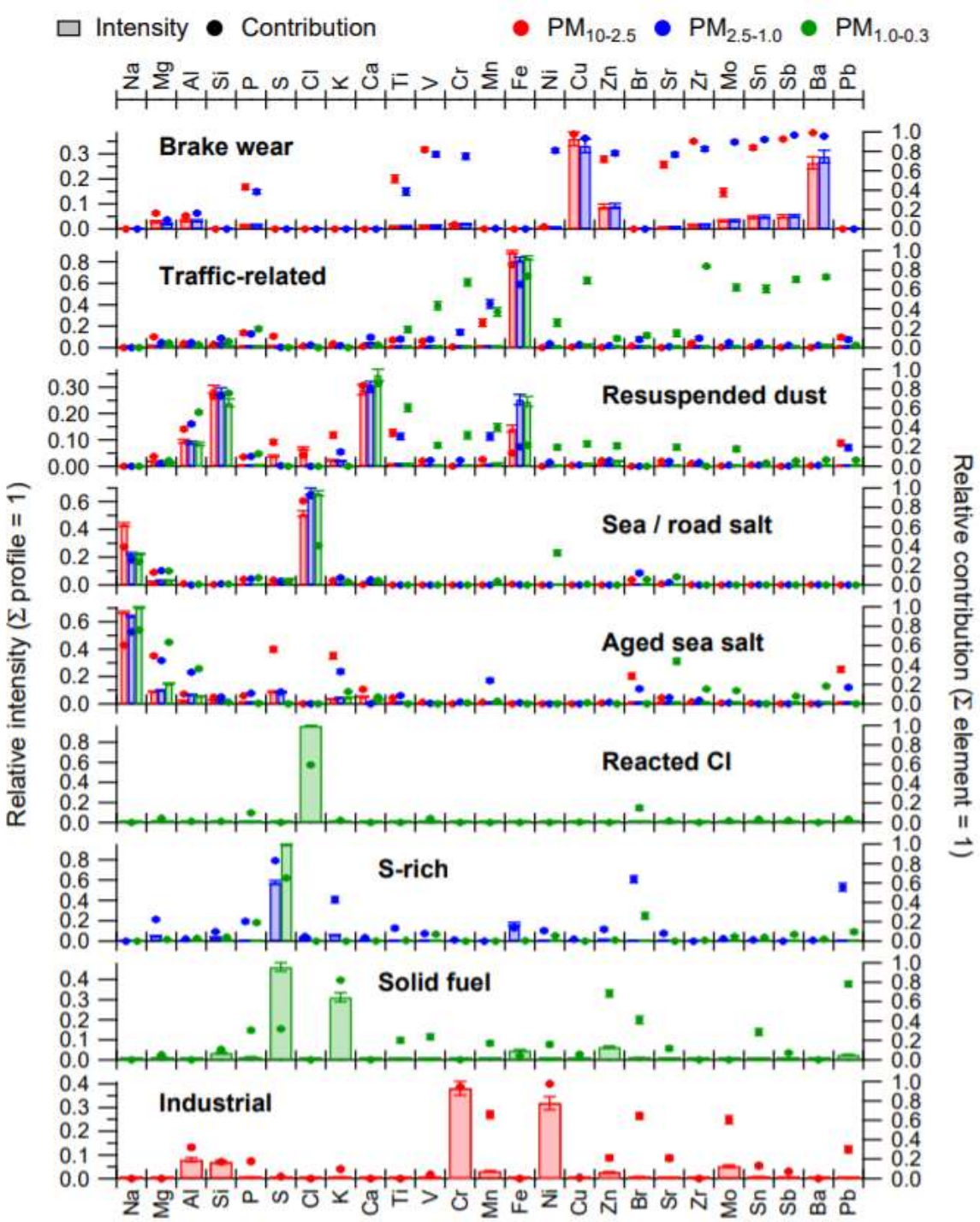
# Evidence base

- Emissions profiles highly variable, making receptor modelling for source apportionment very difficult

