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Research and policy on non-exhaust emissions: a consensus statement from an international workshop

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Background

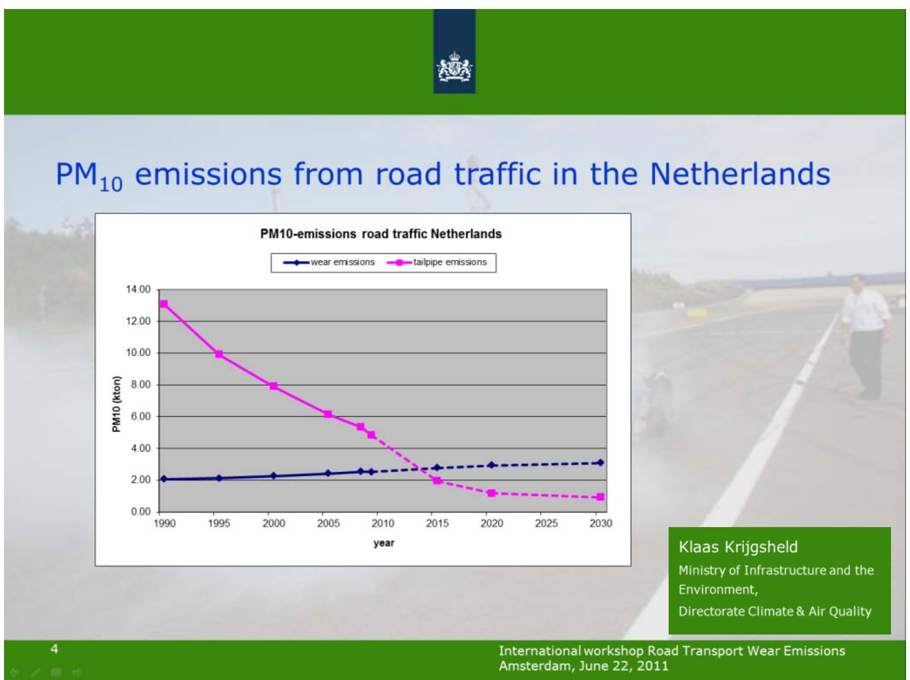
Querol et al., 2004

Table 2
Mean annual levels (μg m^{-3}) of PM10, PM2.5, organic and elemental carbon (OC+EC), mineral elements, marine contribution and secondary inorganic aerosols (SIA), and the equivalent contributions to bulk mass concentrations (% wt), recorded at regional background (RB), urban background (UB) and kerbside stations (RS) in Central, Northern and Southern EU based on the data reported from the examples from Austria, Berlin, Spain, Sweden, Switzerland, The Netherlands and United Kingdom

	Central EU (examples from Australia, Berlin, Switzerland, The Netherlands, UK)			Northern EU (13 sites in Sweden)			Southern EU (10 sites in Spain)		
	RB	UB	RS	RB	UB	RS	RB	UB	RS
μg m^{-3}									
PM10	14–24	24–38	30–53	8–16	17–23	26–51	14–21	31–42	45–55
OC+EC	4–7	6–9	13–21	1–2	2–3	5–6	2–5	4–9	10–18
Mineral matter	1–2	3–5	4–8	2–4	7–9	17–36	4–8	8–12	10–18
Marine aerosols	2–4*	2–4*	2–4*	1–4	1–4	1–4	2–4#	2–4#	2–4#
SIA	7–9	7–13	8–13	3–5	3–5	3–5	5–9	6–11	6–11
PM2.5	12–20	16–30	22–39	7–13	8–15	13–19	12–16	19–25	28–35
OC+EC	3–7	5–8	8–16	1–2	2–3	5–6	2–4	4–8	8–12
Mineral matter	0.5–2	0.4–2	1–2	1–3	2–4	4–6	1–3	2–5	4–6
Marine aerosols	0.2–1	0.2–1	0.2–1	1–3	1–3	1–3	0.2–1	0.2–1	0.2–1
SIA	6–8	6–11	7–11	3–5	3–5	3–5	4–8	7–10	6–10
%									
PM10									
OC+EC	30–35	20–30	40–45	12–15	12–15	12–20	15–25	12–25	25–37
Mineral matter	5–10	10–15	12–15	20–30	35–45	65–70	12–40	25–30	25–37
Marine aerosols	5–20	5–12	5–8	12–30	5–15	4–6	5–20	5–10	3–8
SIA	35–55	30–35	25–28	30–40	15–25	10–15	35–45	20–27	13–25
PM2.5									
OC+EC	30–40	25–35	35–45	15	20–35	30–40	17–30	20–35	30–40
Mineral matter	2–8	2–8	5	15–25	25–30	30–40	8–20	10–20	10–15
Marine aerosols	2–5	1–3	1–2	12–25	12–20	5–15	2–5	1–3	1–2
SIA	35–55	35–40	27–35	35–45	30–35	20–25	17–30	20–35	30–40

*7 μg m^{-3} in coastal areas of The Netherlands.
#11 μg m^{-3} in the Canary Islands.

X. Querol et al. / Atmospheric Environment 38 (2004) 6547–6555



Denier van der Gon et al., 2013

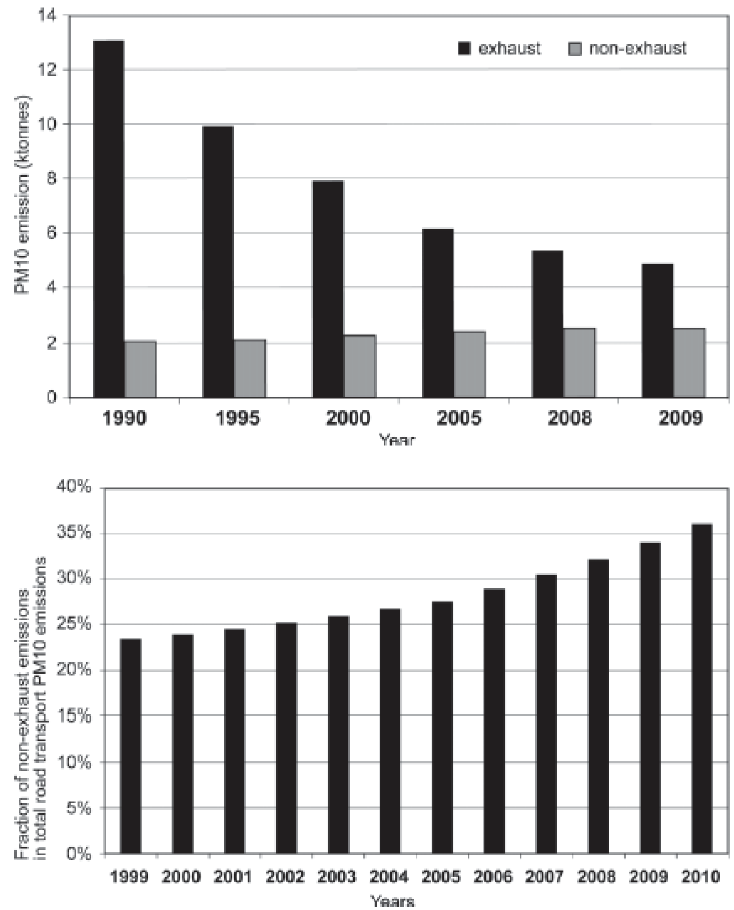
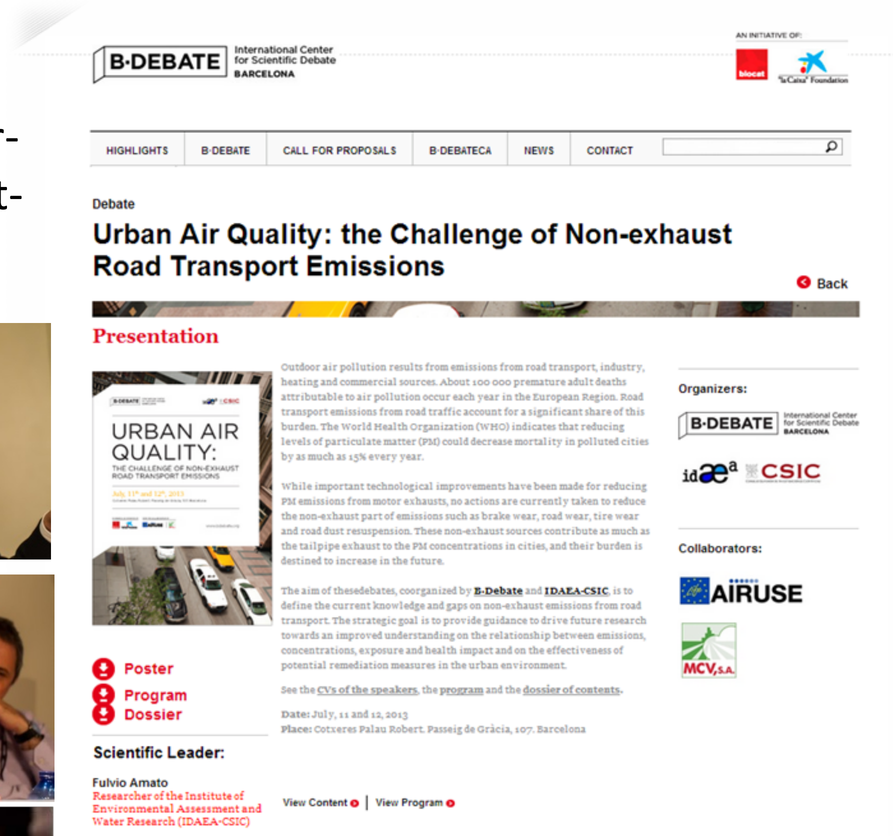


Figure 2. (a) Trend of PM_{10} emission from road transport exhaust and nonexhaust in the Netherlands (source: PRTR, 2011). (b) Average trend in nonexhaust emission for Europe based on extrapolation of base years in the IIASA GAINS model (source: GAINS, 2011).

Workshop: scientific debate

http://www.bdebate.org/en/forum/urban-air-quality-challenge-non-exhaust-road-transport-emissions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Debate

Urban Air Quality: the Challenge of Non-exhaust Road Transport Emissions

Back

Presentation

Outdoor air pollution results from emissions from road transport, industry, heating and commercial sources. About 100 000 premature adult deaths attributable to air pollution occur each year in the European Region. Road transport emissions from road traffic account for a significant share of this burden. The World Health Organization (WHO) indicates that reducing levels of particulate matter (PM) could decrease mortality in polluted cities by as much as 15% every year.

While important technological improvements have been made for reducing PM emissions from motor exhausts, no actions are currently taken to reduce the non-exhaust part of emissions such as brake wear, road wear, tire wear and road dust resuspension. These non-exhaust sources contribute as much as the tailpipe exhaust to the PM concentrations in cities, and their burden is destined to increase in the future.

The aim of thesedebates, coorganized by B-Debate and IDAEA-CSIC, is to define the current knowledge and gaps on non-exhaust emissions from road transport. The strategic goal is to provide guidance to drive future research towards an improved understanding on the relationship between emissions, concentrations, exposure and health impact and on the effectiveness of potential remediation measures in the urban environment.

See the CVs of the speakers, the program and the dossier of contents.

Date: July, 11 and 12, 2013
Place: Cotxeres Palau Robert. Passeig de Gràcia, 107. Barcelona

Poster
Program
Dossier

Scientific Leader:

Fulvio Amato
Researcher of the Institute of Environmental Assessment and Water Research (IDAEA-CSIC)

View Content | View Program

Organizers: B·DEBATE, IDAEA, CSIC

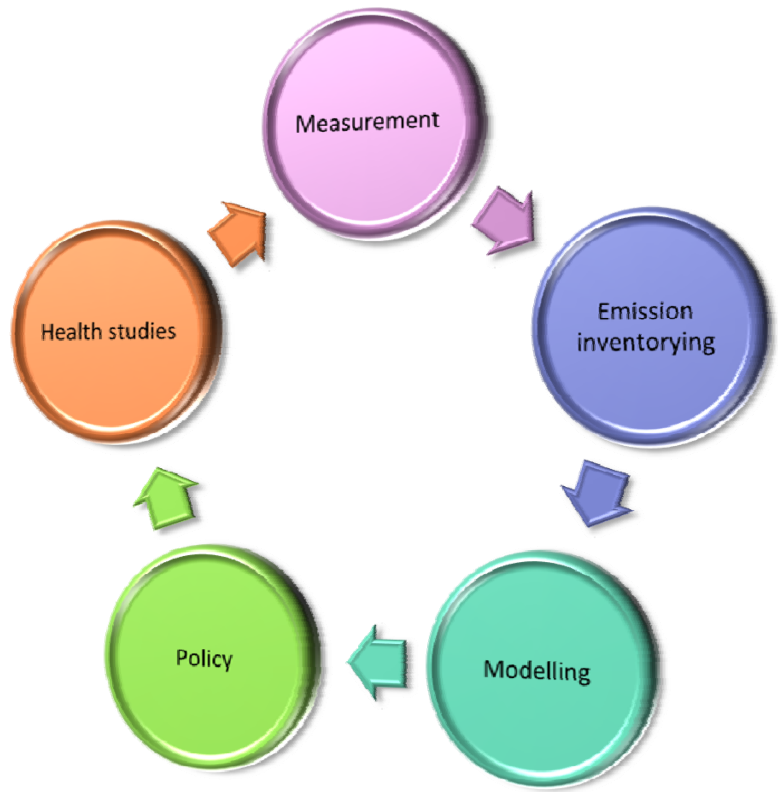
Collaborators: AIRUSE, MCV, S.A.

