EMISSION INVENTORIES FOR AIR QUALITY AND CLIMATE MODELLING IN EUROPE

HIGHLIGHTING SOME RECENT ISSUES, IMPROVEMENTS AND TRENDS

Hugo Denier van der Gon

TNO innovation

with a lot of help from my colleagues

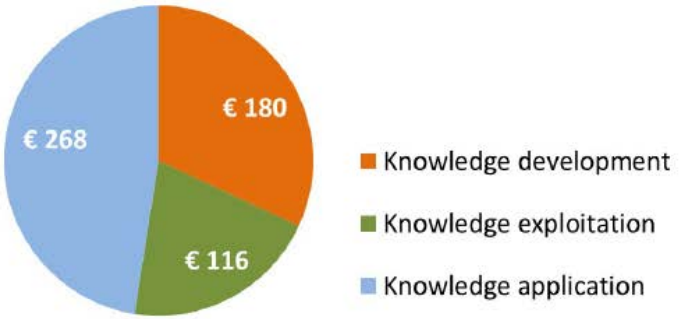
Prettige Kerstdagen

Gelukkig Nieuwjaar

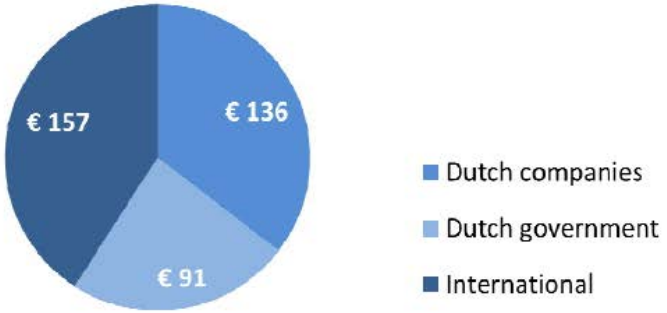
WELCOME TO TNO

- Number of employees (effective average) 2.926
- Consolidated turnover € 518 million

Consolidated turnover (million)

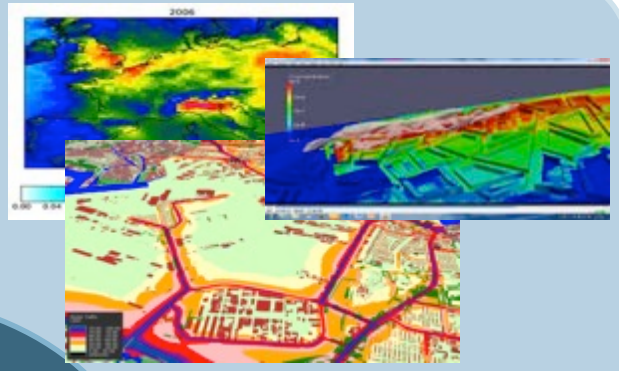


Consolidated market turnover (million)



Environment & Sustainability

Lab Facilities



Emissions, Models & Simulation

Sensors

- Air
- Water
- Noise
- Nano
- Heat

ICT, (big) data

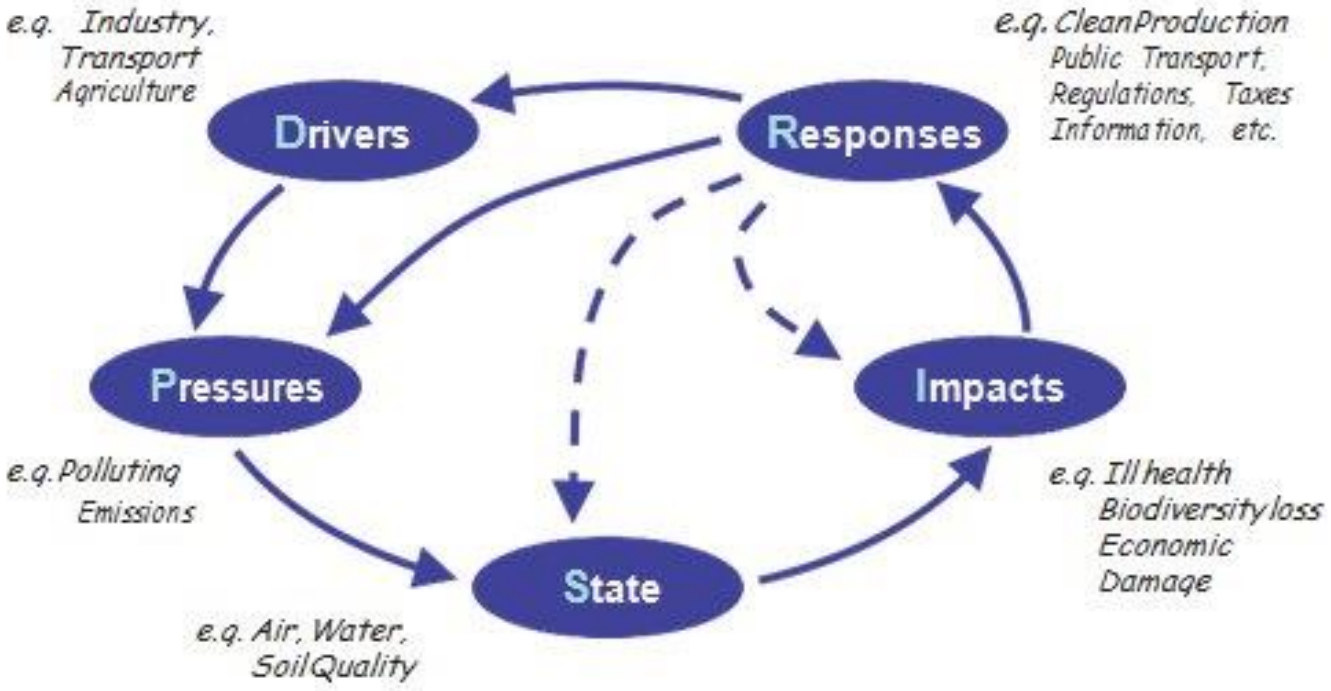
Field experiments

OUTLINE

- Introduction
- Why & How make an inventory ?
- A selection of topics…
  - Greenhouse gases
  - Non-exhaust road transport emissions
  - Woodburning PM
  - Emission timing
  - Validate and Verify
- Questions & Discussion

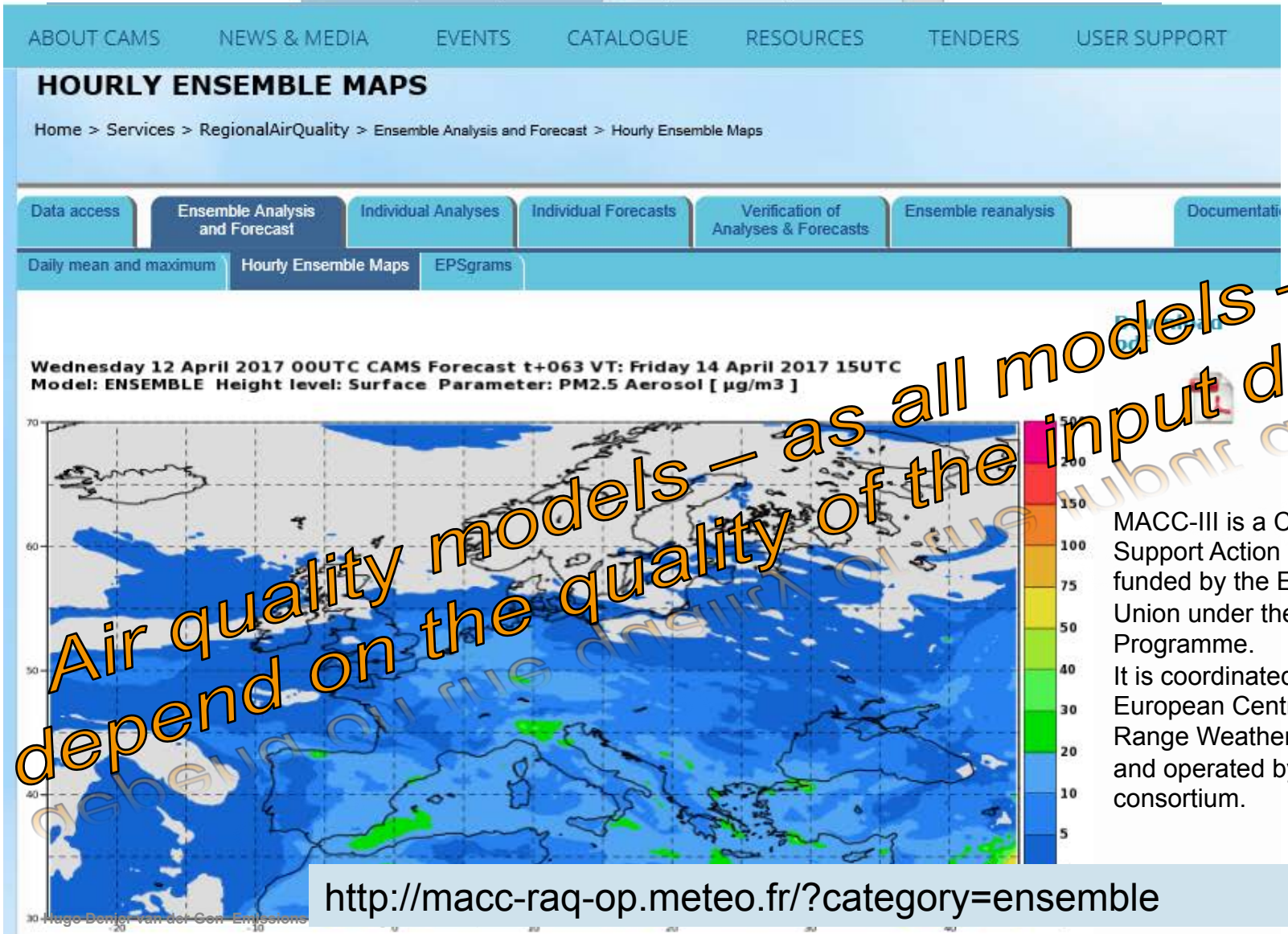
DPSIR FRAMEWORK….

- **Emissions are key!**



USE OF EMISSIONS DATA: INPUT FOR AIR QUALITY FORECASTS

HTTP://ATMOSPHERE.COPERNICUS.EU/ABOUT-CAMS



Air quality models – as all models – depend on the quality of the input data.

MACC-III is a Coordination & Support Action (2014-2015) funded by the European Union under the Horizon 2020 Programme.
It is coordinated by the European Centre for Medium-Range Weather Forecasts and operated by a 36-member consortium.

http://macc-raq-op.meteo.fr/?category=ensemble

EMISSION INVENTORIES….