| Reference | Brake wear | Tyre wear | Re-suspension |
|---|---|---|---|
| Adachi and Tainosho (2004) | Fe, Ba, Cu, Sb, Zr | Zn | – |
| Schauer et al. (2006) | Fe, Cu, Ba | | – |
| Grieshop et al. (2006) | Cu, Sb, Ba and Ga | | |
| Wahlin et al. (2006) | Cr, Fe, Cu, Zn, Zr, Mo, Sn, Sb, Ba and Pb | Al, Si, K, Ca, Ti, Mn, Fe, Zn and Sr (together with road dust) | |
| Tanner et al. (2008) | Cu, Cd | Zn | |
| Canepari et al. (2008) | Ba, Fe, Sb, Sr | – | – |
| Harrison (2009) | Ba, Cu | – | Al |
| Dongarra et al. (2009) | Cu, Mo, Sb | – | |
| Fabretti et al. (2009) | Cu, Zn, Sb, Sn (vehicular abrasion) | – | Rb, Sr, Mn, Fe, As |
| Keuken et al. (2010) | Cu | Zn | – |
| Bukowiecki et al. (2010) | Fe, Cu, Zn, Zr, Mo, Sn, Sb and Ba | | |
| Pey et al. (2010) | – | – | Fe, Ca, Sb, Sn, Cu, Zn |
| Perez et al. (2010) | Sb, Cu, Ni, Sn (wear of brake, tire and other parts) | | Fe |
| Amato et al. (2011a) | Fe, Cu, Zn, Cr, Sn, Sb | OC, S, Zn | Al, Ca, Fe, V |
| Apeagyei et al. (2011) | Fe, Ti, Cu, Ba | Zn, Ca, W, K, Fe, Ti, Cr, Mo | – |
| Duong and Lee (2011) | Ni, Cu | Zn | |
| Ondráček et al. (2011) | Cu, Ba, Fe, Zn | – | |
| Song and Gao (2011) | Sb, Cu, Fe, Pb | Zn, Co | |
| Sahu et al. (2011) | Zn (brake and tyre wear) | – | |
| Peltier et al. (2011) | – | – | Al, Si, Ti, Fe |
| Harrison et al. (2012b) | Ba, Cu, Fe, Sb | Zn | Si, Al |