Goal of the workshop

- Identify gaps and needs for future research

- Consensus statement

www.bdebate.org



Measurements

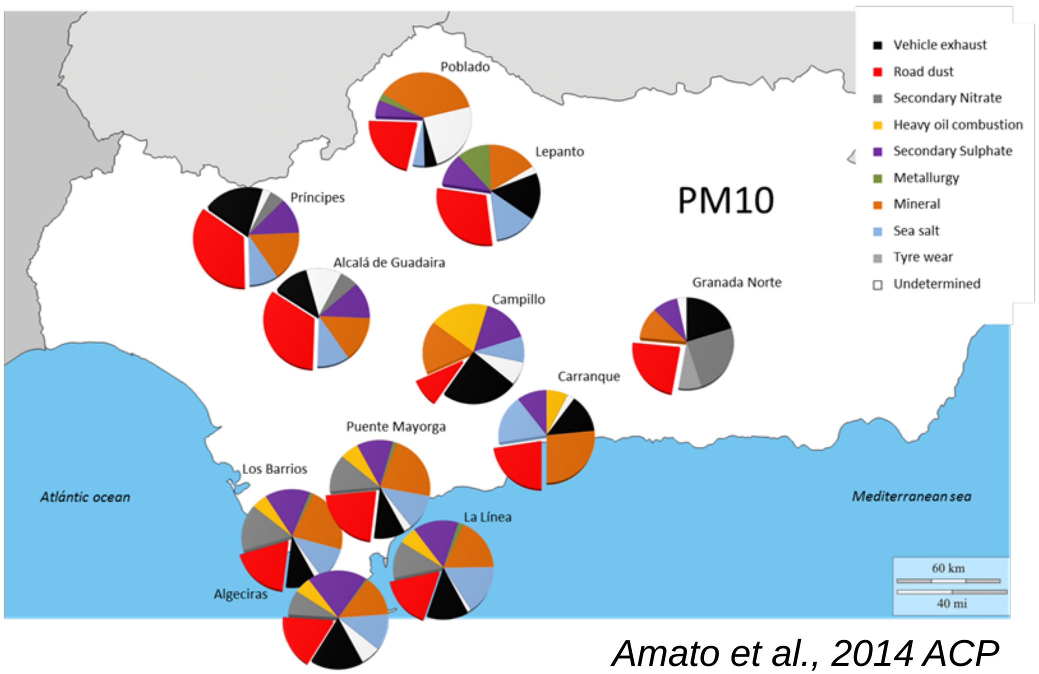
Estimating source contributions, emission factors…

- **COMPOSITION AND SIZE DISTRIBUTION: Use of chemical composition and particle size distributions can allow identification of non-exhaust components**

- **TWIN SITE APPROACH: Subtraction of urban background from roadside data reveals the road traffic contribution**

Source apportionment with aerosol composition

- Resuspension: heavily affected by climate
  - 12% in UK
  - 20-35% in Southern Europe
  - up to 90% in Scandinavia during winter-spring
- Brake wear: from ng/m^3 to 4 µg/m^3
- Tyre wear generally below 2%
- Road wear hardly separated



Amato et al., 2014 ACP

Source apportionment with aerosol size distribution

PMF ANALYSIS OF MERGED SMPS+APS DATA

Harrison, R. M , Beddows, D. C. S., and Dall'Osto, M. PMF Analysis of Wide-Range Particle Size Spectra Collected on a Major Highway, Environ. Sci. Technol., submitted

Matrix of Hourly Measurements:

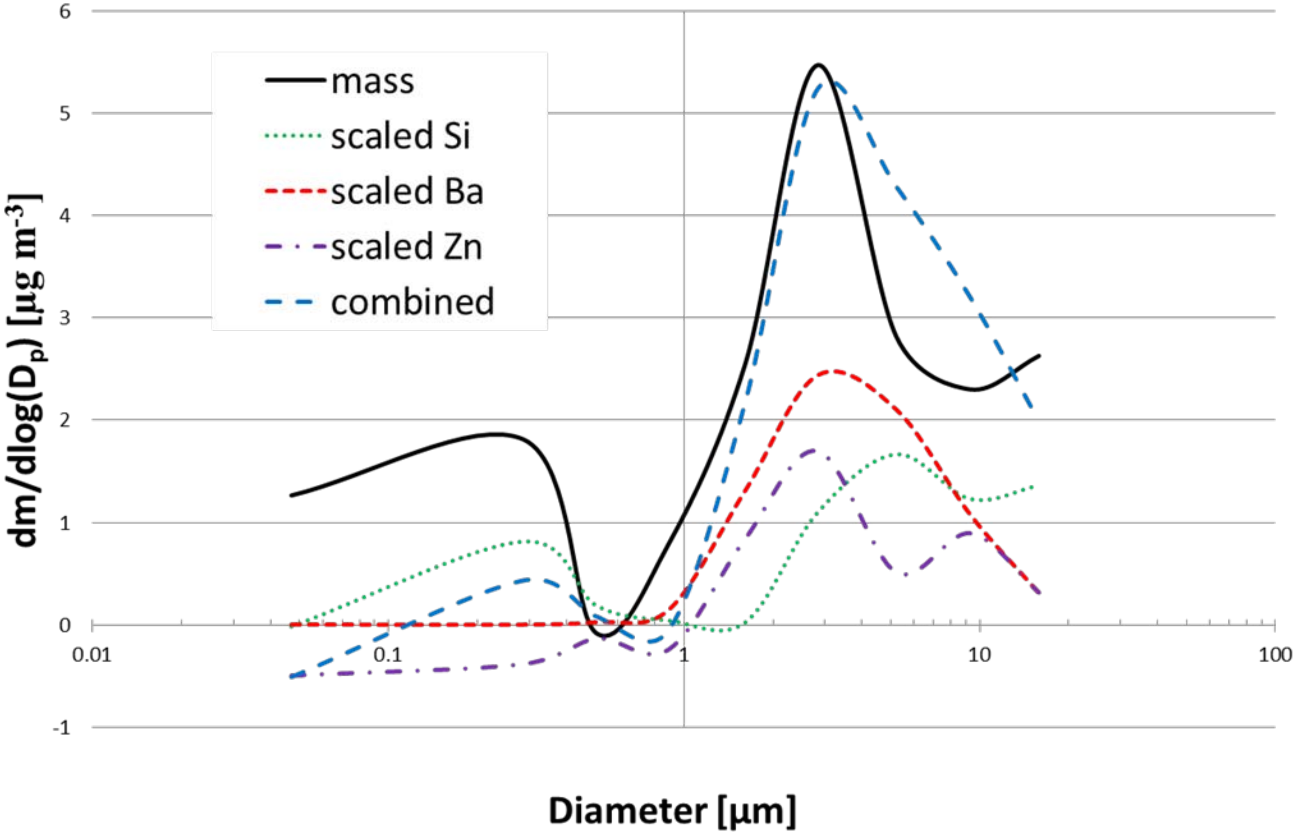
1. Merged SMPS+APS
2. Traffic Counts: LDV/HDV
3. Meteorological

$$x_{ij} = \sum_{h=1}^{p} g_{ij} \cdot f_{hj} + e_{ij}$$

Source	Contribution to total volume (%)	Contribution to traffic increment volume (%)	Assumed density (g cm^{-3})	Contribution to mass (%)
Exhaust, solid	18.8	46.4	2.0	40
Exhaust, nucleation	3.6	8.9	1.0	4
Brake/tyre wear	13.7	33.8	3.0	44
Resuspension	4.4	10.9	2.65	12
TOTAL	40.4%	100%		100%