EMISSION = ACTIVITY X EMISSION FACTOR

- **Uhhhh OK, but is it…..?**

or

BOTTOM-UP EMISSION INVENTORIES AND HYBRID, COMPILED INVENTORIES

- **Classic Emission inventory**

$$Emission_{pollutant} = \sum_{activities} Activity\ rate_{activity} \times Emission\ factor_{activity,pollutant}$$

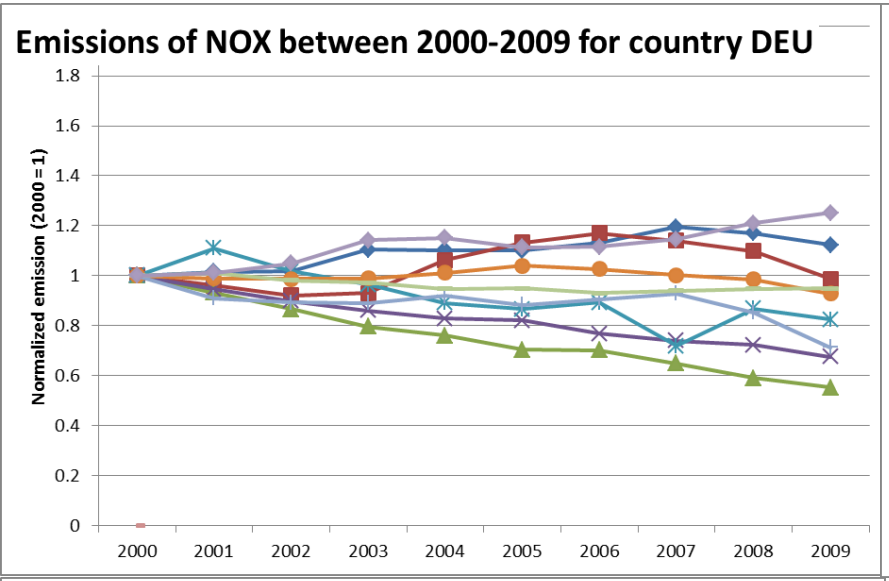
- **EMEP/EEA air pollutant emission inventory guidebook:** Technical guidance to prepare national emission inventories http://www.eea.europa.eu/publications/emep-eea-guidebook-2016
  - Examples: Dutch Emission Registration; The Emissions Database for Global Atmospheric Research (EDGAR) http://edgar.jrc.ec.europa.eu/
- **Hybrid, compiled Emission inventory** (collecting various different bottom-up estimates, possibly including expert judgements)
  - Example TNO-MACC (Kuenen et al., ACP, 2014)

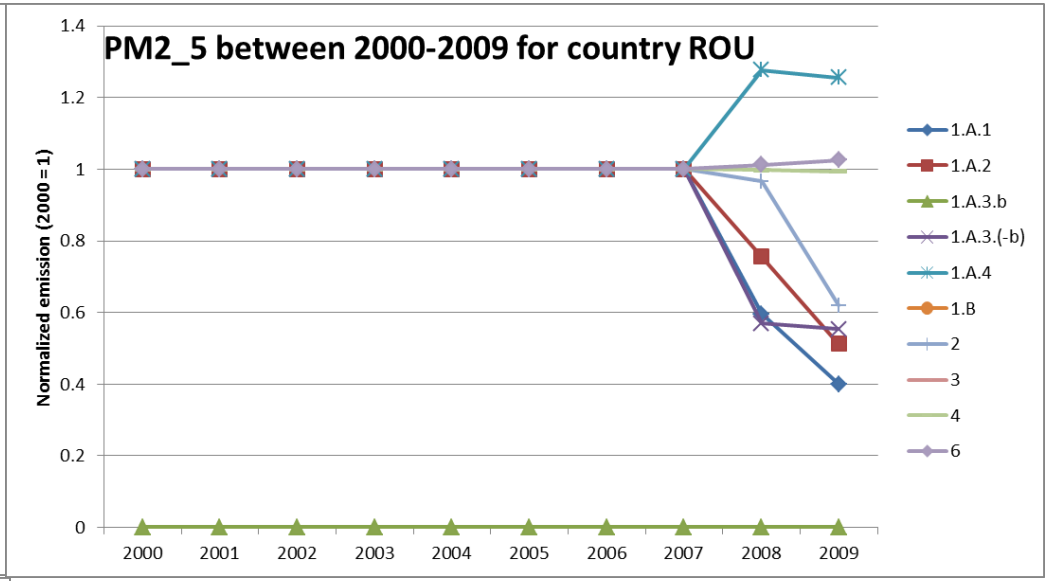
WHY IS "EXTRA" WORK NEEDED?

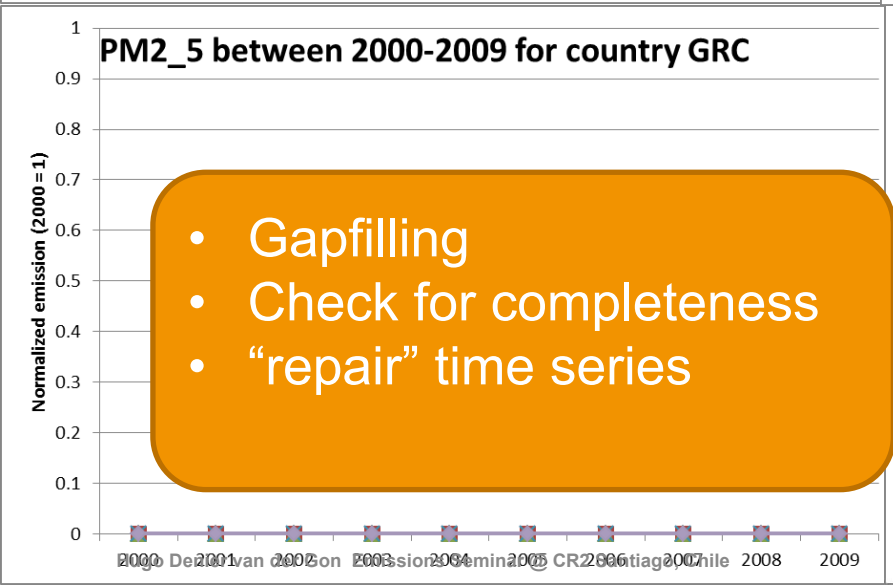
- **In Europe Countries shall make their own inventories and shall provide these to EMEP (The European Monitoring and Evaluation Programme EMEP) (& also in gridded form for modelling).**
- Can be accessed at http://www.ceip.at/
- But……
- Some countries do not comply (or only partly)!
- Time series may be incomplete
- The spatial distribution is not consistent between countries
- ….

Note: Slide is no longer up to date – example of past analysis

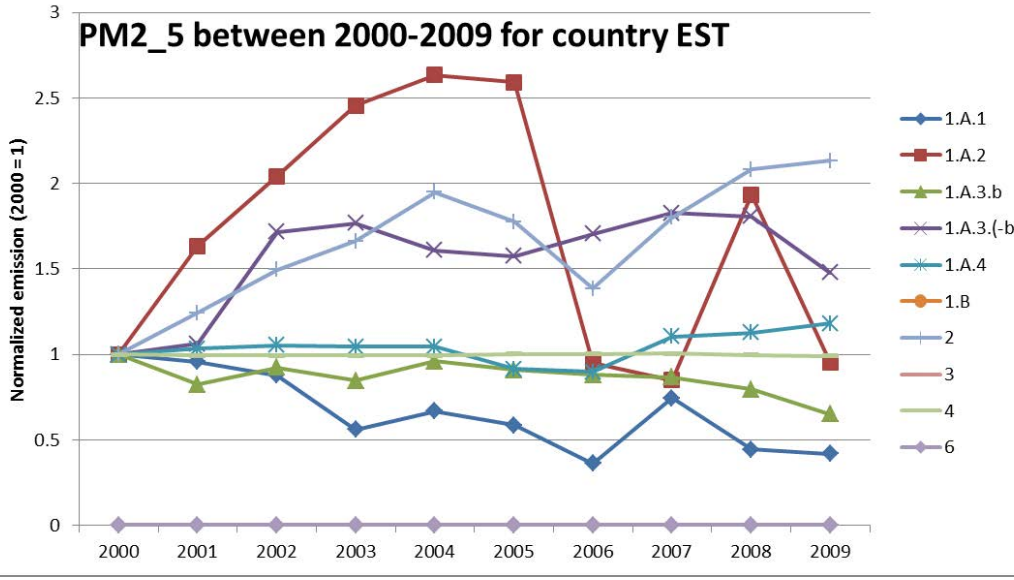
IS THERE A PROBLEM ?



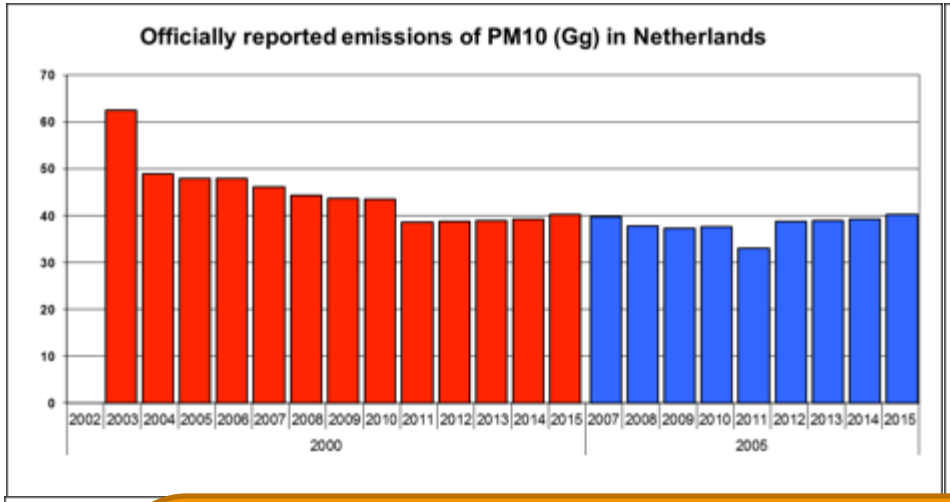


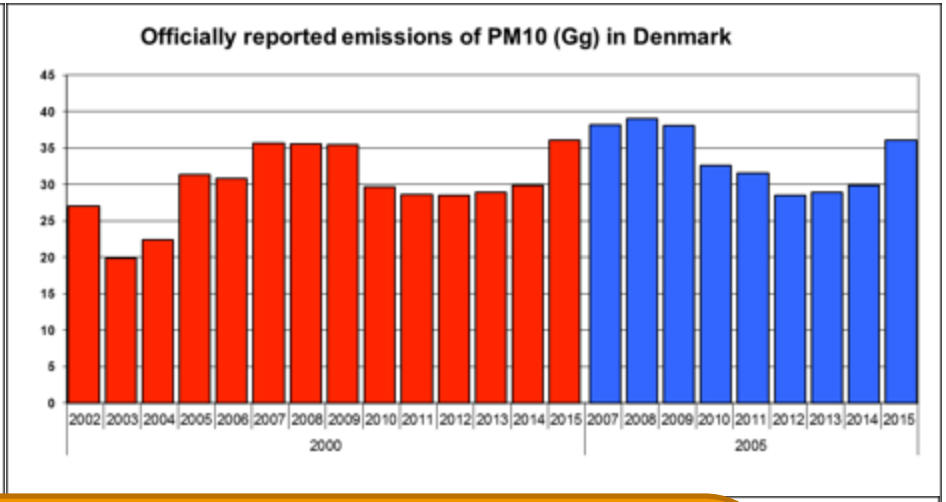


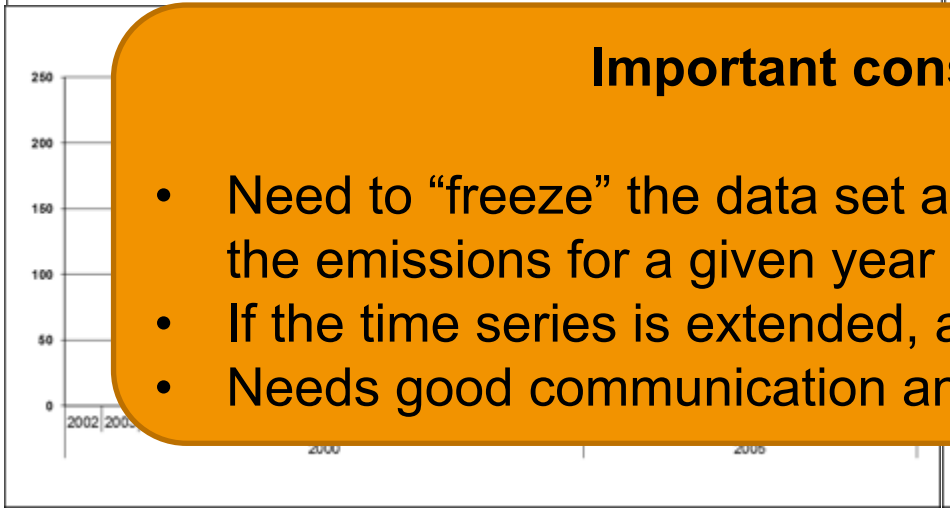
- Gapfilling
- Check for completeness
- “repair” time series