P. Pant, R.M. Harrison: *Atmospheric Environment* 77, 78-97, 2013

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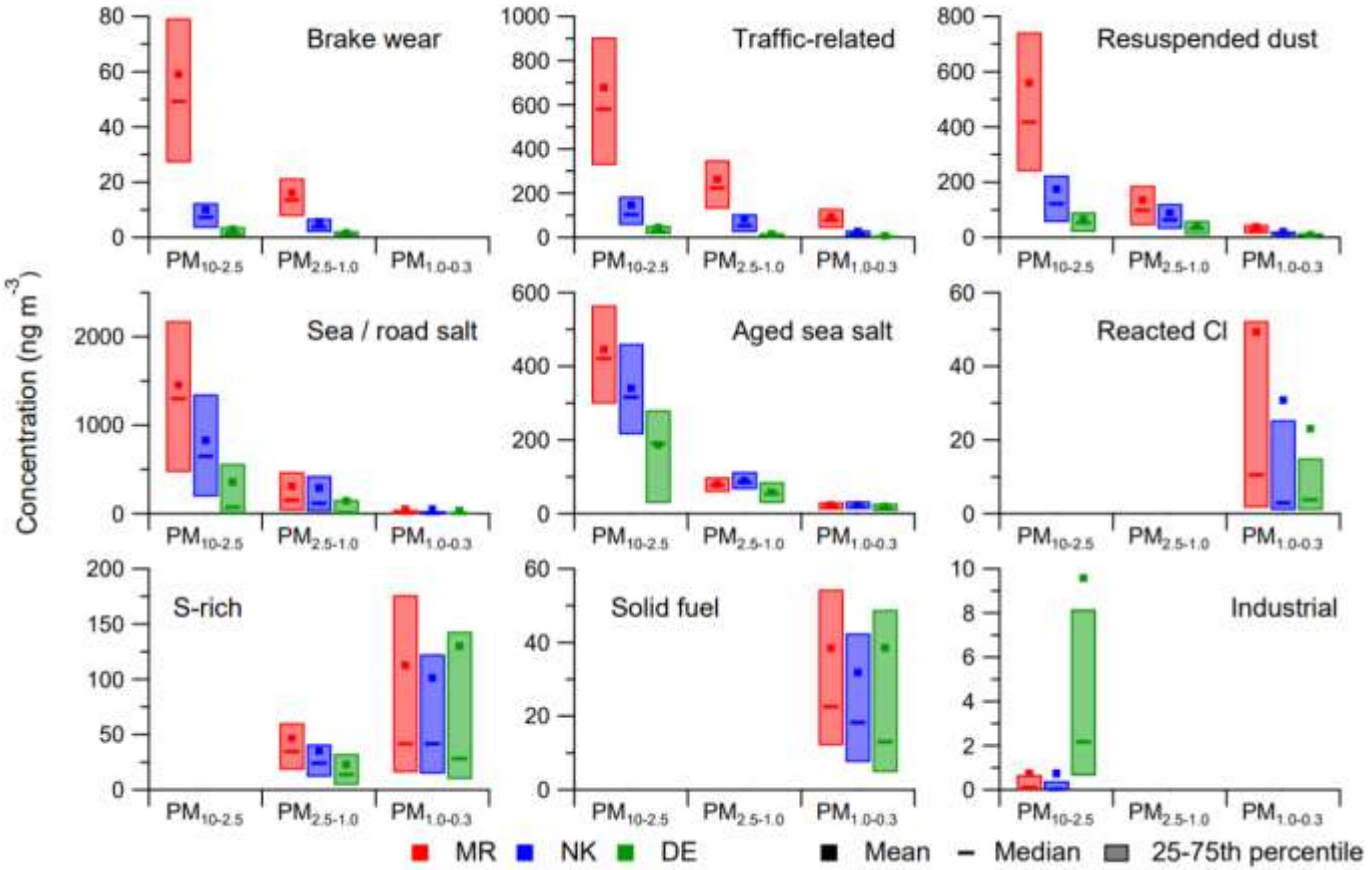



MR=Marylebone Road (roadside)
NK=North Kensington (urban background)
DE=Detling (rural background)

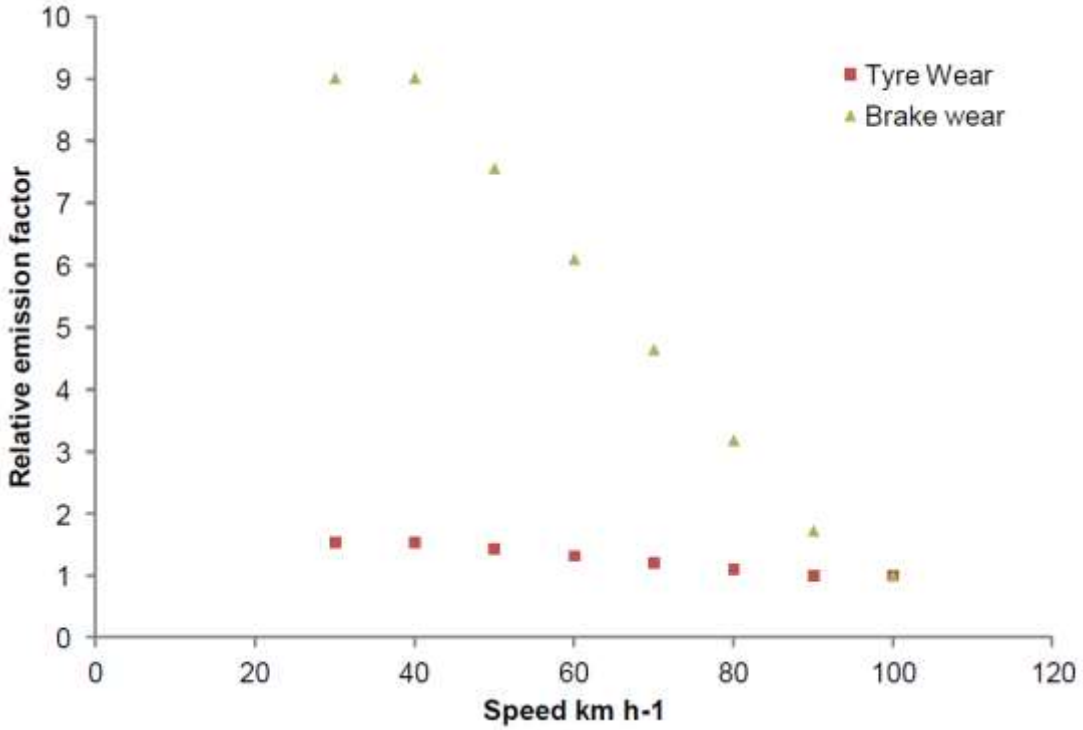
Visser et al., *Atmos. Chem. Phys.*, 15, 11291–11309, https://doi.org/10.5194/acp-15-11291-2015, 2015.