SA with size distribution of metals

Harrison et al., ES&T 2012



Assumes

Brake dust = Ba x 91

Tyre dust = Zn x 50

Resuspension = Si x 3.6

Contributions to mass of 0.9 – 11.5 µm

Brake dust = 55.3 ± 7.9%

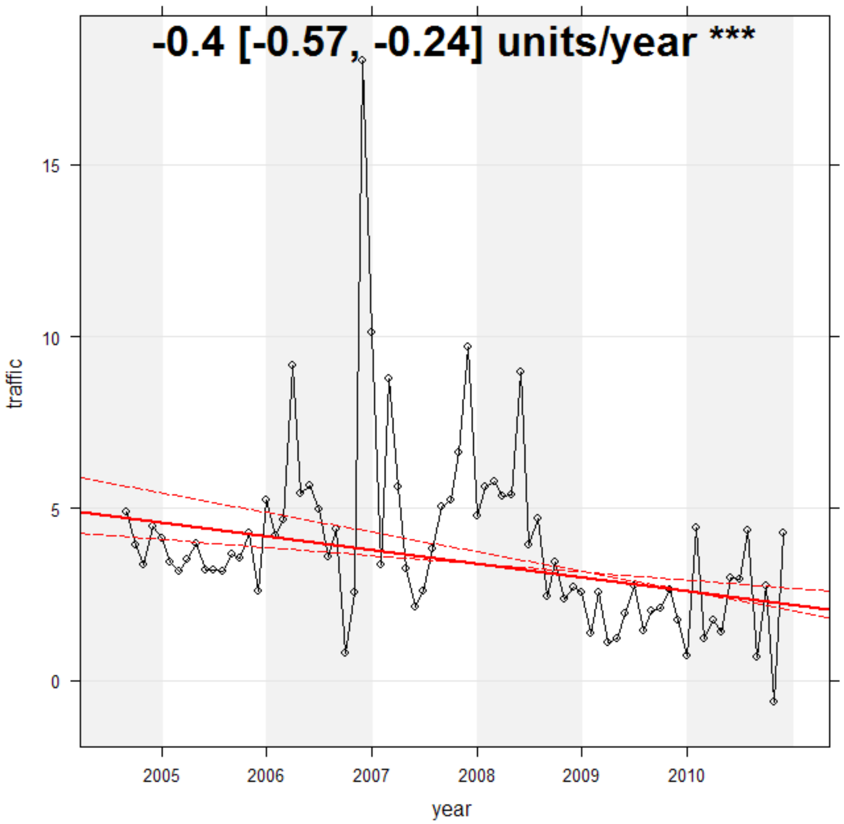
Tyre dust = 10.7 ± 2.3%

Resuspension = 38.1 ± 7%

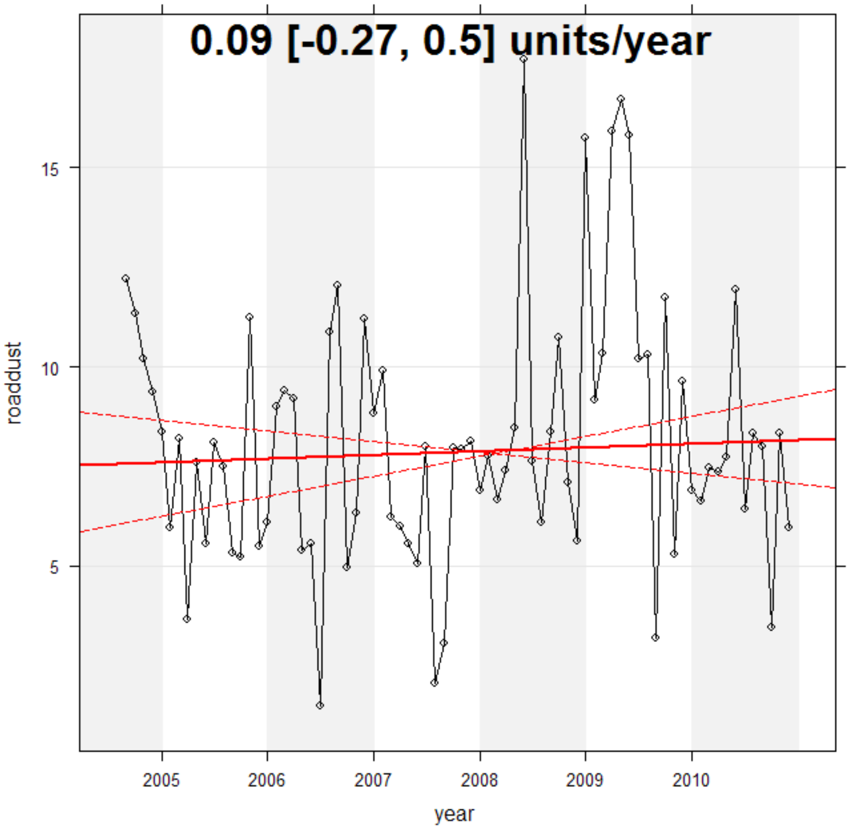
TRENDS OF PMF CONTRIBUTIONS

Amato et al. ACP, 2014

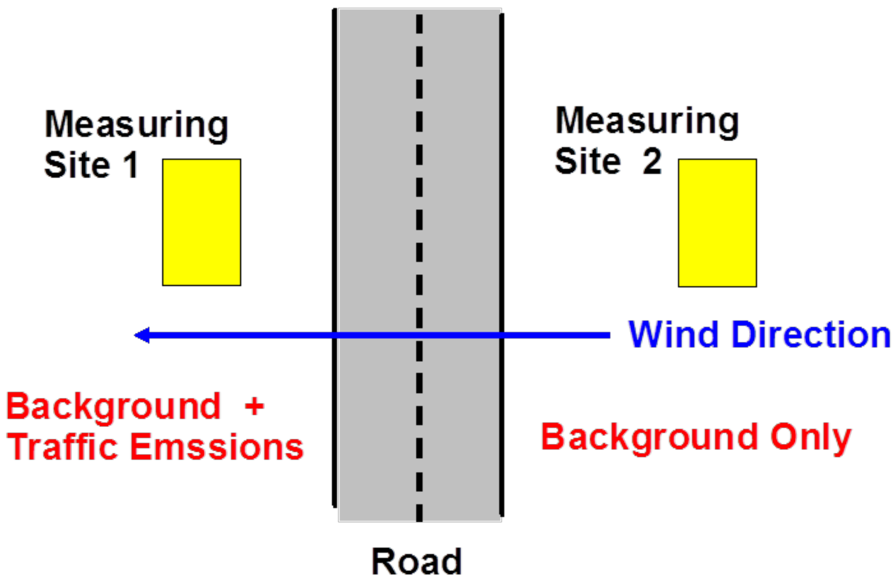
Motor exhaust

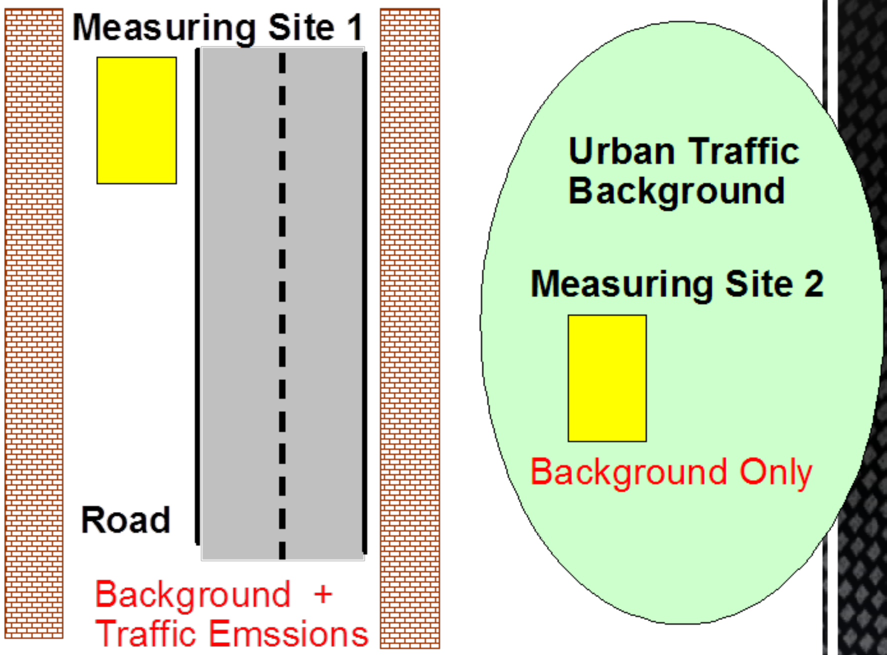


Road dust



TWIN SITE APPROACH





$c_{x,\ motorway\ traffic} = c_{x,\ downwind} - c_{x,\ upwind}$

$c_{x,\ local\ traffic} = c_{x,\ street\ canyon} - c_{x,\ urban\ background}$

Calculation of Emission Factors: Zürich-Weststrasse

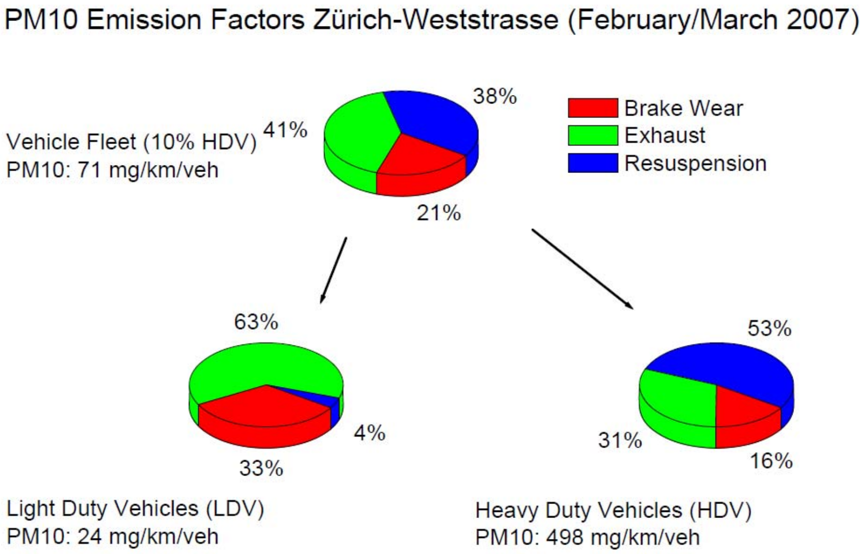
Concentration differences

Traffic counts (LDV, HDV) → **Emission factors**

Dilution (from NOx)

$$d = \frac{\mathrm{EF}_{\mathrm{NO}_x,\mathrm{LDV}} \cdot n_{\mathrm{LDV}} + \mathrm{EF}_{\mathrm{NO}_x,\mathrm{HDV}} \cdot n_{\mathrm{HDV}}}{\Delta \mathrm{NO}_x}$$

$$c_{x,\text{local traffic}} = \mathrm{EF}_{x,\mathrm{LDV}} \cdot \left(\frac{n_{\mathrm{LDV}}}{d}\right) + \mathrm{EF}_{x,\mathrm{HDV}} \cdot \left(\frac{n_{\mathrm{HDV}}}{d}\right) + C$$



Bukowiecki et al., 2009
Ketzel et al., 2007
Gehrig et al., 2004
Amato et al., 2010

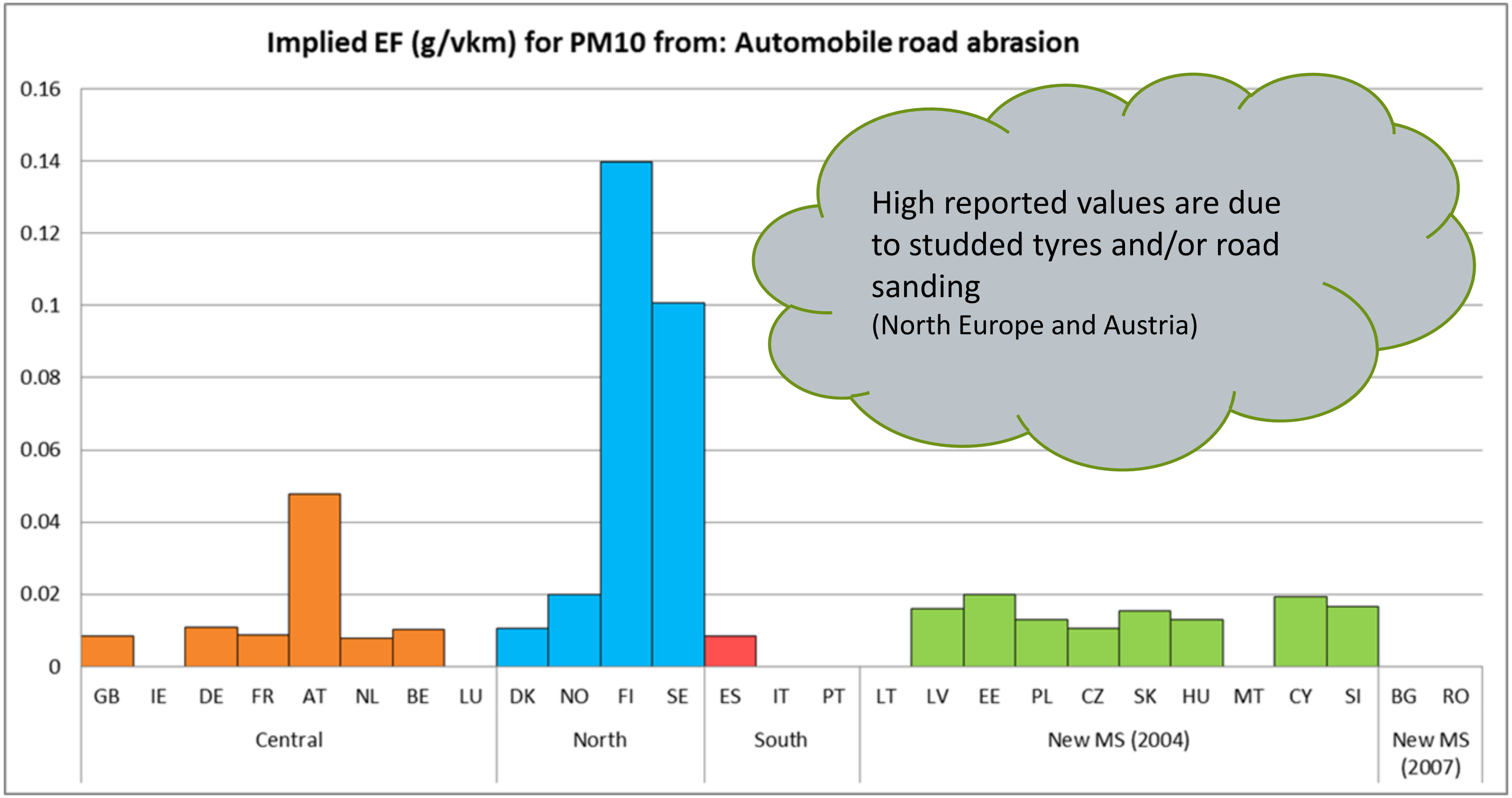
Emission inventorying
(CLRTAP + its protocols)

- Non-exhaust traffic emission sources:
  - 1) Road vehicle tyre and brake wear
    (NFR: 1.A.3.b.vi)
  - 2) Road surface wear
    (NFR: 1.A.3.b.vii)

EU 27 MS which reported non-exhaust emissions in 2012		
	Tyre and brake wear	Road wear
PM10	23	19
PM2.5	23	17
TSP	19	19
As	7	2
Cd	17	3
Cr	17	2
Cu	17	3
Hg	2	1
Ni	17	3
Pb	15	3
Se	13	0
Zn	17	3
PAH	6	1
Indeno	4	1

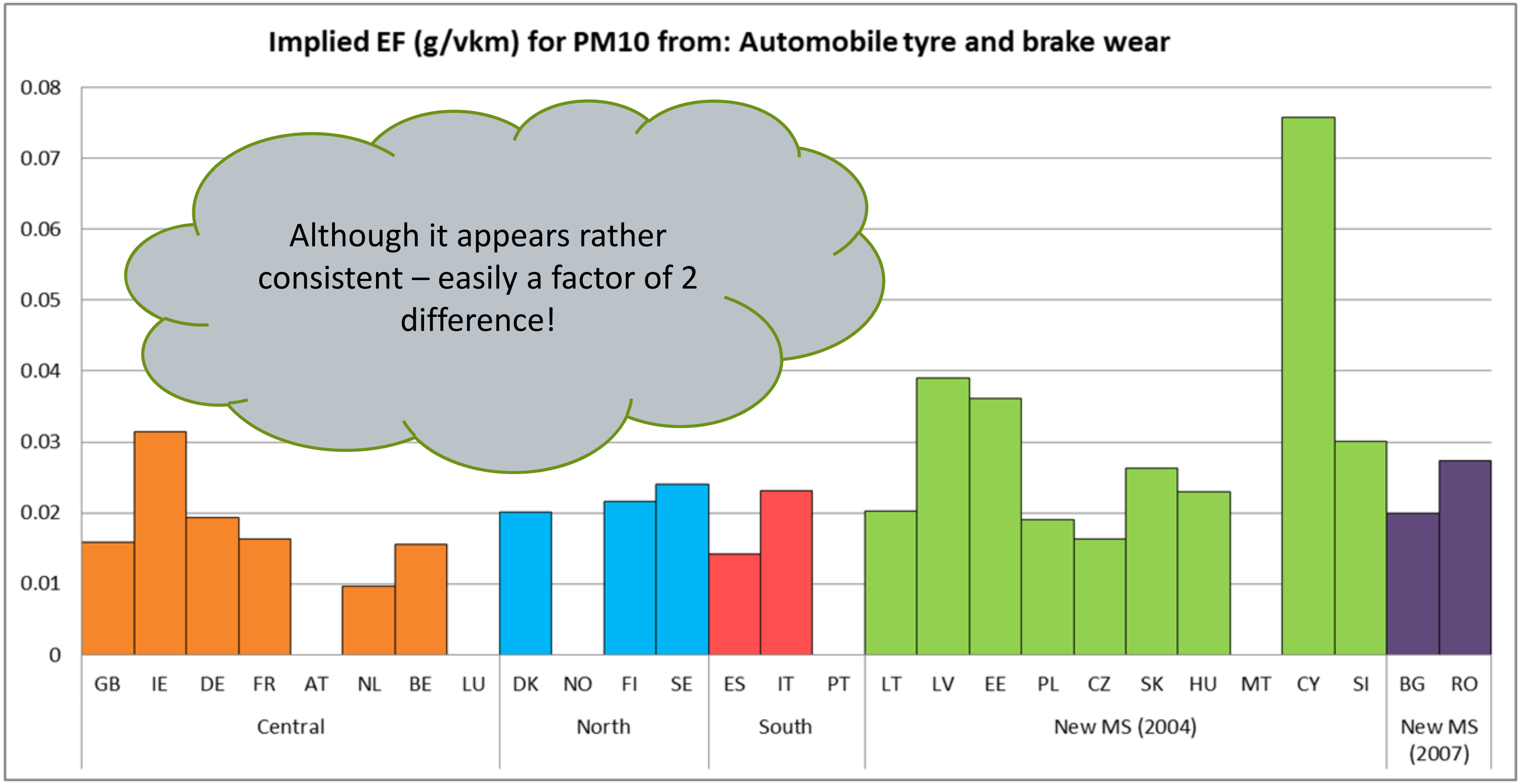
- EMEP/EEA air pollutant emission inventory guidebook — 2009
  http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/#