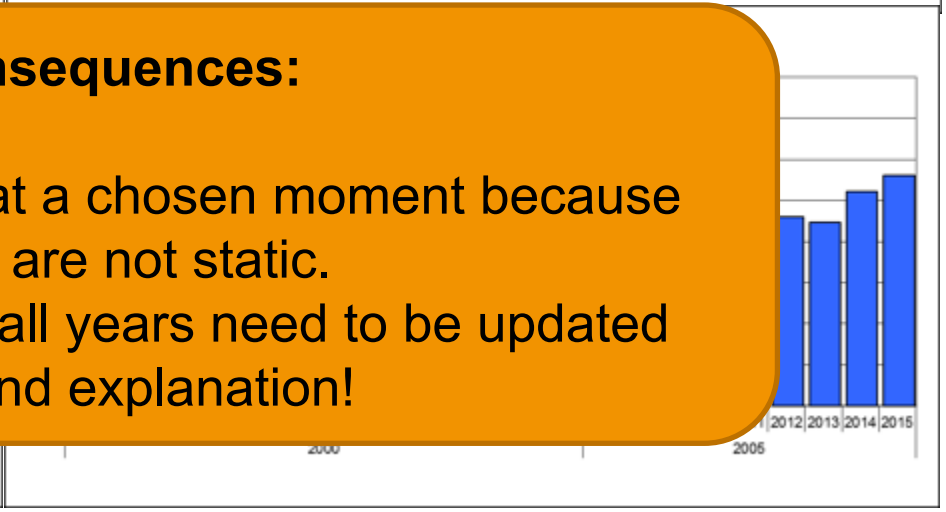


OFFICIALLY REPORTED EMISSIONS OF PM10 (KT)









Important consequences:

- Need to “freeze” the data set at a chosen moment because the emissions for a given year are not static.
- If the time series is extended, all years need to be updated
- Needs good communication and explanation!

Thanks to EMEP- CEIP for keeping the data and making it available!

TNO-MACC-III EMISSION INVENTORY

We make liberal use of country reported emissions (EMEP-CEIP) and IIASA GAINS but cater for the AQ models and user specific needs:

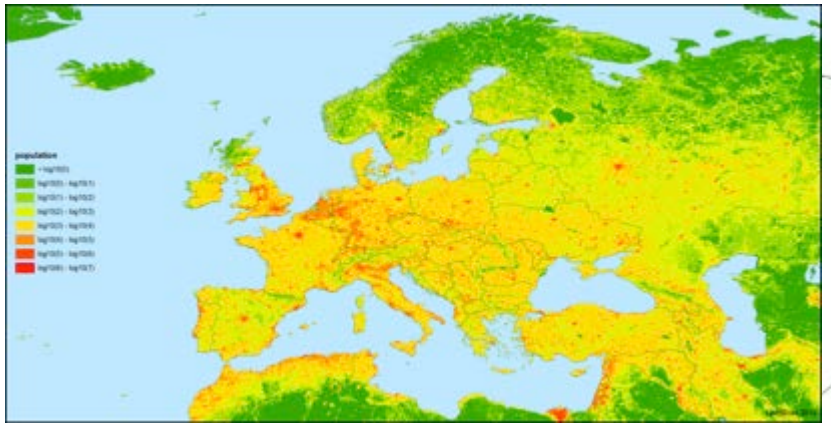
- Pollutants covered:
  - NOx, SO2, NMVOC, NH3, CH4, CO, PM10, PM2.5 (and components)
- Add or "do" components that are not or incompletely reported like EC
- High resolution (~ 7x 7 km), consistent distribution patterns for road transport, agriculture, power plants, industry, etc.
  - UNECE-EUROPE… not limited to EU27
  - Collaborate in interpretation and provide description of input.

See *J. Kuenen et al., ACP, 2014*
http://www.atmos-chem-phys.net/14/10963/2014/**acp-14-10963-2014.pdf**

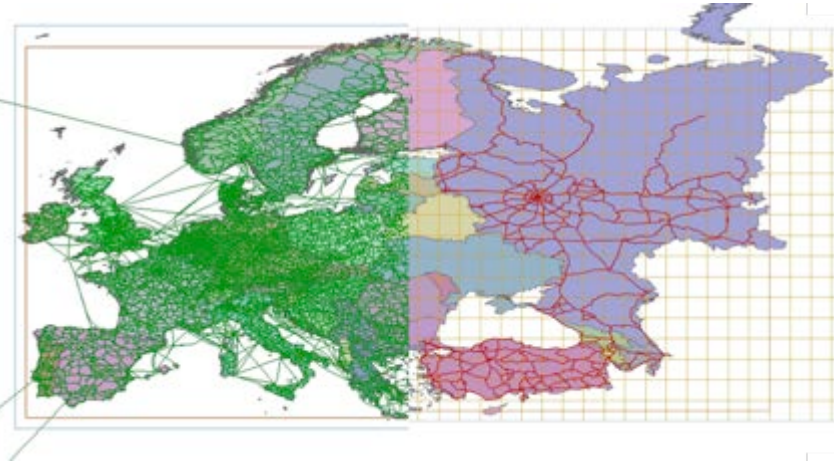
SPATIAL DISTRIBUTION

- Use generic spatial distribution system throughout Europe
- All emission sources distributed using proxy parameters, e.g.

Population density (total, rural, urban)



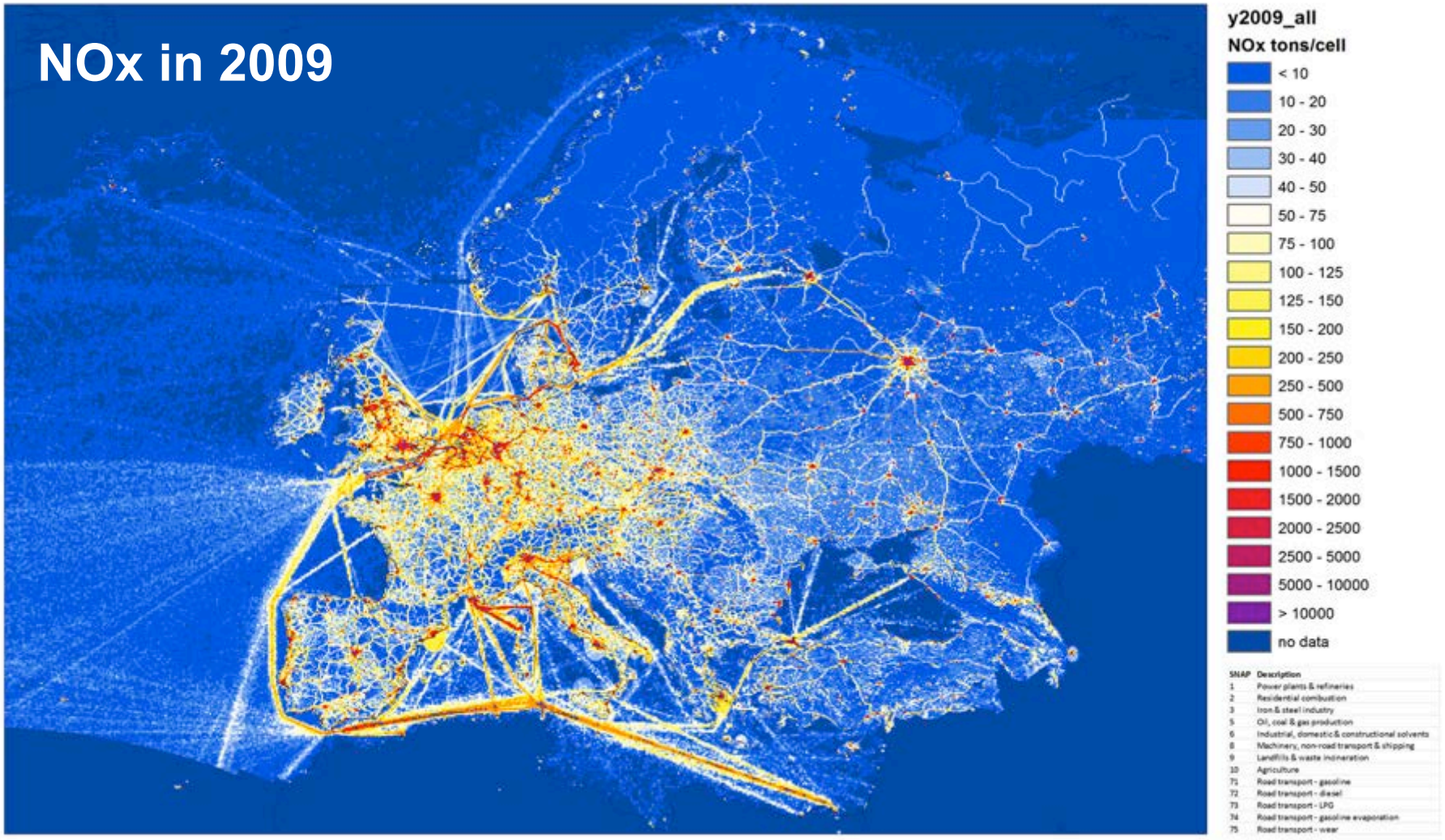
Road network for non-urban emissions



- New developments in TNO_MACC-III include
  - Industrial area land cover from CORINE, for industrial emissions not covered by point sources
  - Improved wood consumption & distribution -> higher consumption in Eastern Europe
  - Improved emissions and trends for international sea shipping, based on review of existing information and expert knowledge

macc Monitoring atmospheric composition & climate

RESULTING EMISSION MAPS

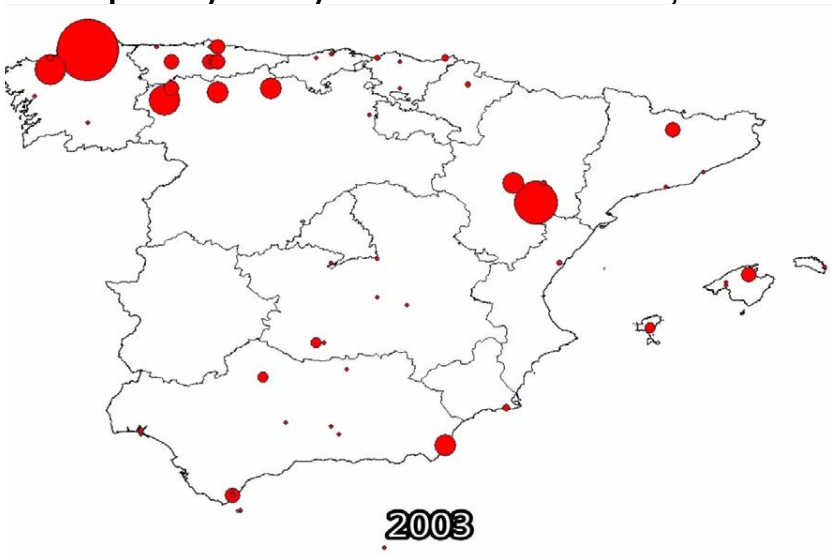


POINT SOURCES

- Use of European Pollutant Release and Transfer Register (and predecessor EPER): http://prtr.ec.europa.eu
  - EPER: 2001 and 2004
  - E-PRTR: annual data from 2007 onwards