# Effects

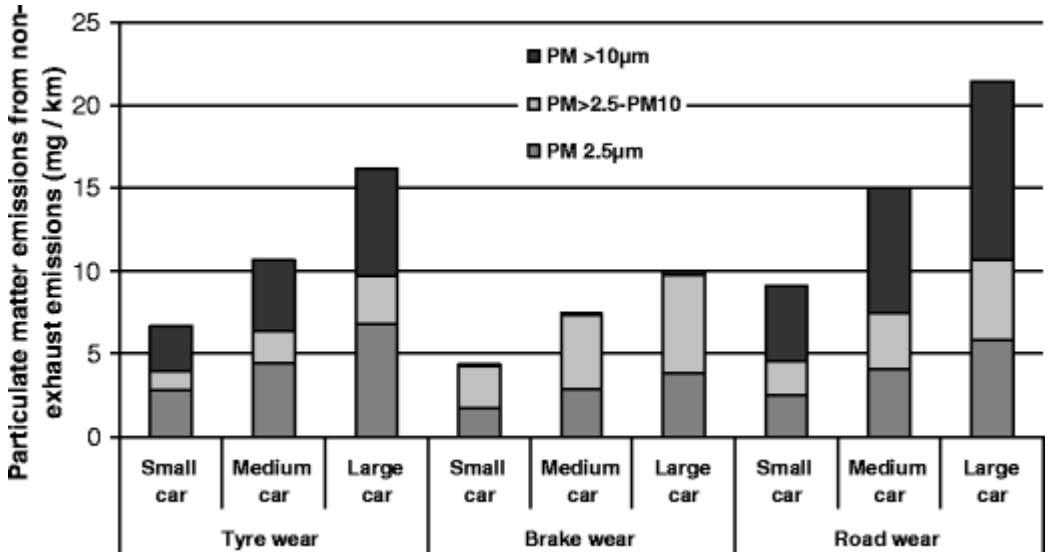
- Most non exhaust emissions are thought to be more of a significant contribution to $PM_{10}$ than $PM_{2.5}$ (although the $PM_{2.5}$ contribution is becoming more significant)
- Health outcome data are generally more strongly associated with $PM_{2.5}$ than $PM_{10}$, suggesting non exhaust emissions are not as important, however this may change as $PM_{2.5}$ concentrations continue to decrease
- Brake and tyre wear particles in particular are known to contain PAHs and metals, which are known to be toxic by inhalation
- The effects of microplastics by inhalation are not known
- The metals, PAHs and microplastics can have an effect on the wider environment (rivers, soils, groundwater)
- Currently there is little or no direct regulation or mitigation of this as a source of atmospheric pollution beyond ambient $PM_X$ directives