Automobile road abrasion



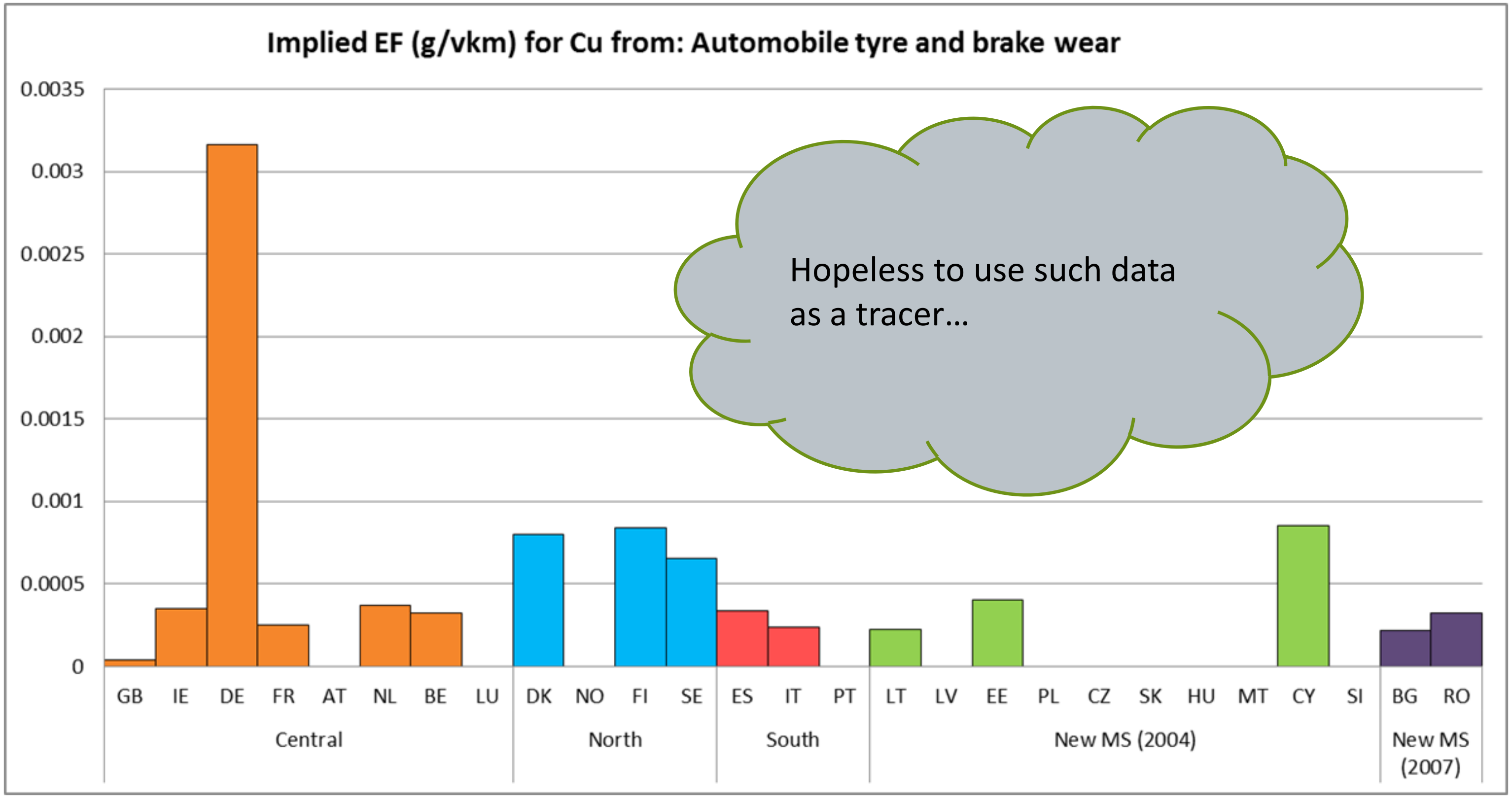
- Several MS missing
- Note: it is possible that MS report all wear under one category

Automobile tyre and brake wear



- Malta reported 0.5 gPM10/vkm -> removed
- Cyprus probably a reporting error as well
- Norway did not report PM10 from brake & tyre wear

Can we use reported HM (Cu) emission data for this purpose?

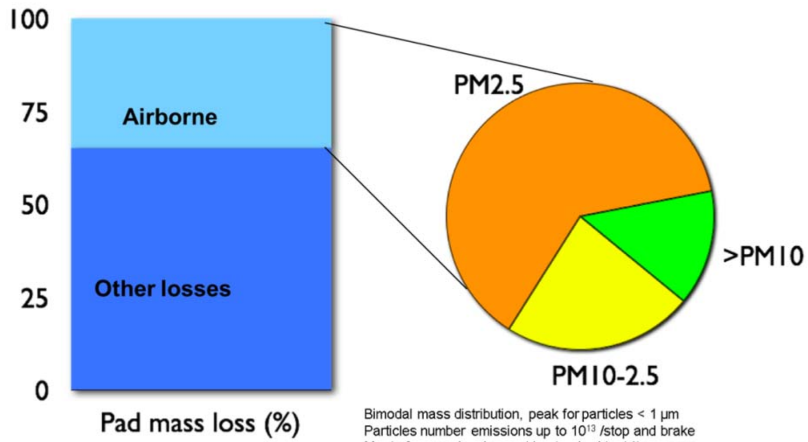


- No consistency between countries, many missing values

Wear emission quantification:

Mass balance approach

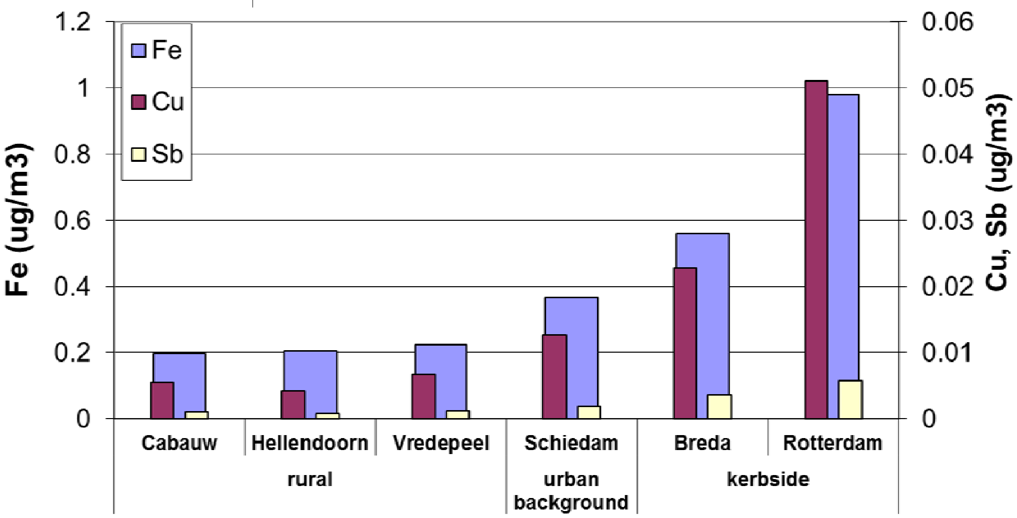
- weight loss of original brake pad (or tyre) compared to end-of-life brake pad (tyre)
- in relation to km driven -> EF (mg/vkm)
- fractionation of total wear into size classes is a major uncertainty!



Bimodal mass distribution, peak for particles < 1 µm
Particles number emissions up to 10^{13} /stop and brake
Most of copper leaches out in standard test *)

Test bench brake wear emissions - after Garg et al. ES&T 2000; *) Hur et al., J Environ Monit 2003

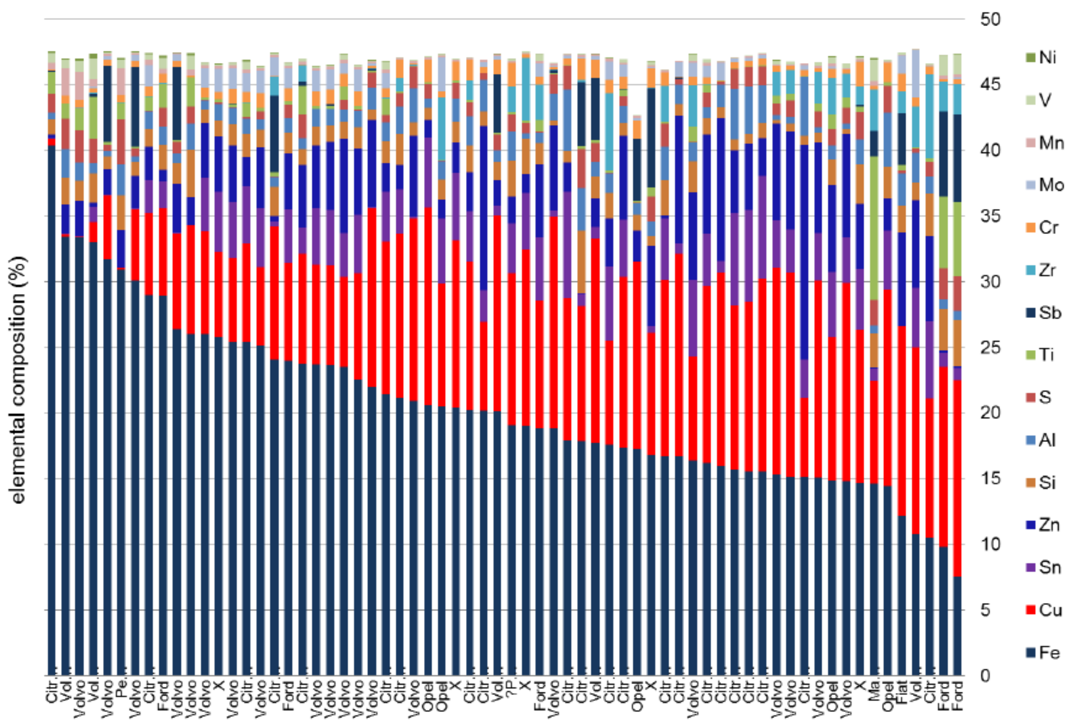
Wear emission quantification:
Tracers approach

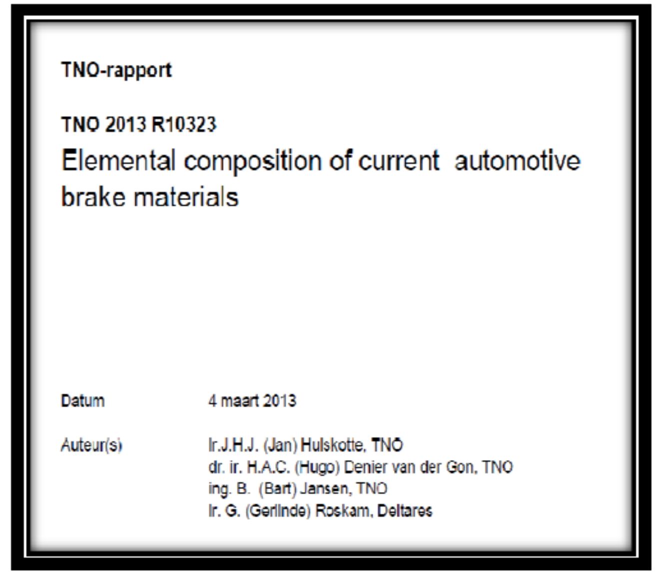


- Back calculation of PM emission from observed tracer concentration
- Uncertainties
  - How unique is the tracer?
  - Depending on brake / tyre composition
  - Depending on veh type (passenger cars, heavy duty, etc.)
  - Changes over time

To support the tracer approach we need more and better data

- **Aim**: provide an elemental composition profile of brake wear emissions in the Netherlands and Europe
- 65 brake pads and 12 brake discs analysed with XRF





TNO-rapport

TNO 2013 R10323

Elemental composition of current automotive brake materials

Datum	4 maart 2013
Auteur(s)	Ir.J.H.J. (Jan) Hulskotte, TNO dr. ir. H.A.C. (Hugo) Denier van der Gon, TNO ing. B. (Bart) Jansen, TNO Ir. G. (Gerlinde) Roskam, Deltares

		Cu/Fe	Sb/Fe	Cu/Sb
Observed ambient air (street stations)	Breda	0.041	0.006	6.4
	Rotterdam	0.052	0.006	8.8
measured brake pad		0.498	0.117	4.3
Assume wear = 50/50 (disc / pad)		0.096	0.021	4.6
Hypothesis =70/30 (disc/ pad)		0.045	0.010	4.6

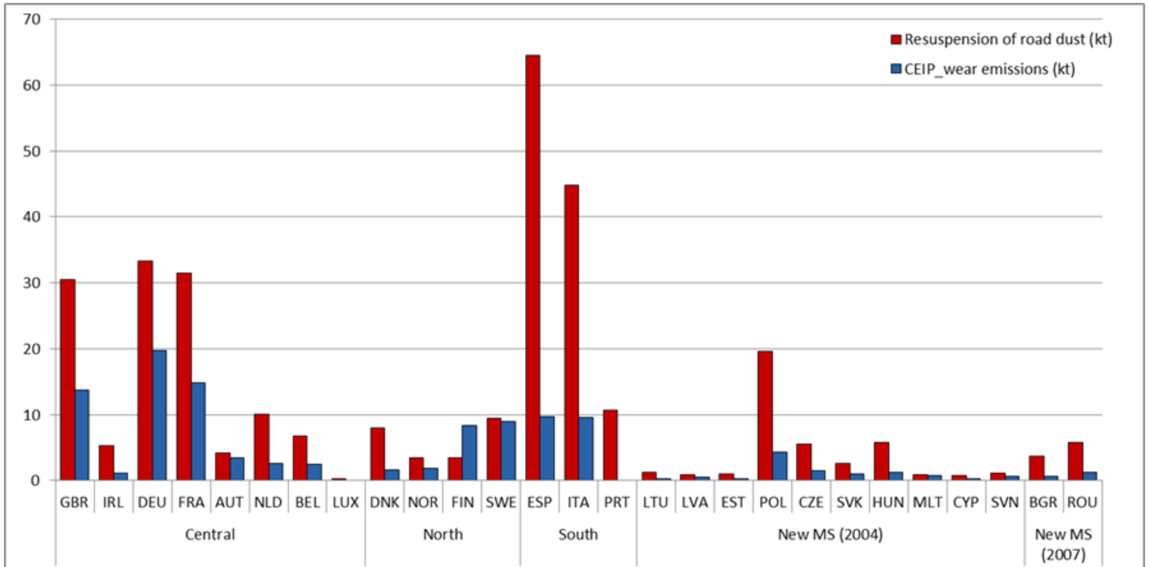
Resuspension of road dust

- Not included in standard emission reporting

 (If we would, will also effect PM National Emission Ceilings)

- Not considered a “primary” source of emission
- Can be seen as anthropogenic process
- Part of the reason why models underestimate PM10 concentrations

Resuspension (kt) vs officially reported wear emissions (kt)



European model systems including traffic resuspension

- Emission inventory or parameterization

- Parameterization should be applicable across the whole domain
- Input datasets should be available and cover the whole domain

- PM composition profile (?)
- Spatially explicit (?)
- Temporally explicit (?)