- Used in TNO-MACC-II as relative proxy for distributing emissions for specific sector/fuel combinations (2004 proxy for years 2003-2005, 2007 also for 2006)

- Where E-PRTR data not available or not suitable, TNO PS info from TNO_MACC-I has been used as proxy for distributing emissions



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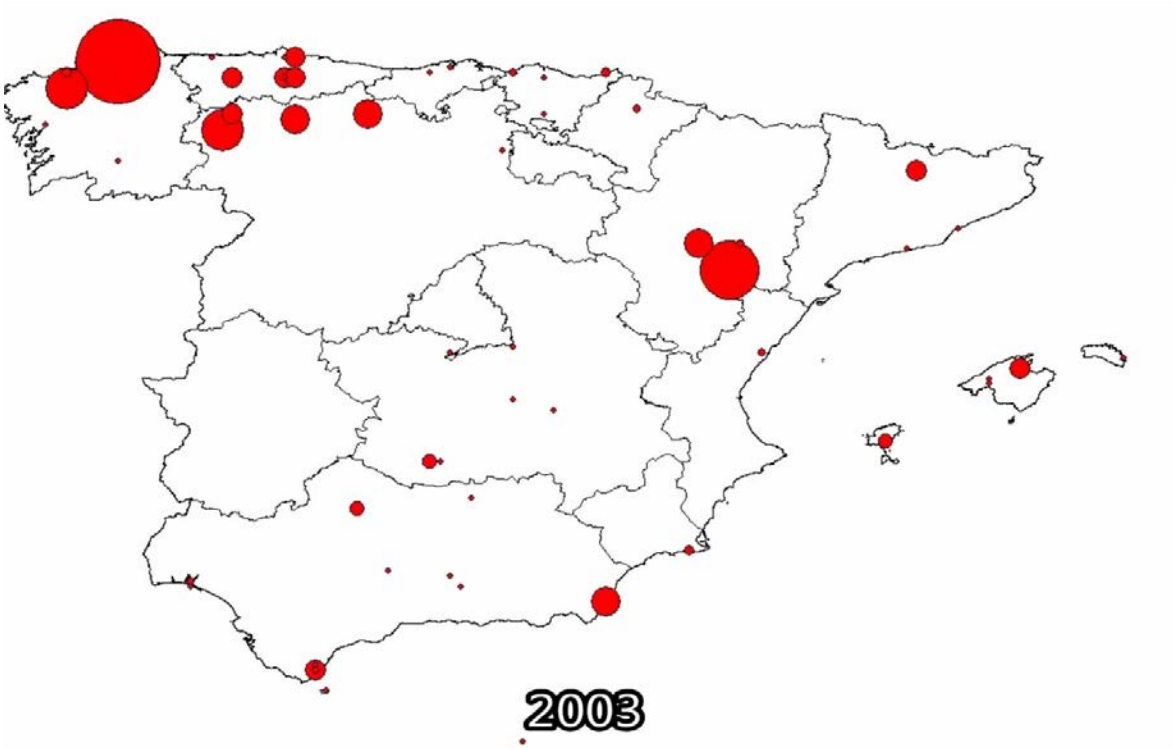
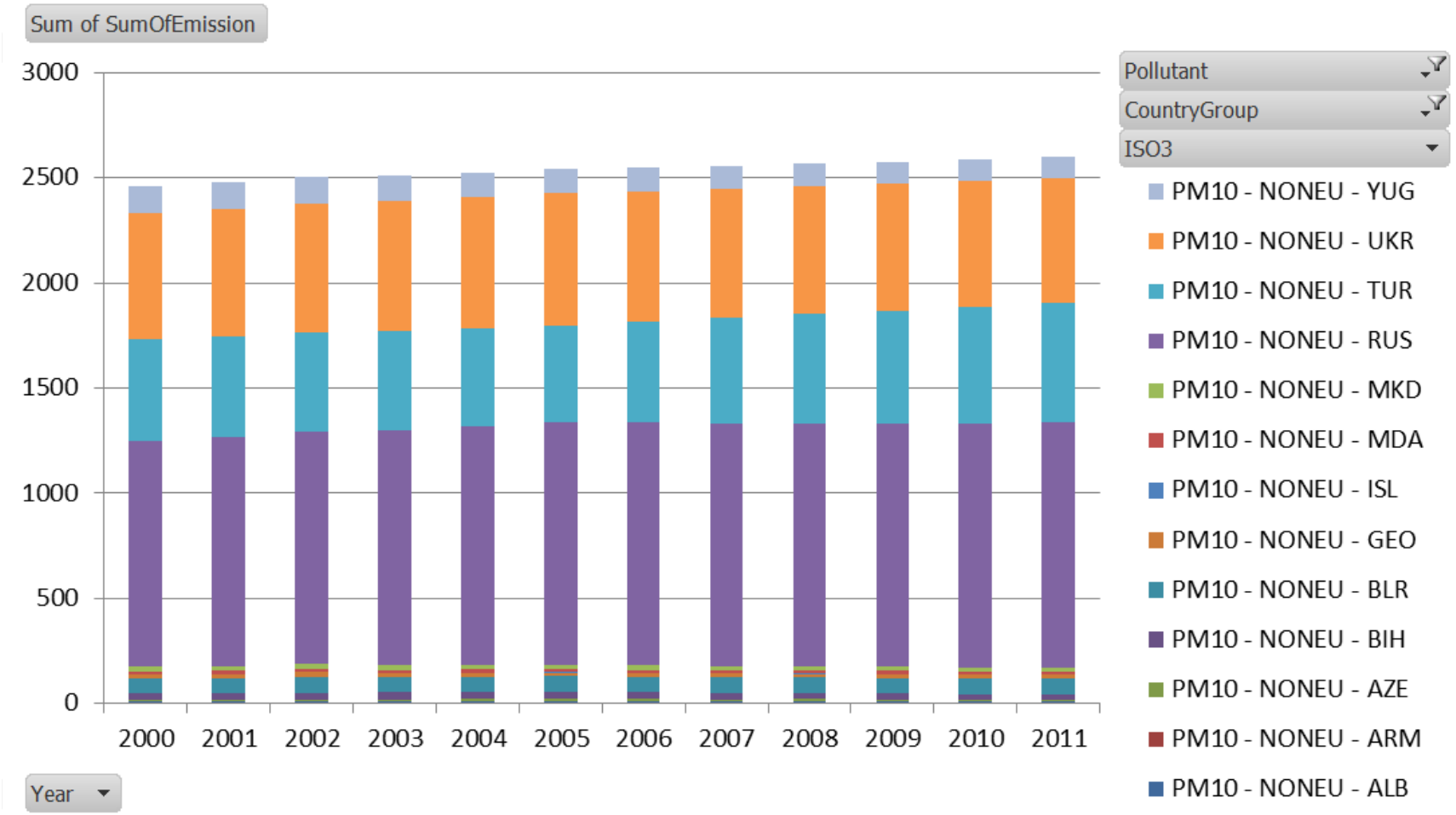
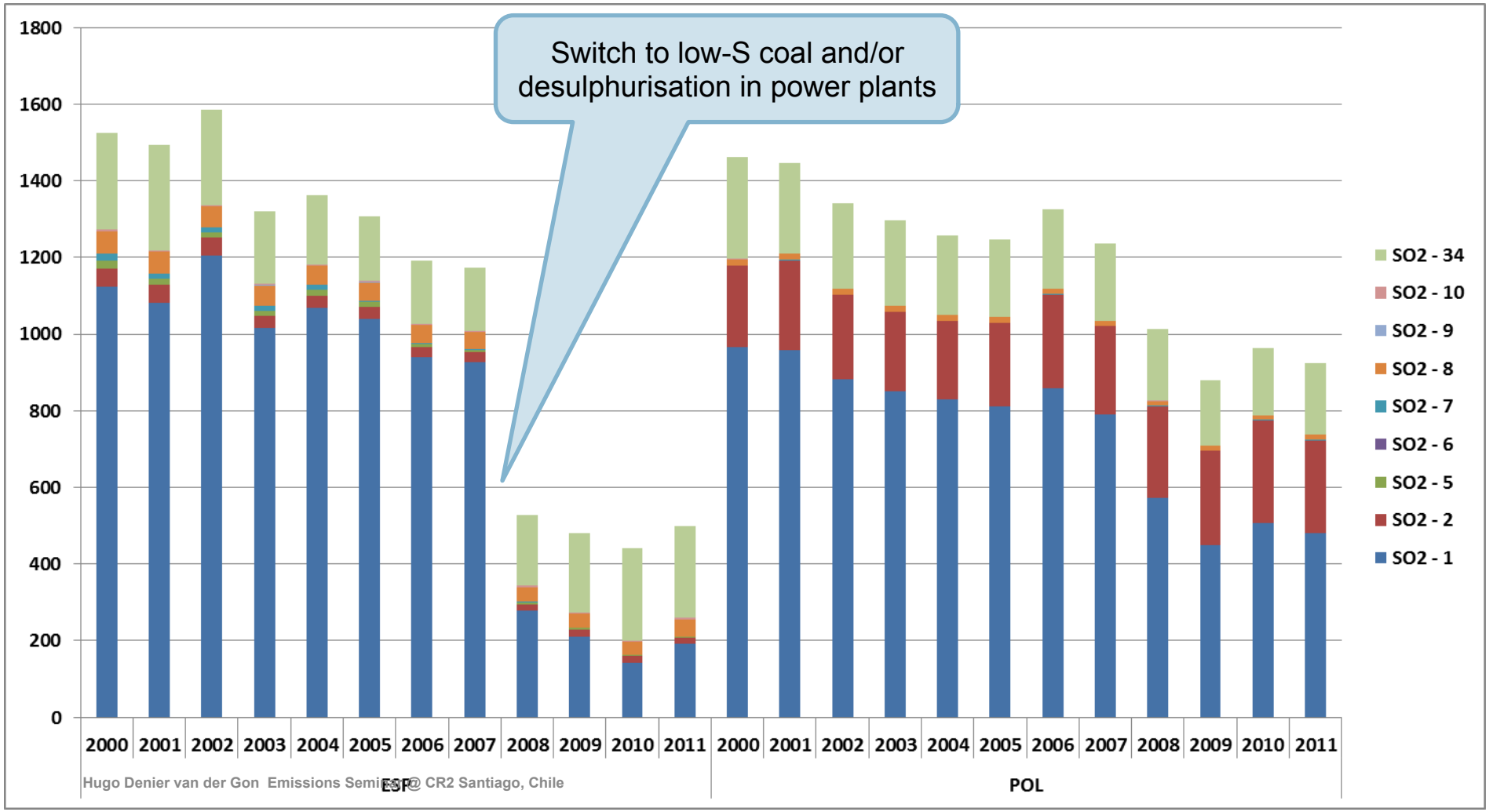