# Emissions modelling

- While emissions data exists, it is not as comprehensive as exhaust emissions




AQEG, 2019




Simons, A. *Int J Life Cycle Assess* (2016) 21: 1299. https://doi.org/10.1007/s11367-013-0642-9

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# Future vehicles

- Electric/hybrid/self-driving vehicles are heavier than the equivalent specification internal combustion engine vehicles
  - More energy dissipation required during braking
  - Larger contact area between tyre and road needed – more wear and resuspension
- Regenerative braking significantly mitigates the brake wear emissions

# Research questions

- What is the extent of non exhaust emissions?
  - Do we expect emission hotspots in locations not traditionally monitored, e.g. motorway slip roads?
- What is the size and composition of these particles?
  - If tyre abrasion particles are large, are they even a problem for $PM_{10}$?
- Are they having an effect on peoples health and/or the wider environment?
- What do we expect these emissions to do in the future?
  - Will we see a net benefit or disbenefit from electric/hybrid/self-driving cars?
- How can we mitigate these emissions and public exposure?

# Mitigating traffic/behaviour?

- Reduce the number of vehicles on the road, e.g. congestion charging, public transport, cycling etc.
- Separate public from traffic through urban planning
  - $PM_{2.5\text{-}10}$ tends to be relatively localised due to gravitational settling and impaction
- Promote less aggressive driving (e.g. smart roads) to reduce acceleration, braking and fast cornering, although evidence supporting the effectiveness of this is currently lacking
- In colder countries, regulations concerning the use of studded tyres present a major challenge, trading off road wear vs safety

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# Trees/green walls?

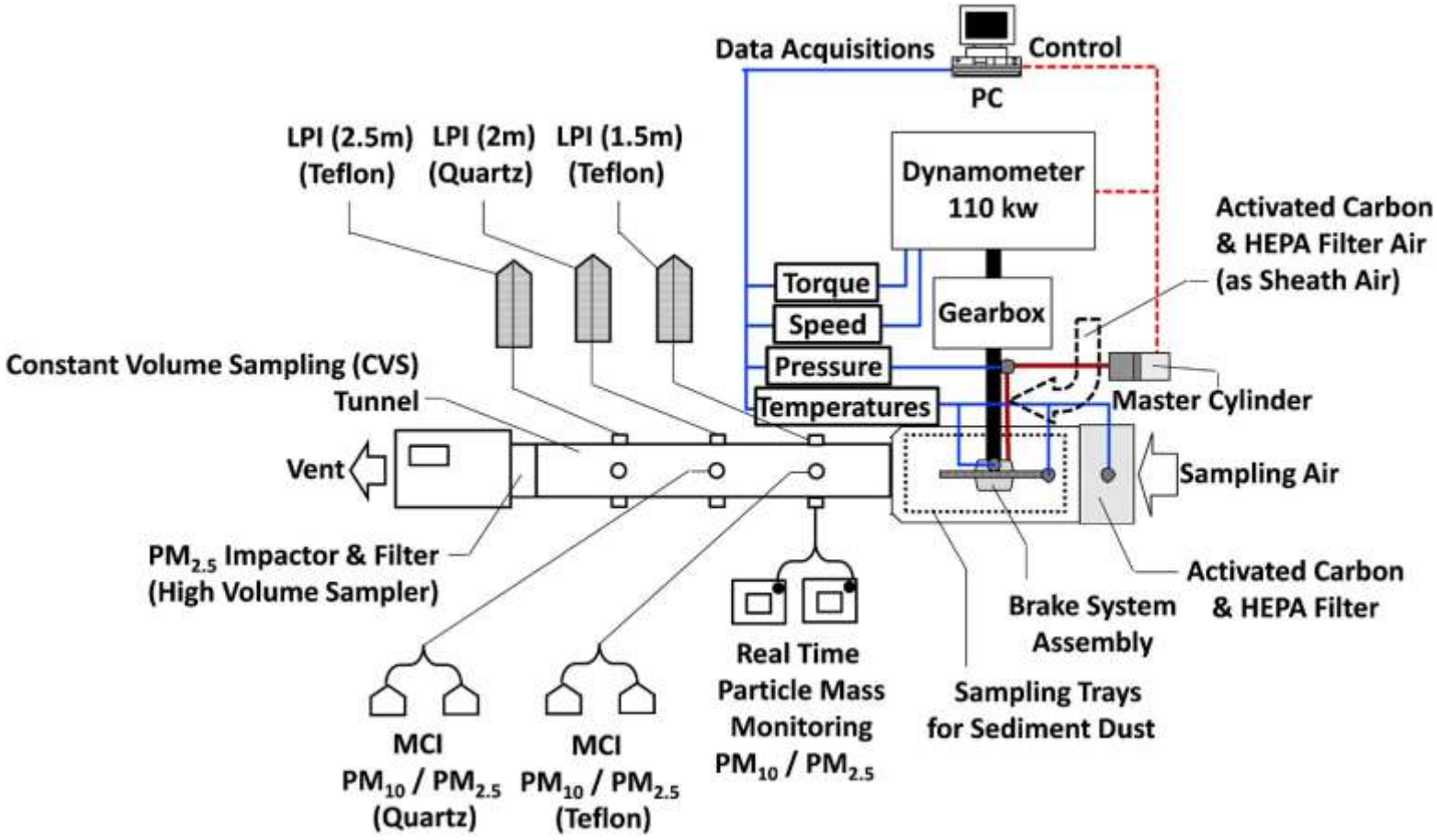
- Trees, hedges or green walls could be placed between roads and pedestrians
  - While these are very limited in their ability to trap $NO_2$ and $PM_{2.5}$, they are slightly more efficient at removing $PM_{10}$
  - They keep people further away from the roads, reducing exposure
  - They have other benefits, e.g. sound suppression, visually appealing
- Consideration must be paid to potential disbenefits, e.g. disrupting street canyon air flow, release of biogenic VOCs