Model	Approach
EMEP	Schaap et al., 2009
LOTOS-EUROS	Schaap et al., 2009
RCG	Schaap et al., 2009
CALIOPE	Pay et al. 2012
CHIMERE	-

A first approximation of fugitive dust (re)emitted by traffic

LOTOS-EUROS (Schaap et al., 2009)

A literature study was performed to establish separated EF’s for

3 types of roads (highway, rural, urban),

2 types of traffic (HDV, LDV)

Majority of the data were available for Western Europe.

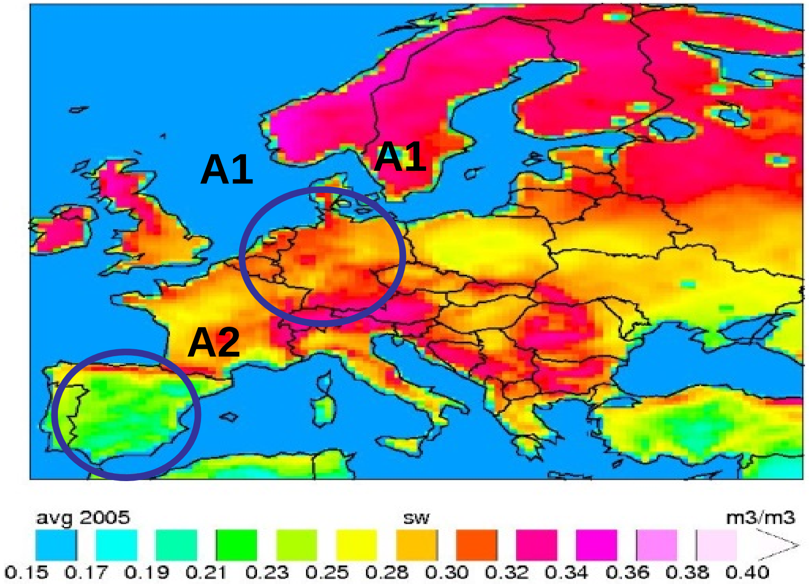
Rural emission factor was just a guess!

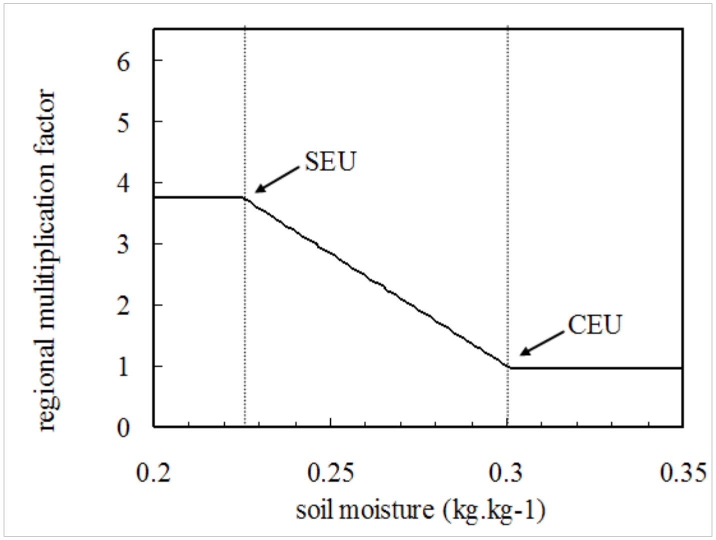
First guess EF’s for Western Europe :

EF PM2.5-10	HW	Rur	Urb
HDV	198	432	432
LDV	22	48	48

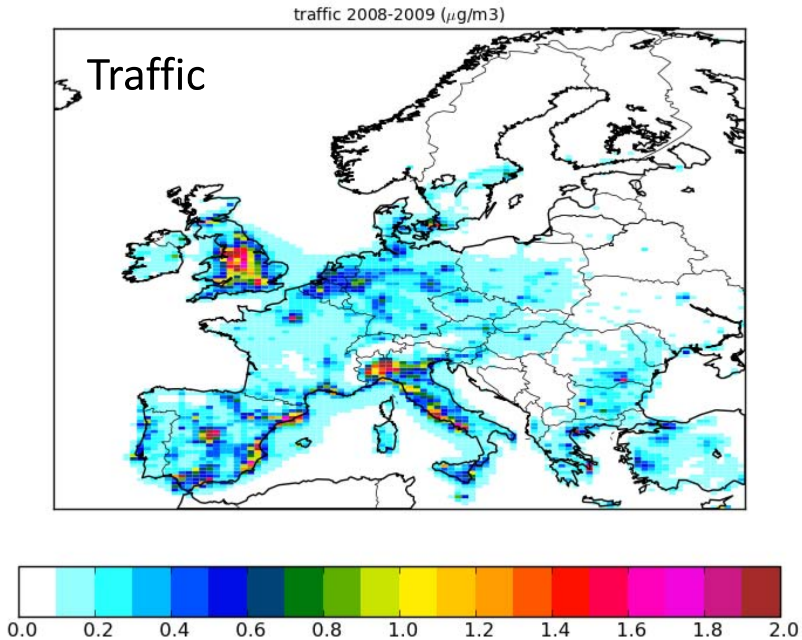
How to extrapolate to Europe as a whole?

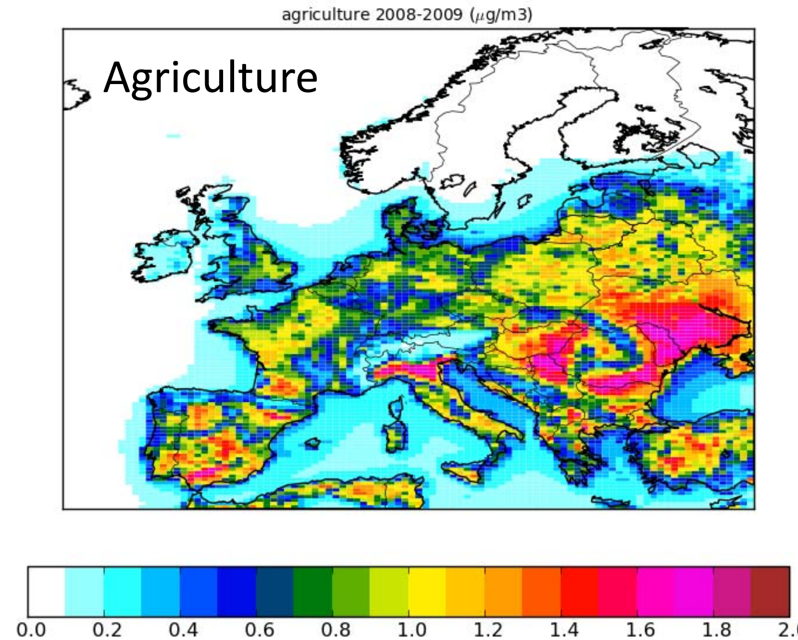
- Regional factor on basis of:
  - observed mineral $PM_{\Delta\ URB-RUR}$ (lit.) corrected by mixing layer height
  - soil moisture map

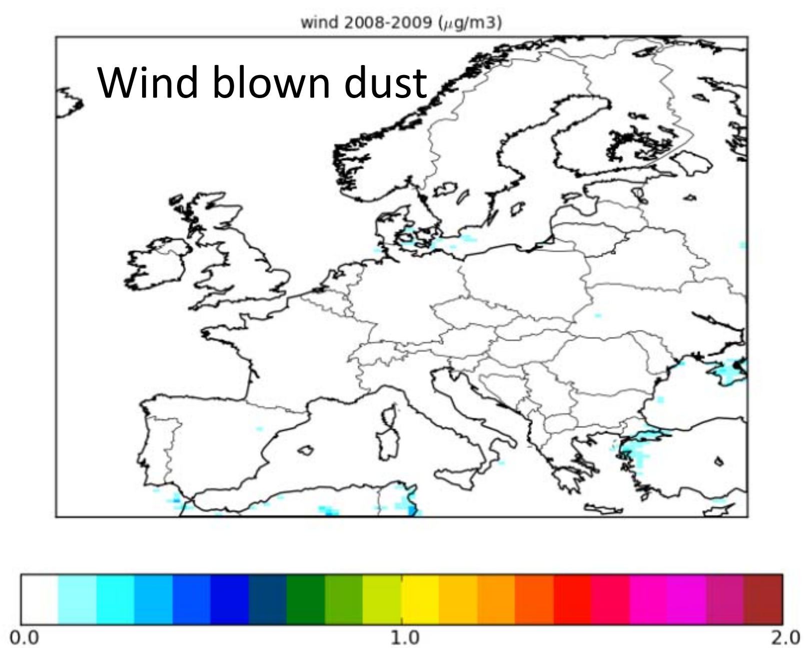


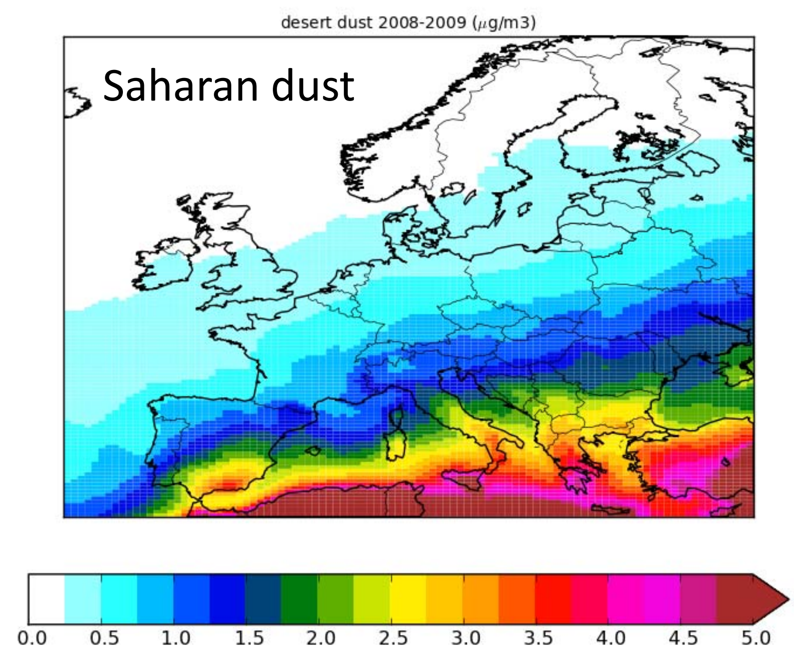


Schaap et al., 2009 TNO report

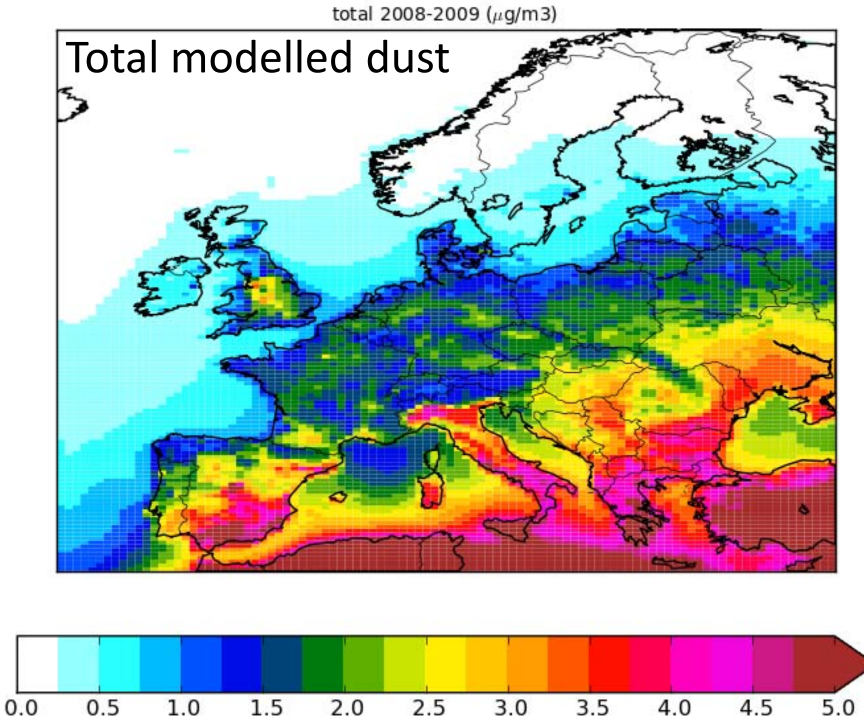

traffic 2008-2009 (μg/m3)
Traffic
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