TNO-MACC_III PM10 TRENDS 2000-2011

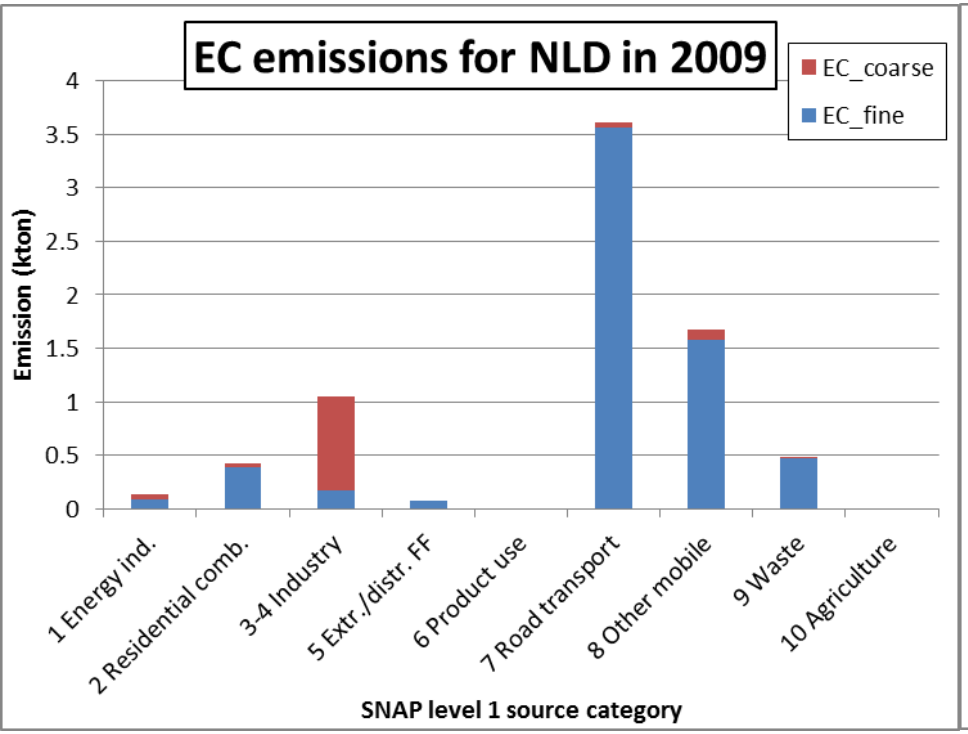


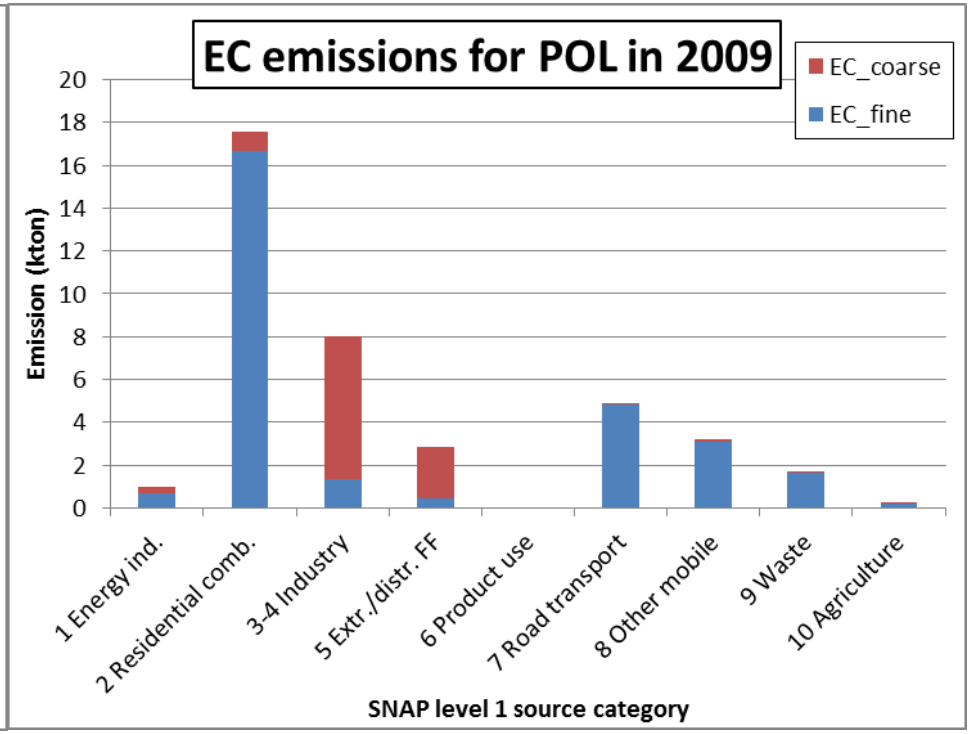
CONSISTENT EMISSIONS DATA BROKEN DOWN BY SOURCE SECTOR BY COUNTRY. EXAMPLE SO2 FOR SPAIN AND POLAND.



Example of derived

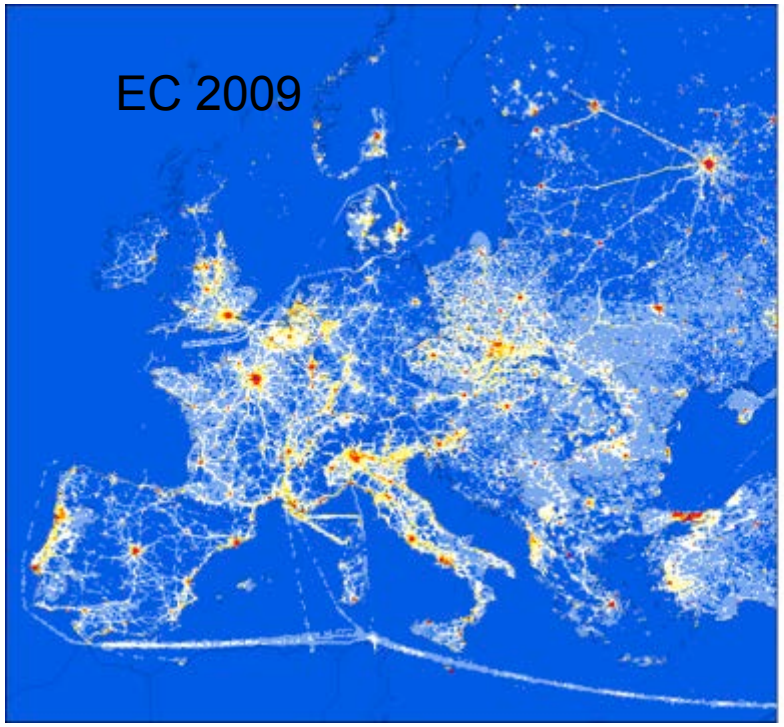
Elemental carbon emissions by country by sector

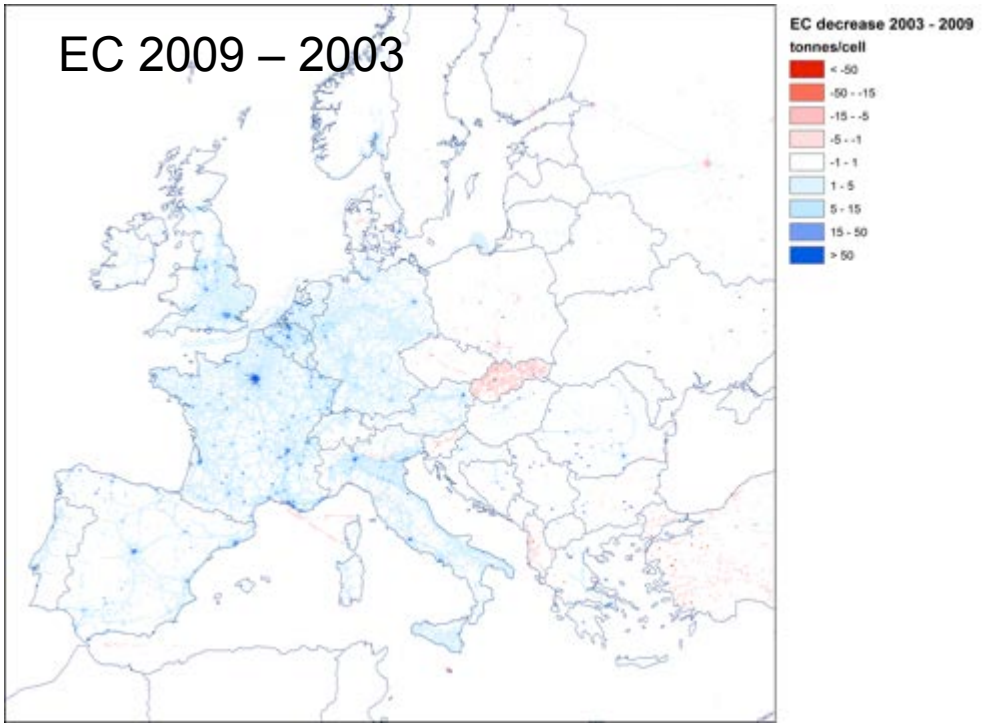




Dominant sources vary by country!
Effective policy in Netherlands addresses road transport,
in Poland focus should be on residential combustion

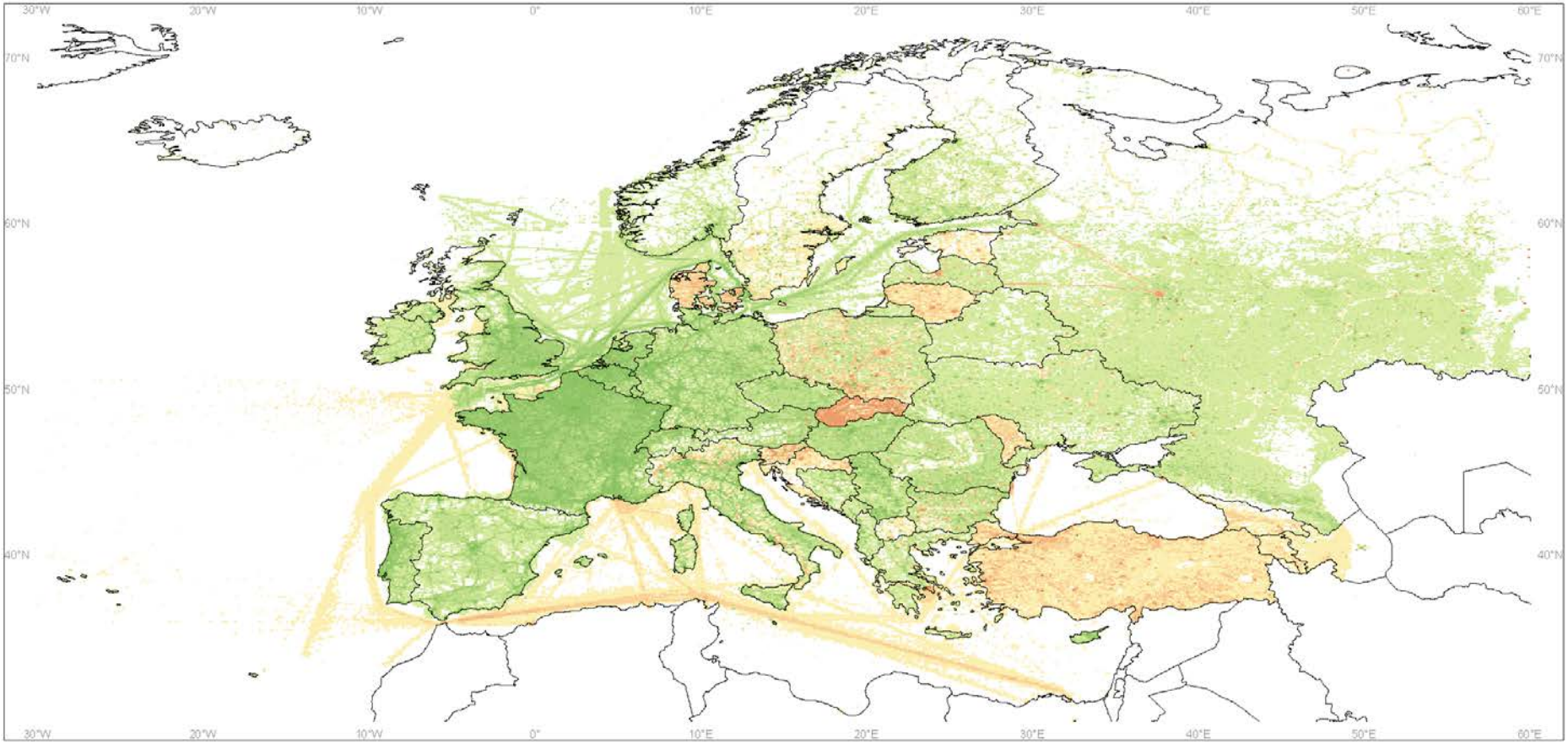
SPATIAL DISTRIBUTION AND CHANGE OVER TIME (TNO-MACC EMISSION INVENTORY)