# Supressing resuspension?

- Increasing road tread depth can help suppress resuspension
- Road sweeping/washing technology well established
- Road can be treated with calcium magnesium acetate or magnesium chloride to promote water retention, preventing the dust from drying out
- Washing/sweeping/treatment not currently regarded as a general solution
  - Results from trial programmes have been mixed
  - Even if they worked reliably, would require continual use to prevent build-up
- Sweeping/washing in especially dusty environments (e.g. around construction/demolition sites) is still prudent

# Tyre/Brake emissions standards?

- While certain aspects of tyre/brake formulation are regulated, this is with respect to composition and not explicitly emissions
- A standardised method for measurement of brake emissions is currently in development and type approval standards may follow




H. Hagino et al. / *Atmospheric Environment* 131 (2016) 269-278

# Tyre/Brake formulation?

- There is a strong commercial motivation to reduce emissions from brakes, so companies are currently investing in R&D on this topic
  - In addition to responding to future regulations, customers would benefit from cleaner wheels
- Tyre formulation will likewise have to adapt to any future legislation
- Newly developed products could be fitted to the existing fleet, so could be implemented relatively quickly

# Dust capture?

- Filtration around brake pad to capture brake emissions
  - Or we just go back to drum brakes…
- Flow around wheel directed through a filter in the wheel arch
  - Would collect most forms of non exhaust emissions, although concept is currently unproven
- These solutions would likely only apply to new vehicles
- Would add to the maintenance schedule of vehicles

# Summary

- As emissions of exhaust PM continues to decrease, non exhaust emissions will become more and more significant for the ambient PM budget close to roads
- The problem is not going away with electric/hybrid vehicles, although the net effect of regenerative braking vs increased vehicle mass remains to be seen
- More research is needed to better characterise the emissions and their effects on human health and the environment
- Brake and tyre technology are not currently regulated according to airborne emissions, but may be in the future
- While technical mitigations may be possible, reducing traffic volume and separating traffic from pedestrians are currently the most effective solutions