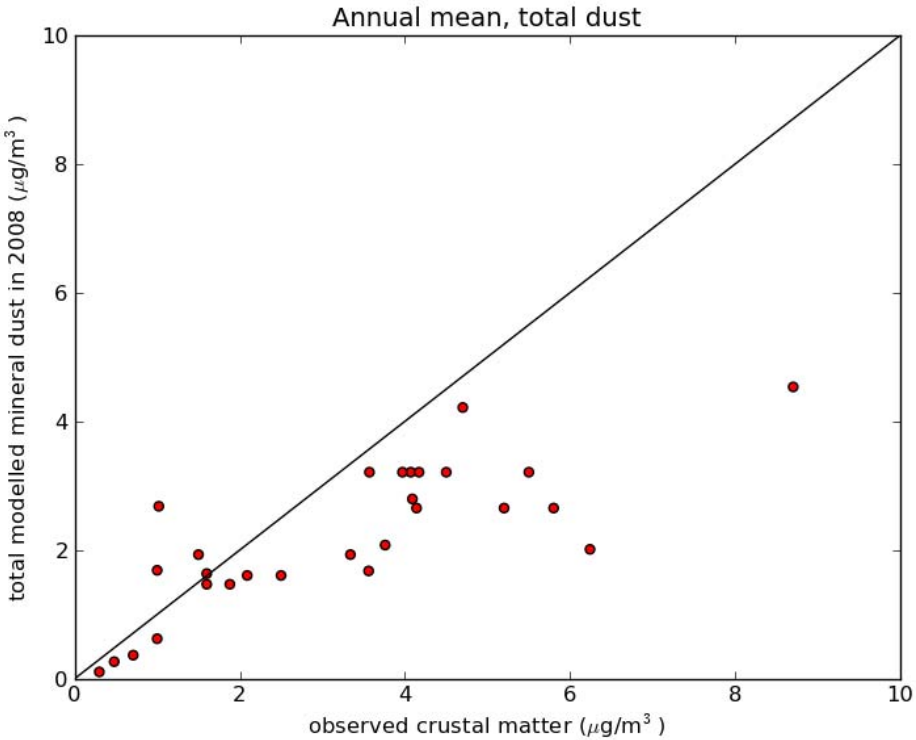

agriculture 2008-2009 (μg/m3)
Agriculture
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

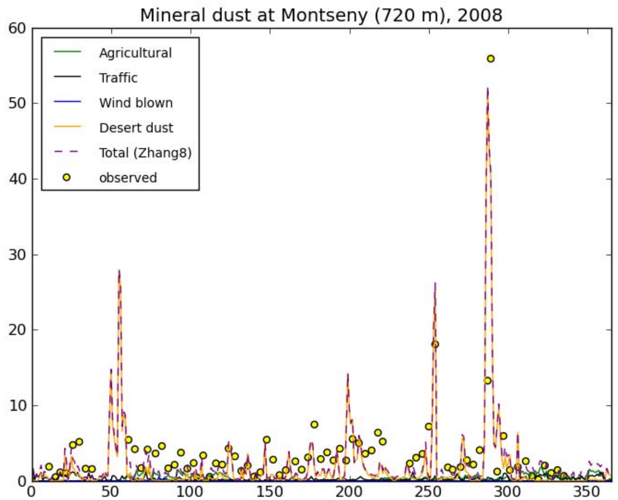

wind 2008-2009 (μg/m3)
Wind blown dust
0.0 1.0 2.0

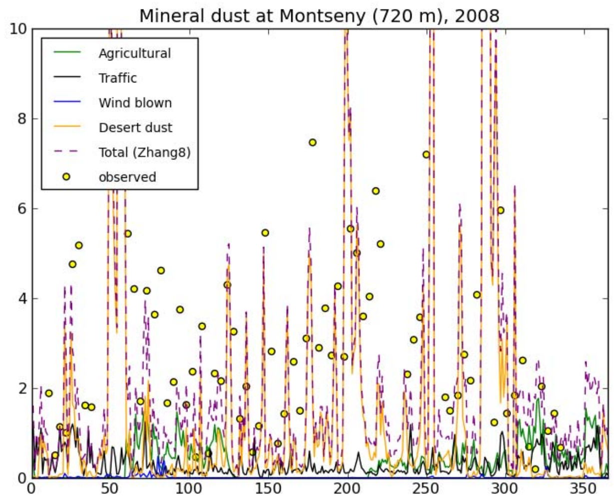

desert dust 2008-2009 (μg/m3)
Saharan dust
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

Comparison to compilation of observations

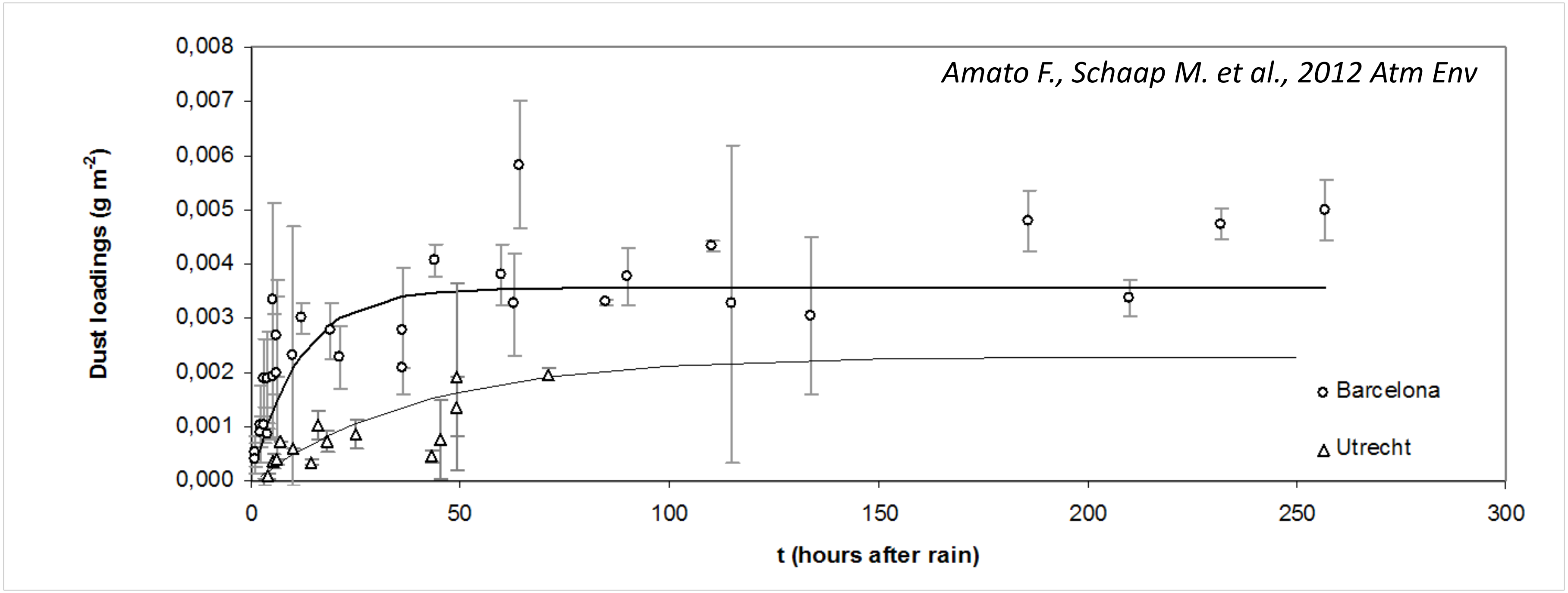








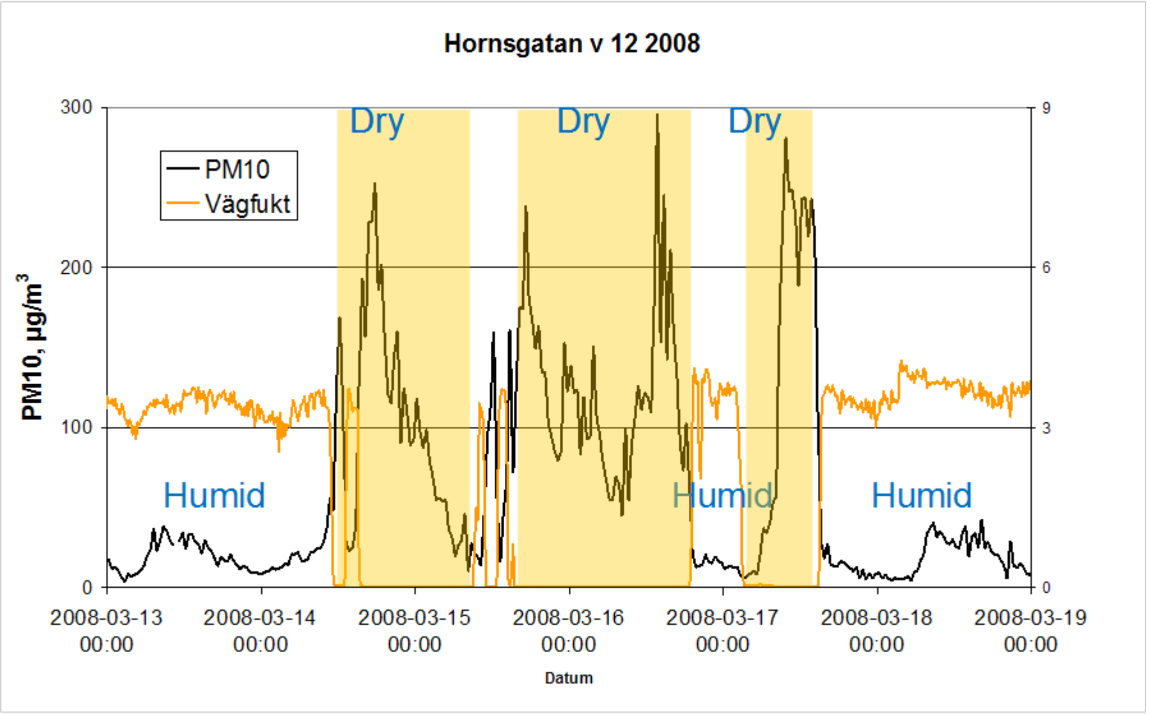
Temporal variability: experimental observations



On-off seems not a good assumption.

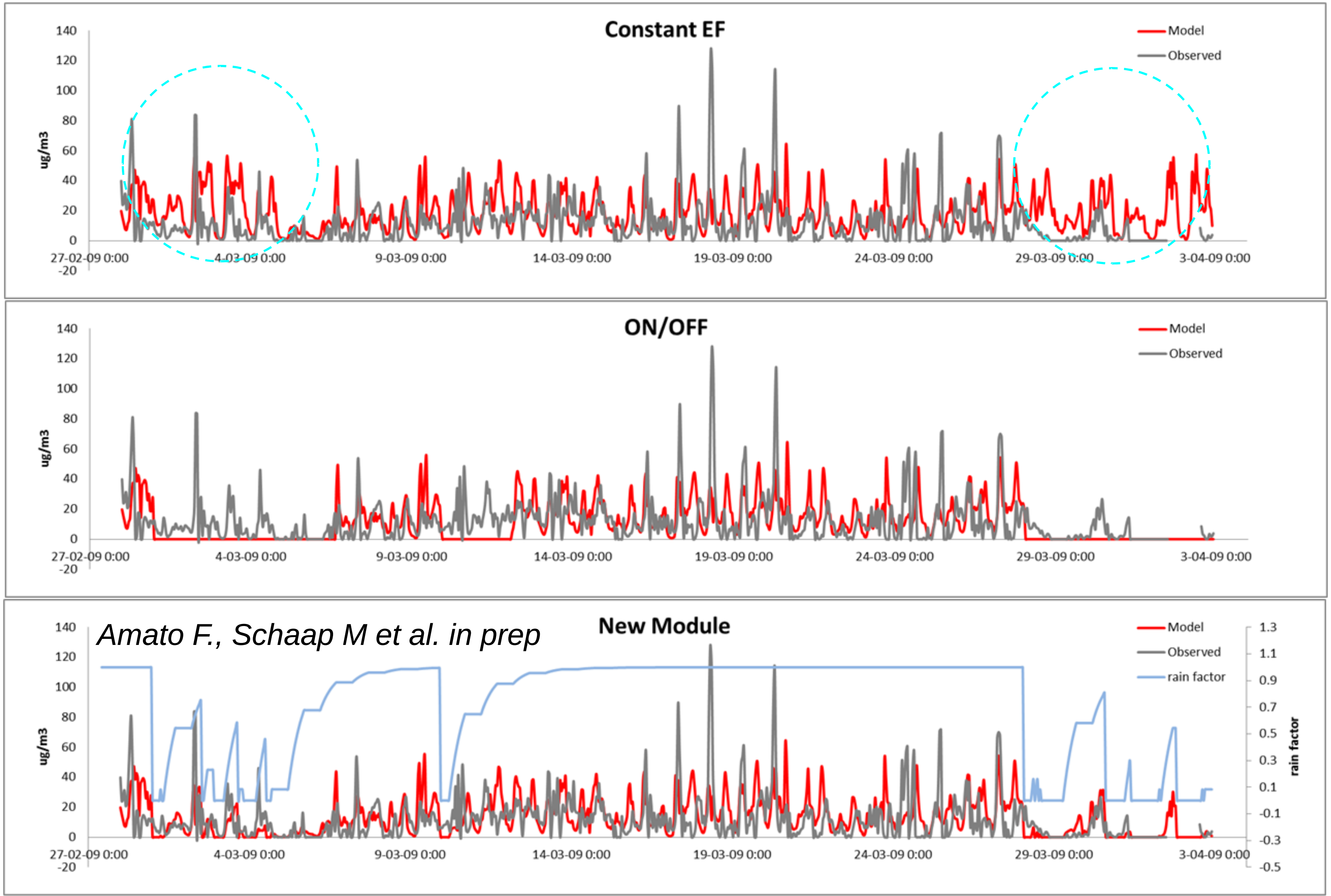
Emission modules implementing road moisture

- Omstedt et al., 2005 (Sweden)
- Kauhaniemi et al., 2011 (Finland)
- Amato et al., 2012 (Spain and the Netherlands)
- Denby et al., 2013 (Norway, Sweden Finland and Denmark)