Source: Kuenen,J. , A. Visschedijk, M. Jozwicka, and H. Denier van der Gon, TNO-MACC_II emission inventory; a multi-year (2003–2009) consistent high-resolution European emission inventory for air quality modelling ACP, 14, 10963-10976, 2014

CHANGE IN PM2.5 EMISSION BETWEEN 2000 AND 2011 (GREEN = REDUCTION; RED = INCREASE)

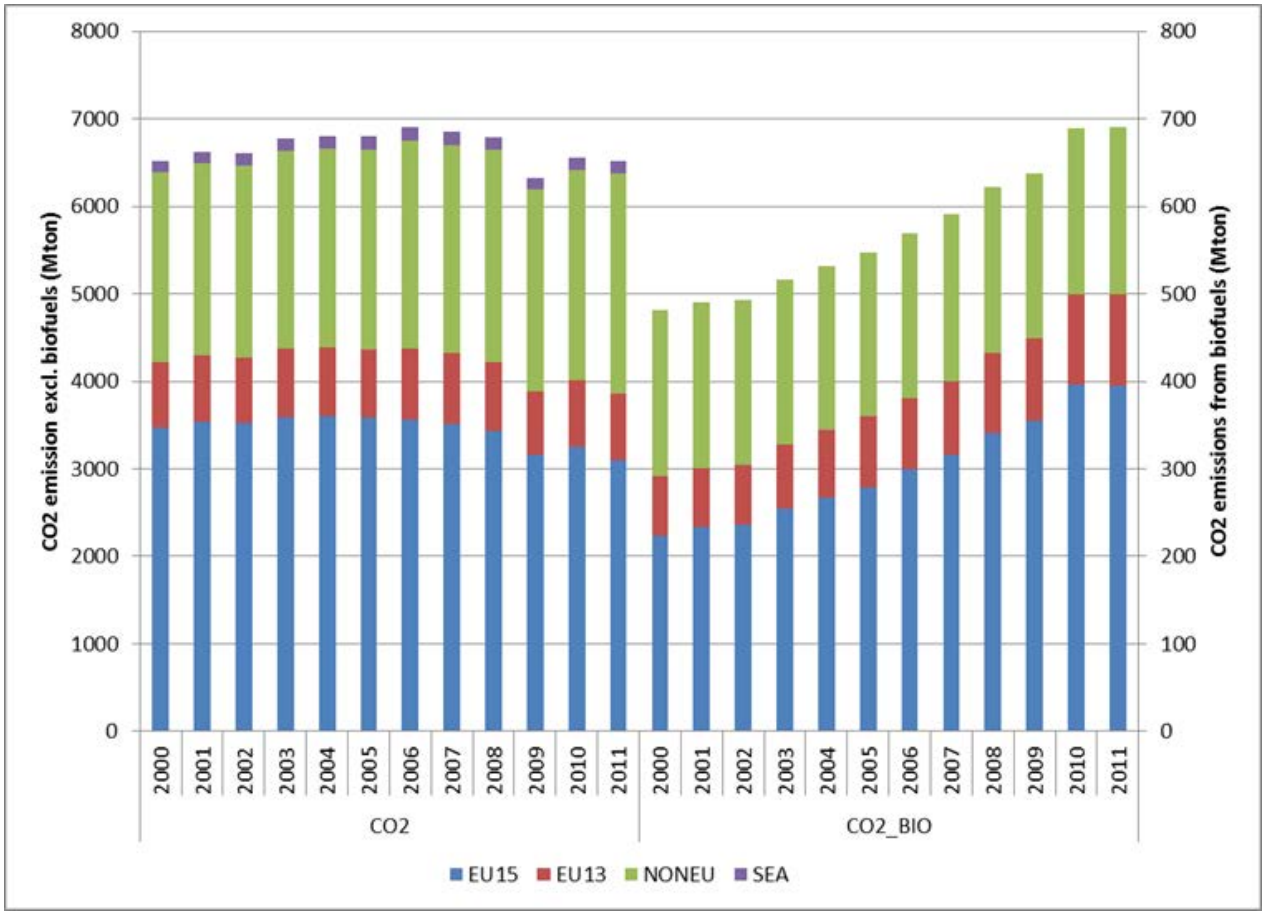


PM2.5 2000-2011 All Sectors 01 MACC-III

tonnes/cell

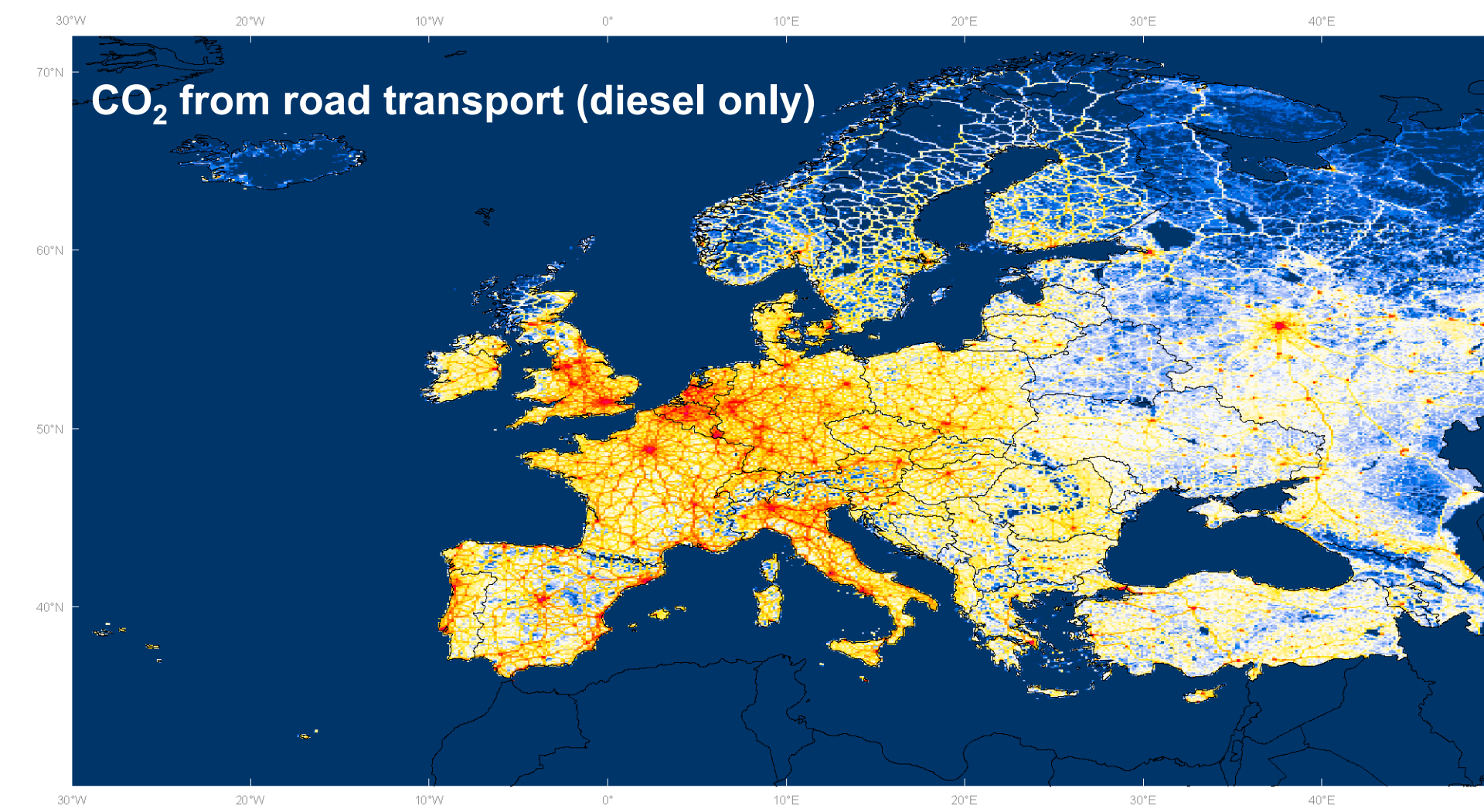
-1e+6 -1e+4 -1e+2 -3 0 3 1e+2 1e+4 1e+6

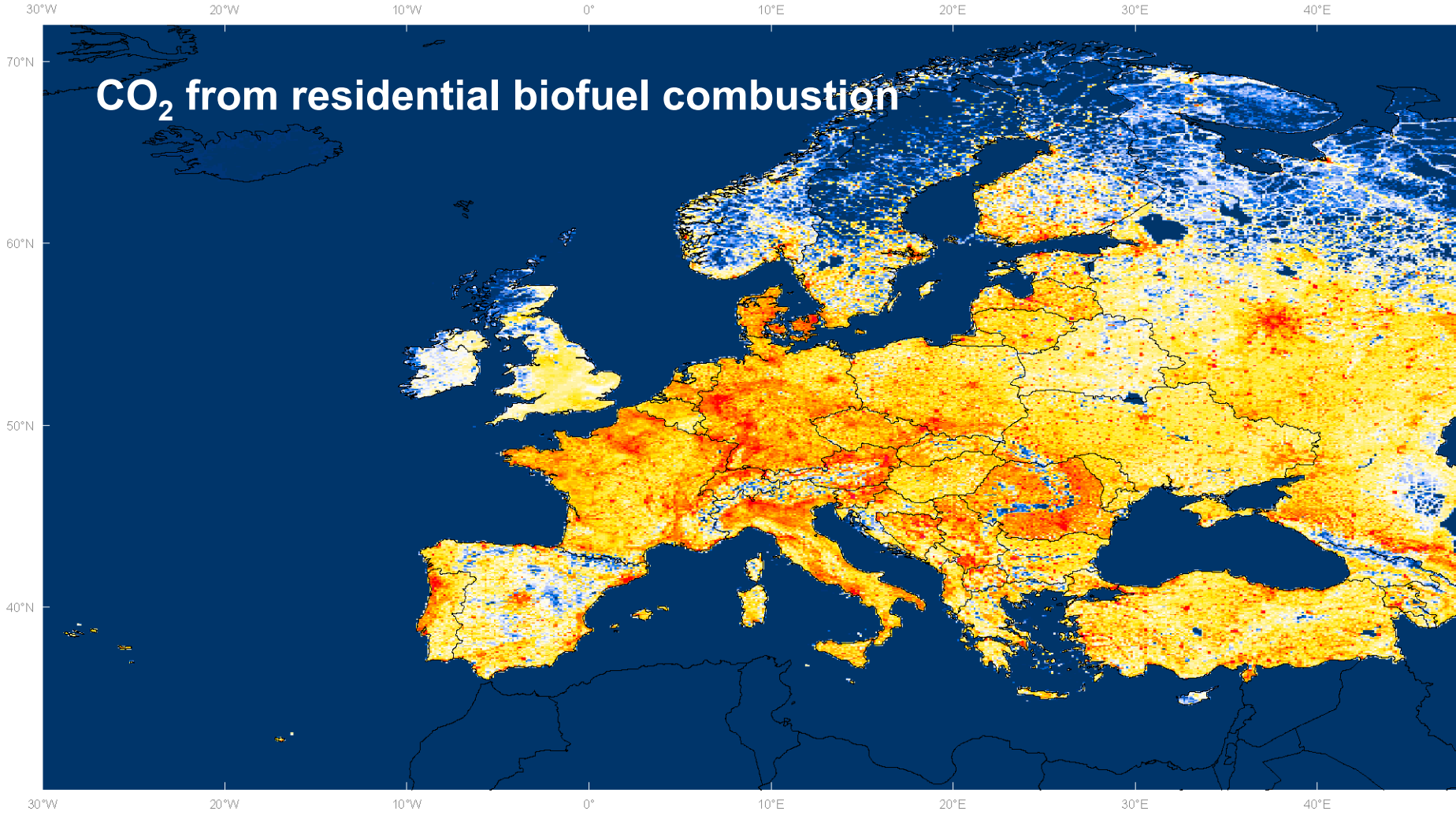
CO_2 EMISSIONS EXCLUDING BIOFUEL COMBUSTION & CO_2 FROM BIOFUEL COMBUSTION (ON RIGHT AXIS)



per year and per country group (EU15 = EU Member States as of 1-1-1995 plus Norway and Switzerland, EU13 = New EU Member States joined after 1-1-1995, NONEU = all other countries, SEA = sea regions).

Rather stable Fossil CO2 (note the crisis in 2009); increasing biofuels but still factor 10 difference


CO_2 from road transport (diesel only)
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
70°N
60°N
50°N
40°N
2009 Sector 72 CO2
1e+01
1e+02
1e+03
1e+04
1e+05


CO_2 from residential biofuel combustion
30°W
20°W
10°W
0°
10°E
20°E
30°E
40°E
70°N
60°N
50°N
40°N
2009 Sector 02 CO2 BIO
1e+01
1e+02
1e+03
1e+04

THE (RE)NEW(ED) OPPORTUNITY…

HISTORIC PARIS AGREEMENT ON CLIMATE CHANGE

Paris, 12 December 2015 – An historic agreement to combat climate change and unleash actions and investment towards a low carbon, resilient and sustainable future was agreed by 195 nations in Paris today.

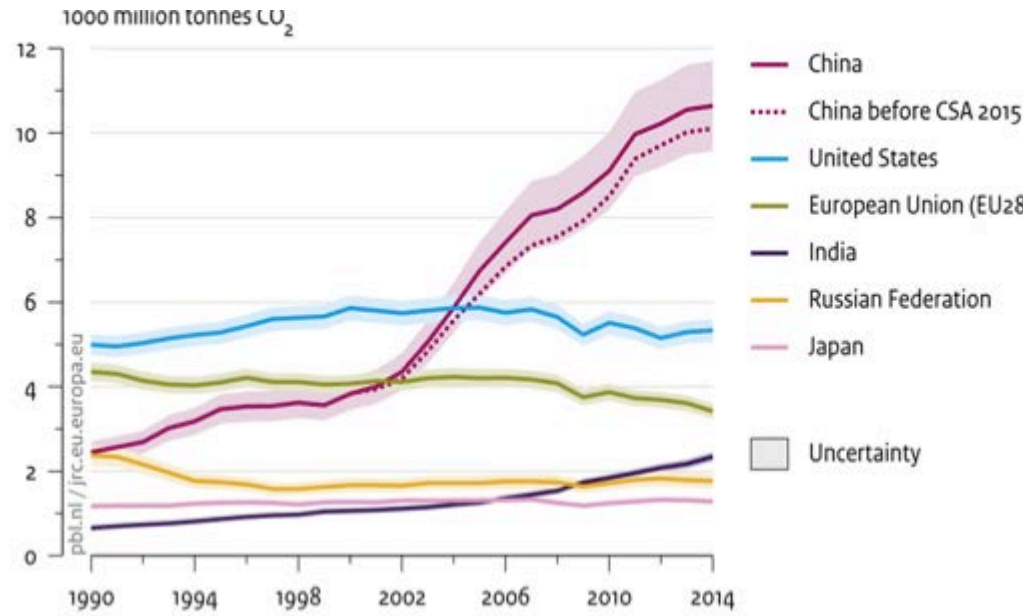
GREENHOUSE GASES

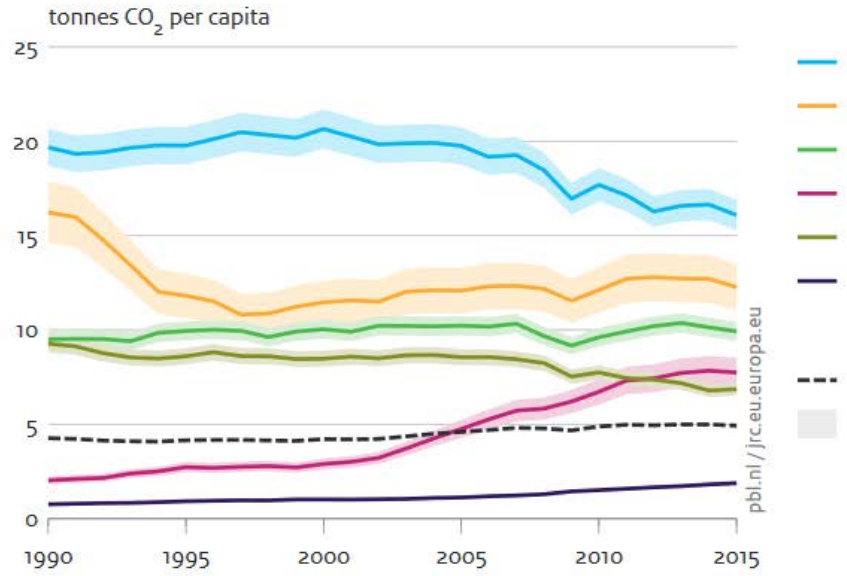
- CO_2 and biofuel CO_2 in the European TNO inventories
- **Towards independent verification**
- Measuring concentrations around Rotterdam (CO_2, CO, CH_4)
- Developing quick scans for CH_4 emissions from landfills
- Campaign for Oil and Gas CH_4 leakage in Groningen gas field
- Cooperation with satellite experts (SRON) to verify point sources
- Identifying tracers and markers e.g. ethane for fossil NG leakage
- Carbon footprint of different fuels

Complexity? –

zooming out makes the answers simpler....

CO_2 EMISSIONS FROM FOSSIL-FUEL USE AND CEMENT PRODUCTION IN THE TOP 5 EMITTING COUNTRIES AND THE EUROPEAN UNION





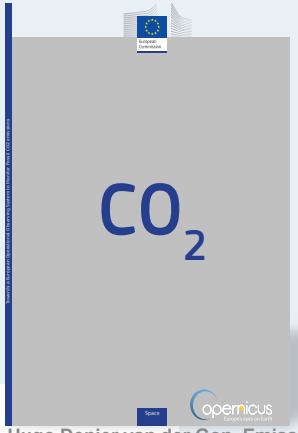
Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China,

Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016); UNPD 2015 (WPP, Rev. 2015)

Climate Change… the bigger challenge!

CO_2

1. What are the critical uncertainties and limitations of current inventories of fossil CO_2 emissions based on fuel use statistics?
2. How could inventories be improved using independent space-borne measurements of atmospheric CO_2?



"CO_2 report" : Towards a European Operational Observing System to Monitor Fossil CO_2 Emissions

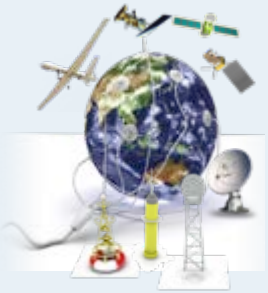
http://www.copernicus.eu/main/towards-european-operational-observing-system-monitor-fossil-co2-emissions

The top-down atmospheric approach

Improving emissions inventories

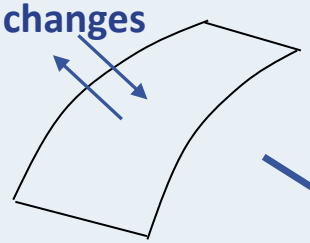
Top-down

Measurement systems for atmospheric CO_2



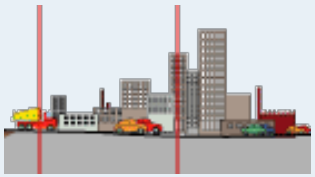
Inverse modeling

Sources and sinks for CO_2 on a gridded basis with temporal changes



Bottom-up

Emission inventories from statistical data



Maps of emissions per sector of human activity

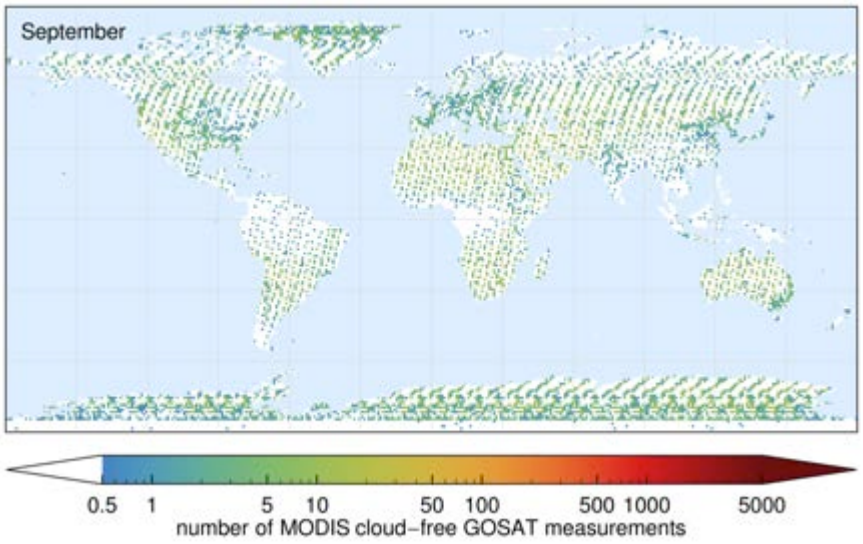
Improved Inventories

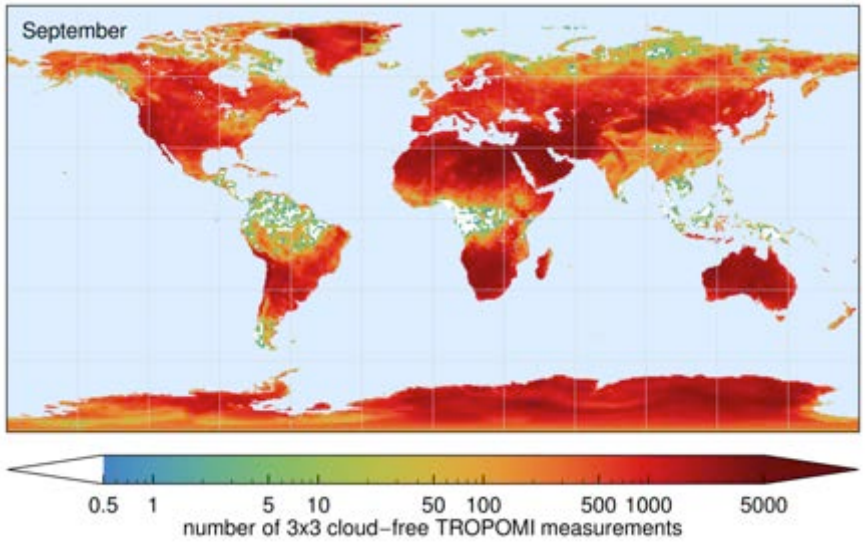
- UNFCCC
- Regional authorities
- Emission Trading markets
- Effort Sharing Decision sectors
- Public