Christer Johansson, SLB-analys

Effect of precipitation: 3 approaches



Influence of tyre type on direct PM emission

Road simulator

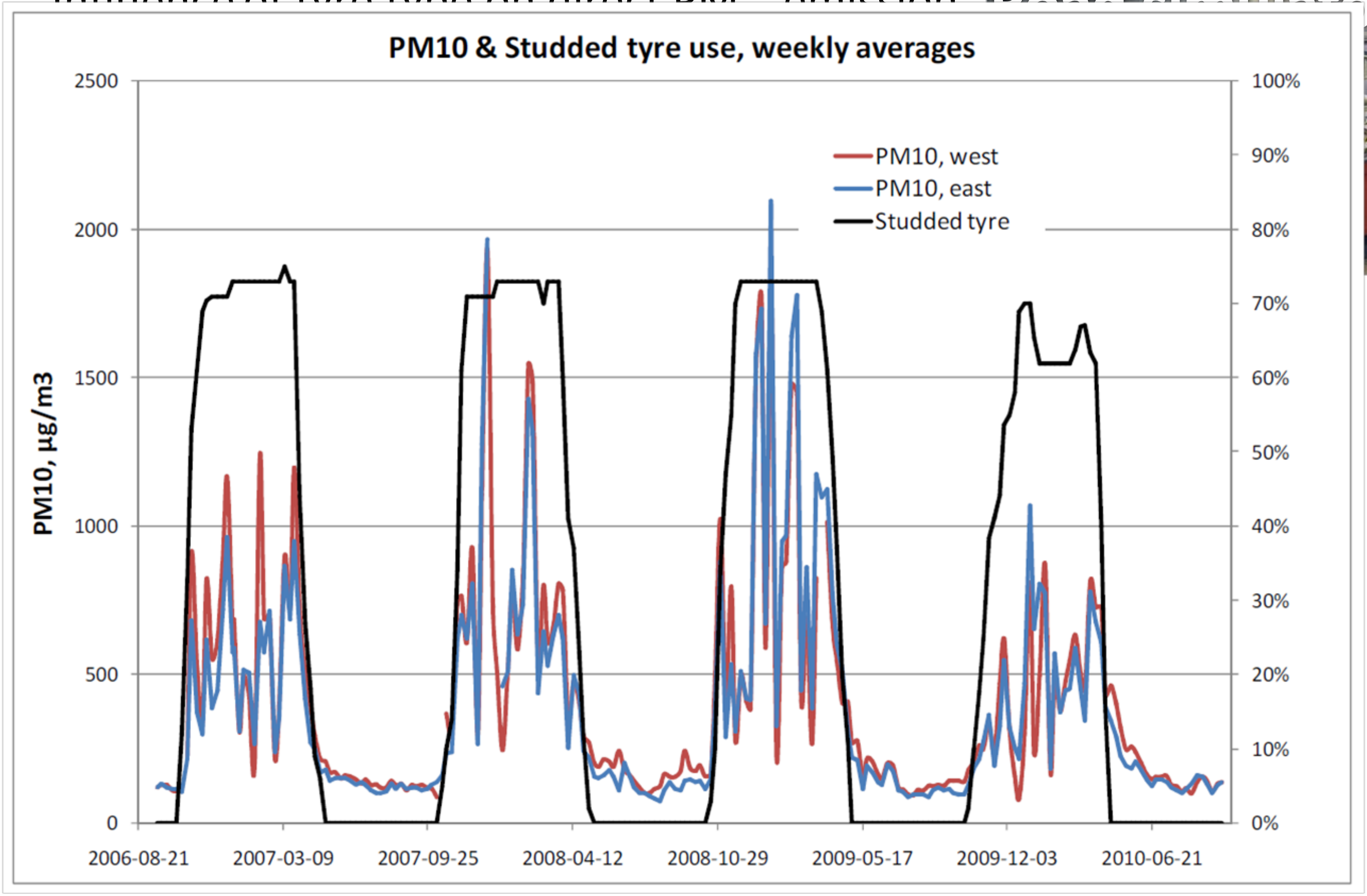
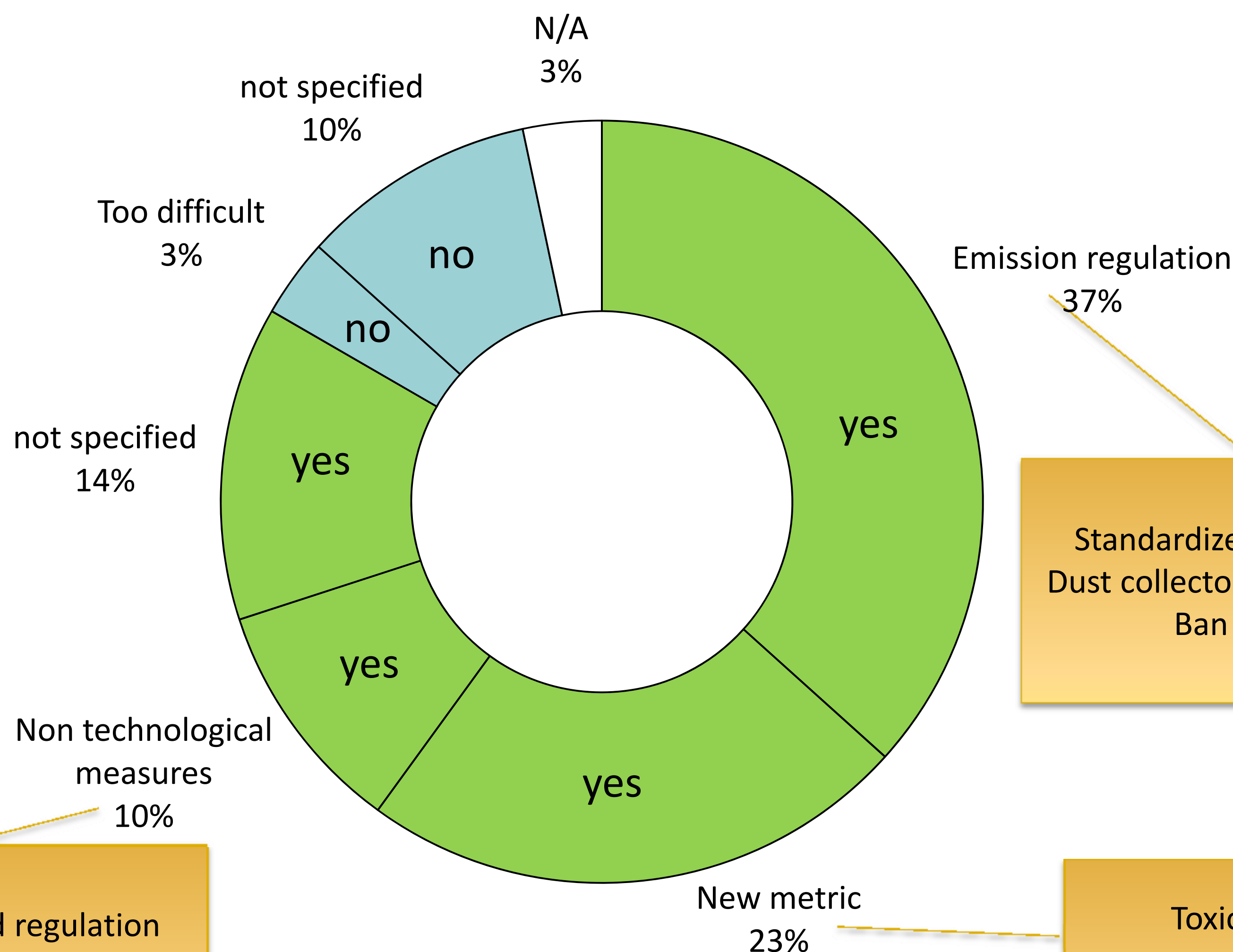


Figure: Michael Norman, SLB-Analys, Stockholm

Policy

Do you think non-exhaust emissions should be controlled by legislation? If so, how?



Standardized braking cycle
Dust collector implementation
Ban of toxics

Traffic speed regulation

Reduction of HDV

Toxic elements

Ambient non-exhaust PM threshold

Policy

Measure	Norway	Sweden	Finland
Reduce studded tyres	Fees in cities since 2000	Prohibition in certain streets since 2010	-
Improved pavements	Improved since the 90ies	Tested in Norrköping	-
Improved sand material	-	-	Tests in Helsinki
Dust binding	$MgCl_2$	$MgCl_2$, CMA	$CaCl_2$
Sweeping/ vacuuming	In combination with dust binding	Tests in some larger cities	Ambitious winter sand removal. Tests within KAPU and REDUST projects
Speed reductions	Environmental speed limits	Tests	-

Mitigation of non-exhaust emissions

1. Minimize the sources
    a. Improve wear properties of materials
    b. Reduce the wear potential of traffic

2. Minimize suspension to air
    a. Remove dust from road surface (sweeping, vacuuming)
    b. Bind dust to road surface (dust binding, moistening)
    c. Adjust traffic (less traffic, lower speed, less heavy vehicles)

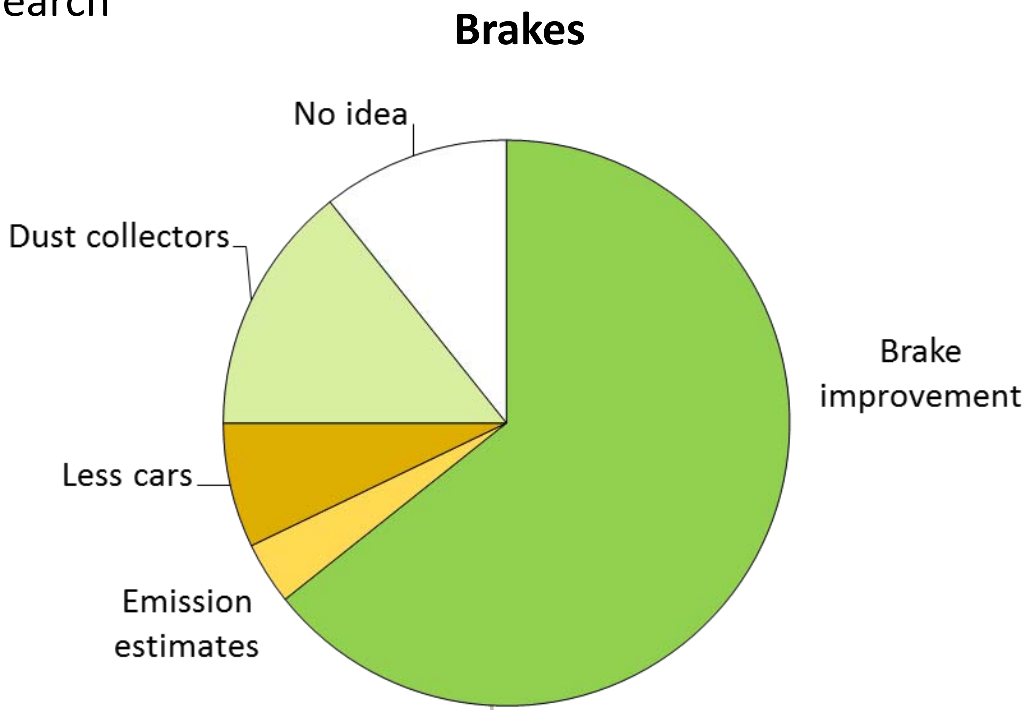
3. Optimized strategies combining 1 and 2

Minimize the sources: road pavement

Pavement property	Influence on direct emission
Maximum stone size (D_{max})	**Higher** D_{max} results in **lower emissions**
Rock wear resistance	**Higher wear resistance** results in **lower emissions**
Alt 1.: Rubber mixed asphalt	**Slightly lower emissions** than reference asphalt
Alt. 2.: Porous asphalt	No effects yet assigned to the construction. Low emission, but assigned to more durable rock
Alt. 3.: Concrete	**Higher direct emissions** than reference asphalt, but **lower total wear.** Lower total emission in reality?

Minimize the sources: brakes and tyres

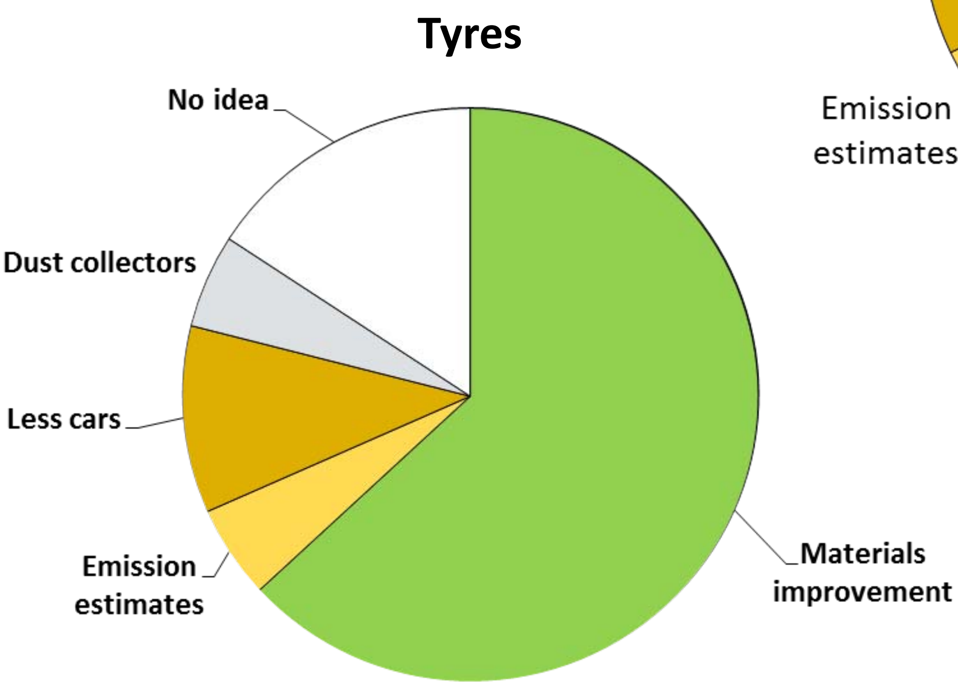
- Generally unexplored
- Much scope for future research



Different composition

Alternative braking system

Reduce toxic content



Minimize suspension to air: Dry cleaning

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Review

A review on the effectiveness of street sweeping, washing and dust suppressants as urban PM control methods

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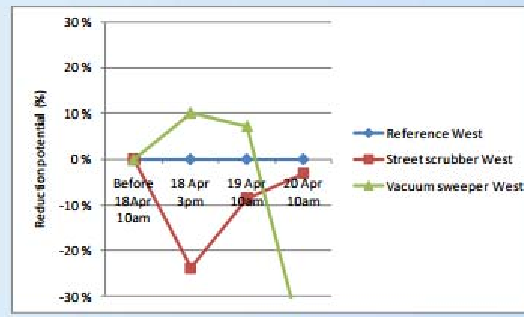
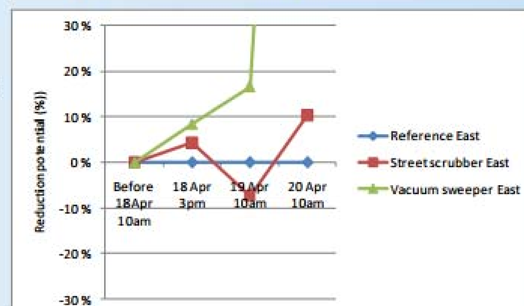
...elona, Spain

Redust

Street cleaning - reduction potentials in the 2011 demonstration tests

- Figure shows the reference corrected relative changes in the average emission levels during Suurmetsäntie street cleaning demonstration tests
- Variation in the average emission levels is significant depending on the street section and direction. Combining results from both directions (averages in the table) indicates in general:
  - There are no short-term PM10 reductions expected for the vacuum sweeper. In fact the vacuum sweeper seemed to increase the emission level. This is possible since the operation may mobilize dust from the surface and the moisture binds it to the surface (it is designed to reduce the dust emission during operation)
  - In case of the street scrubber there was some reduction in emission level during the study period
- The results here apply to the short-term influence (days) and a relatively low emission level of about 1500 to 2000 µg/m³ (Sniffer-TEOM emission concentration)





	Day of treatment	1 day after	2 days after	3 days after
Street scrubber	0 %	-10 %	-8 %	4 %
Vacuum sweeper	0 %	9 %	12 %	88 %

Study	
Chow et al., 1990	gic PM10
Kantamaneni et al., 1	
Kuhns et al., 2003	potentials
Norman and Johanss	
Gertler et al., 2006	ncreased the PM10
Düring et al., 2007	levels
Baumbach et al. 200	
Aldrin et al., 2008	

Minimize suspension to air:
Wet cleaning

- Sweden: 6% reduction at traffic site (Norman and Johansson, 2006)
- Spain: 7-10% reduction at traffic site (Amato et al., 2009; Karanasiou et al., 2011)
- Taiwan: down to 30% reduction for TSP (Chang et al., 2005)
- Germany: 2 $\mu g/m^3$ reduction (John et al., 2006)
- Canada: 2-3 $\mu g/m^3$ reduction at traffic site (Dobroff et al., 1999)

- Negative results in Norway, The Netherlands and Milan (Amato et al., 2010: Keuken et al., 2010)

Minimize suspension to air:
Dust binding

- Scandinavia: Sweden, Norway, Finland
- Alpine: Austria, North Italy
- Central EU: Germany, UK
- South EU: Spain

Minimize suspension to air: Dust binding

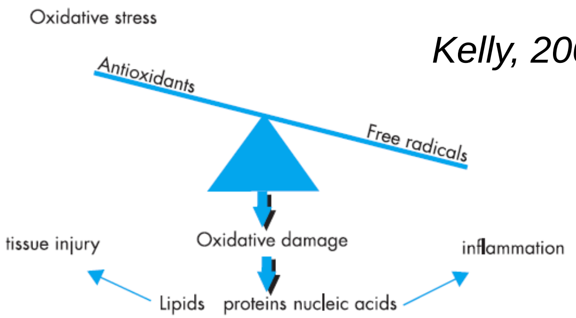
	Study (Country)	Site	Type of site	Dosage	# of stations	Pollutants	DTI	# of applications	Time of application	Effect on PM levels	Length
CMA	Barratt et al., 2012 (UK)	A3211 Upper Thames Street	Congested road corridor beneath a wide bridge	10-20 g/m2	1	NOx, PM	na	150	na	Daily CMA application >10 mg m-2 only: 38% reduction in local PM10 compared to non CMA days, equating to a decrease in annual mean of c. 16%. No effect at 10 mg m-2 application rate.	na
		A2 Blackheath	Road corridor impacted by emissions from construction site opposite	10-20 g/m2	1	NOx, PM	33,000	53	between 23-02	44% reduction in local PM10 compared to pre-trial period, equating to a decrease in annual mean of c. 12%. No effect compared to non CMA days	na
		A2 New Cross	Single lane road corridor	10-20 g/m2	1	NOx, PM	45,500	53	na	The analyses could not identify any significant effect	na
		A12 Blackwall Tunnel	Heavily trafficked road corridor in an open location, partial application	10 g/m2	1	NOx, PM	75,000	39	na	The analyses could not identify any significant effect	only 1 lane out of 3
		Horn Lane, Acton	Industrial roads	10 g/m2	1	NOx, PM	na	35	na	On-road application: 18% reduction in local PM10 compared to non CMA days.	na
		Mercury Way, Lewisham	Industrial	10 g/m2	1	NOx, PM	na	57	na	Tentative 22% reduction in local PM10 compared to non CMA days following on-site application	na
		Marylebone road	Heavily trafficked road corridor in a street canyon	10-20 g/m2	1	NOx, PM, Tracers	70,000	136	between 22-03	The analyses could not identify any significant effect	na
	Norman and Johansson (2006) (Sweden)	Vallstanas	Highway	40 g/m2	3	NOx, hourly PM	60,000	21	night hours	35% reduction of daily PM10 mean	1 km
	www.life-cma.at (Austria and Italy)	Klagenfurt	Large urban area	20 g/m2	3	NOx, hourly PM		na	na	30% reduction of daily PM10 mean	up to 164 km
	Reuter (2010) (Germany)	B14 Neckartor	Heavily trafficked road	na	na	na	na	na	na	No reduction	1.2 km
	AIRUSE LIFE (2013) (Spain)	Industria road, Barcelona	Urban road	10-20 g/m2	5	NOx, PM, Chemistry, BC	15,000	10	between 5-9	No reduction on daily PM10 and PM2.5-10 mean; episodic reduction of tracers	2.3 km
$MgCl_2$	Aldrin et al. (2008) (Norway)	Strømsås tunnel, Drammen	Tunnel	20-40 g/m2	1	hourly PM	6,000	43	variable: 0–4, 8–10, 13–14, 18–19	56% reduction of PM10	4 km
	AIRUSE (2013) (Spain)	Industria road, Barcelona	Urban road	20 g/m2	5	NOx, PM, Chemistry, BC	15,000	2	between 5-9	Reduction on daily PM10 and PM2.5-10 mean not confirmed by elemental tracers	2.3 km

Health studies

- ❑ Only few in-vivo toxicity and epi studies focused on non-exhaust emissions
- ❑ Based on first studies: non exhaust can be as hazardous as tailpipe
- ❑ Particle mass, size, surface (shape) and chemistry all affect PM toxicity

Toxicity studies:

- ❑ Oxidative stress (ROS) as biological mechanism (Kelly, 2003; Borm et al., 2007; Ayres et al., 2008)
- ❑ Brake-tyre wear have higher oxidative potential than tailpipe (Yanosky et al., 2012; Gasser et al., 2009)
- ❑ Tyre wear induce formation of ROS (Gualtieri et al., 2005, 2008; Mantecca et al. 2009, 2010)
- ❑ Road wear toxicity comparable to diesel (Gustafsson et al. 2008)



Kelly, 2003;

Epidemiological studies:

- Still very few long time series on tracers or source contributions
- PM2.5-10 has been used as proxy (Perez et al., 2009; Meister et al., 2012; Stafoggia et al., 2013)
- Ostro et al., EHP 2012 found significant increased mortality risk for road dust particles in Barcelona
- MED-Particles Project suggests association between Fe, Mn, Cu and Ti and cardiovascular disease in Rome and Barcelona (unpublished results)
- Similar results in Burnett et al., 2000; Ostro et al., 2007 and 2010.

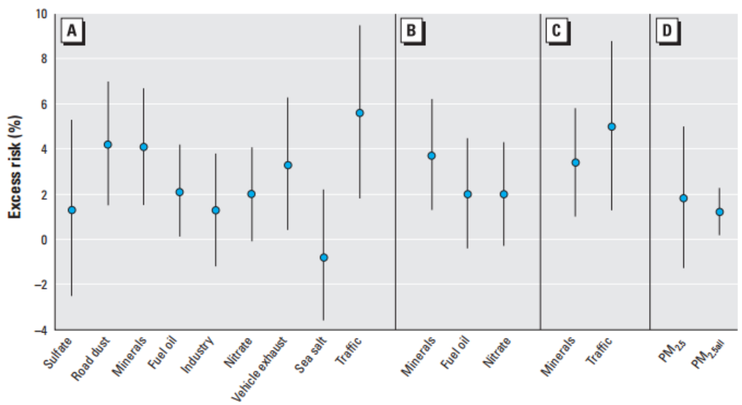


Figure 2. All-cause mortality excess risks (95% CIs) associated with IQR increases in sources of $PM_{2.5}$ (lag 2): single-source models (*A*), multisource models (*B*), multisource models with traffic (*C*), and PM mass models (*D*). $PM_{2.5}$, mass from periodic sampling; $PM_{2.5all}$, mass from daily sampling.

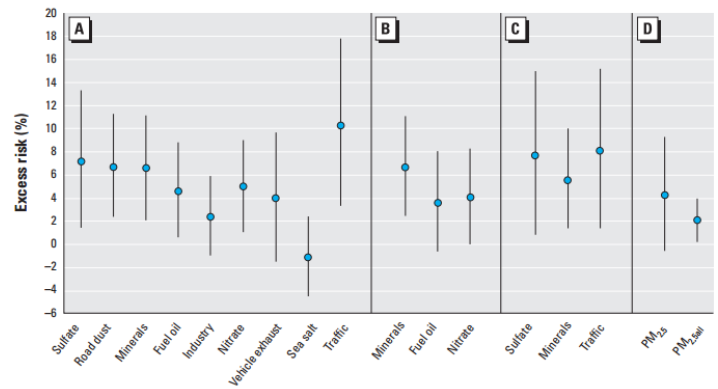


Figure 3. Cardiovascular mortality excess risks (95% CIs) associated with IQR increases in sources of $PM_{2.5}$ (lag 2): single-source models (*A*), multisource models (*B*), multisource models with traffic (*C*), and PM mass models (*D*). $PM_{2.5}$, mass from periodic sampling; $PM_{2.5all}$, mass from daily sampling.

Ostro et al., EHP 2012

Conclusions

- There air quality and health issues (more in vivo and epi studies are needed)
- SA techniques should aim at improving the separation of road wear, tyre wear, brake wear adn resuspension is needed
- Interaction between road surface texture – moisture – dust load – dust emission
- Need of scientific, harmonized and consistent bottom-up inventories for Wear emissions
- Road dust resuspension is important but currently NOT reported
- Modellers need more quantitative information on resuspension (emission factors and parameterizations). First modules are promising but need further development.
- What are the optimal mitigation techniques and strategies (different climates, different measures)?

Thank you for your attention!

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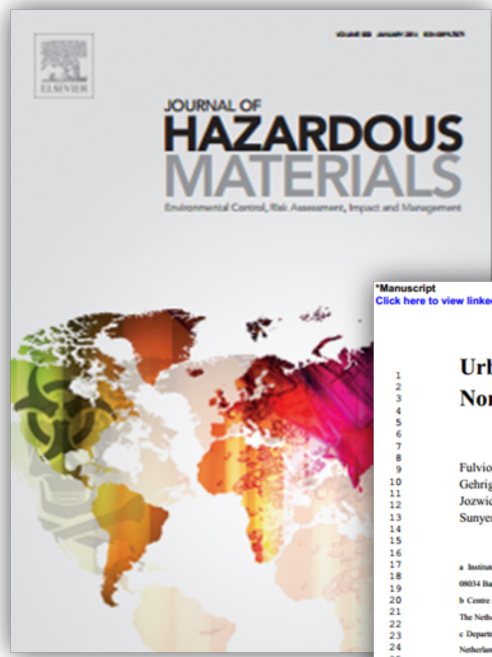
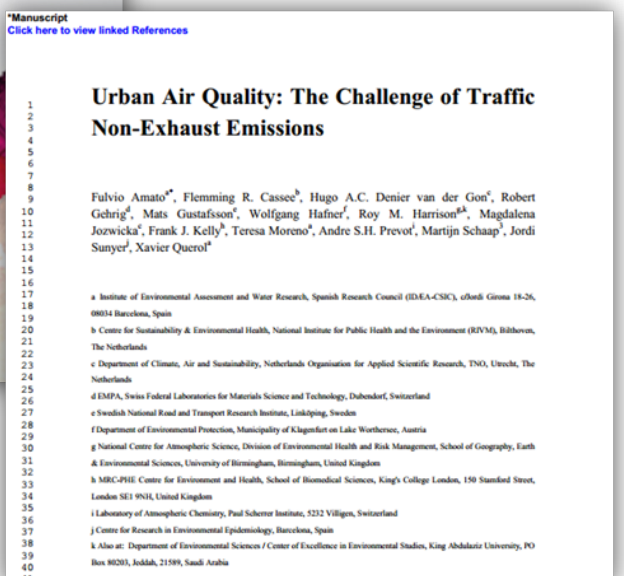


In press



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Urban Air Quality: The Challenge of Traffic Non-Exhaust Emissions

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