- CO_2 emissions of subnational governments / regions need also to be mapped within a regionally complete picture (covering all human activities).

	active period	Type observation	Footprint size (km x km)	# meas. per time unit	Sensitivity per meas. (XCH4 %)	Coverage
SCIAMACHY	2002-2012	Scanning (960 km)	~60x30 (**1800 km²**)	1.35 per sec **(6)**	low	Global in 6 days
GOSAT	2009-…	pointing	Diameter ~10 km (**80 km²**)	1 per 4.5 sec **(1)**	moderate	Global but with holes
TROPOMI	2017-…	Pushbroom (2600 km)	~7x7 (**50 km²**)	216 per sec **(980)**	moderate	Global in 1 day

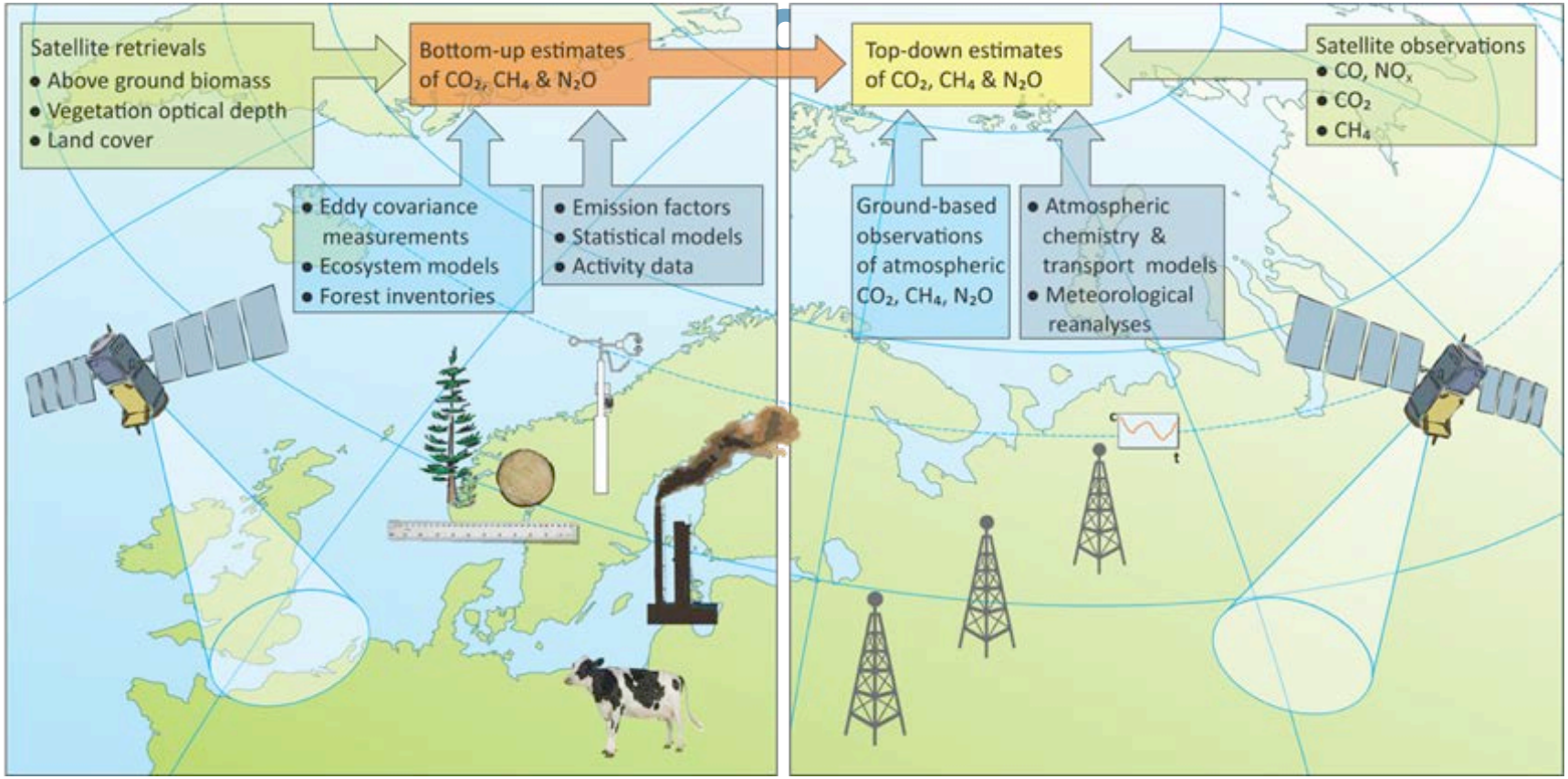
Important : **coverage** (incl. absolute number of useful meas.),footprint size,sensitivity
(Only few % cloud free observations)





TROPOMI should be much better suited to detect point sources CH_4

TOWARDS VERIFICATION OF REPORTED



EARTH OBSERVATION DATA…

NEW OPPORTUNITIES FOR EMISSION INVENTORIES

AIR POLLUTION
WHAT IS IT MADE OF?

NOx emissions = NO + NO2;
It is what it is….

PM = ….?

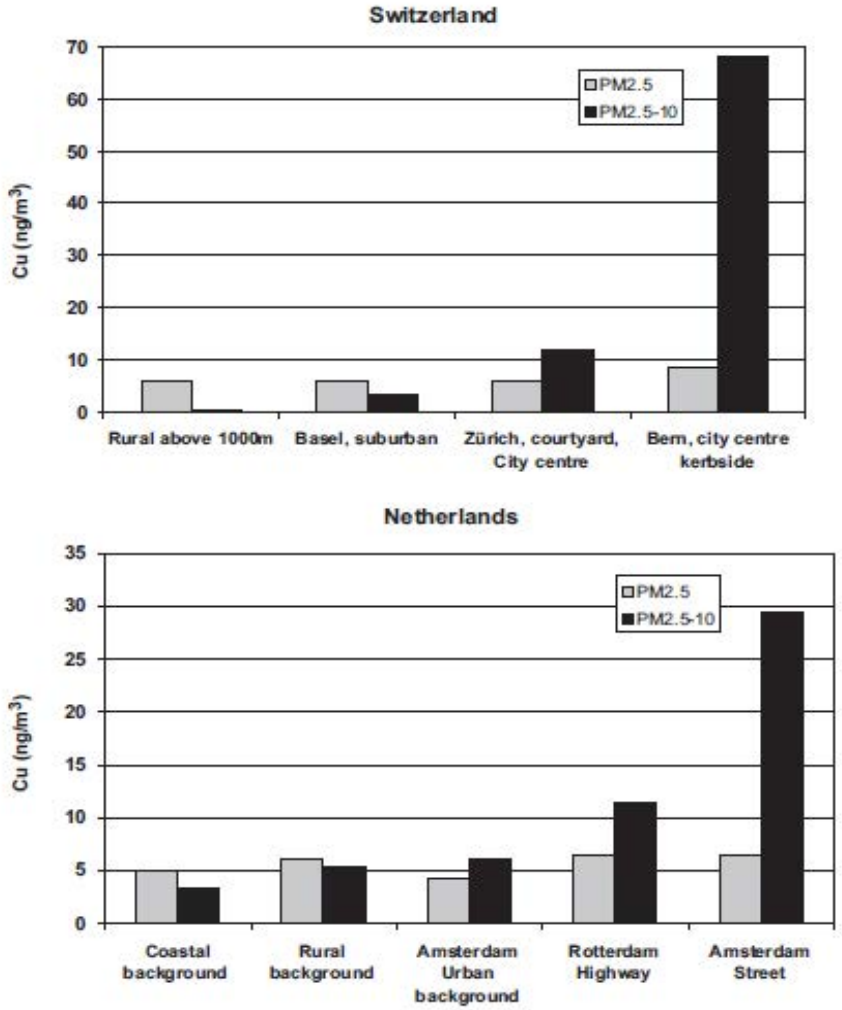


Fig. 4. Concentration of Copper in ambient PM samples at various locations in the coarse fraction (PM2.5–10) and the fine fraction (PM2.5) for Switzerland (top) and the Netherlands (bottom). (Recalculated from data by Hueglin et al., 2005 and Visser et al., 2001, respectively.)

WHEN BRAKE WEAR TURNED OUT TO BE THE MISSING COPPER SOURCE….

Denier van der Gon et al., Atmospheric Environment 41 (2007) 8697–8710

TROOPER STUDY (RIEDIKER ET AL)

Study about traffic particles and cardiovascular health

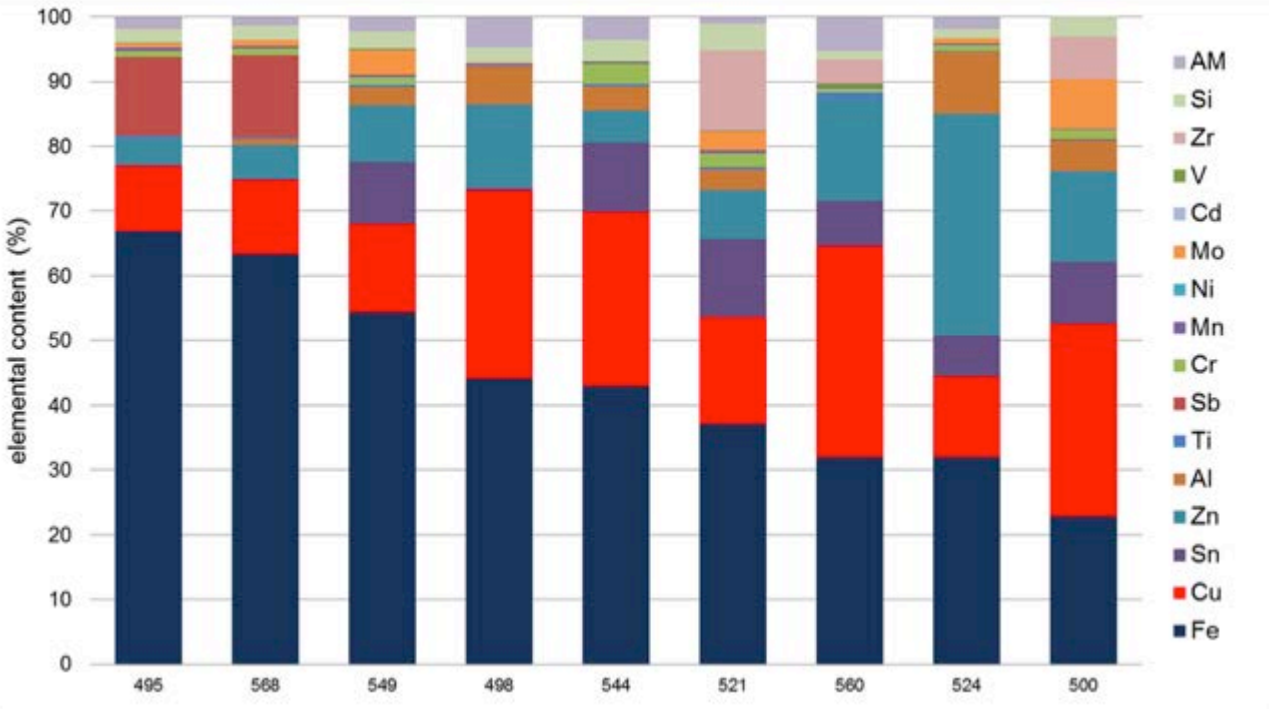
- NC highway patrol troopers
- Troopers work up to 9 hrs inside their cars
- Health effects associated with metals in PM2.5 (brake wear)

Riediker, et al. 2003. Environ Sci Technol. 37:2084-2093.

Riediker, et al. 2004. Am J Respir Crit Care Med. 169:934-940.

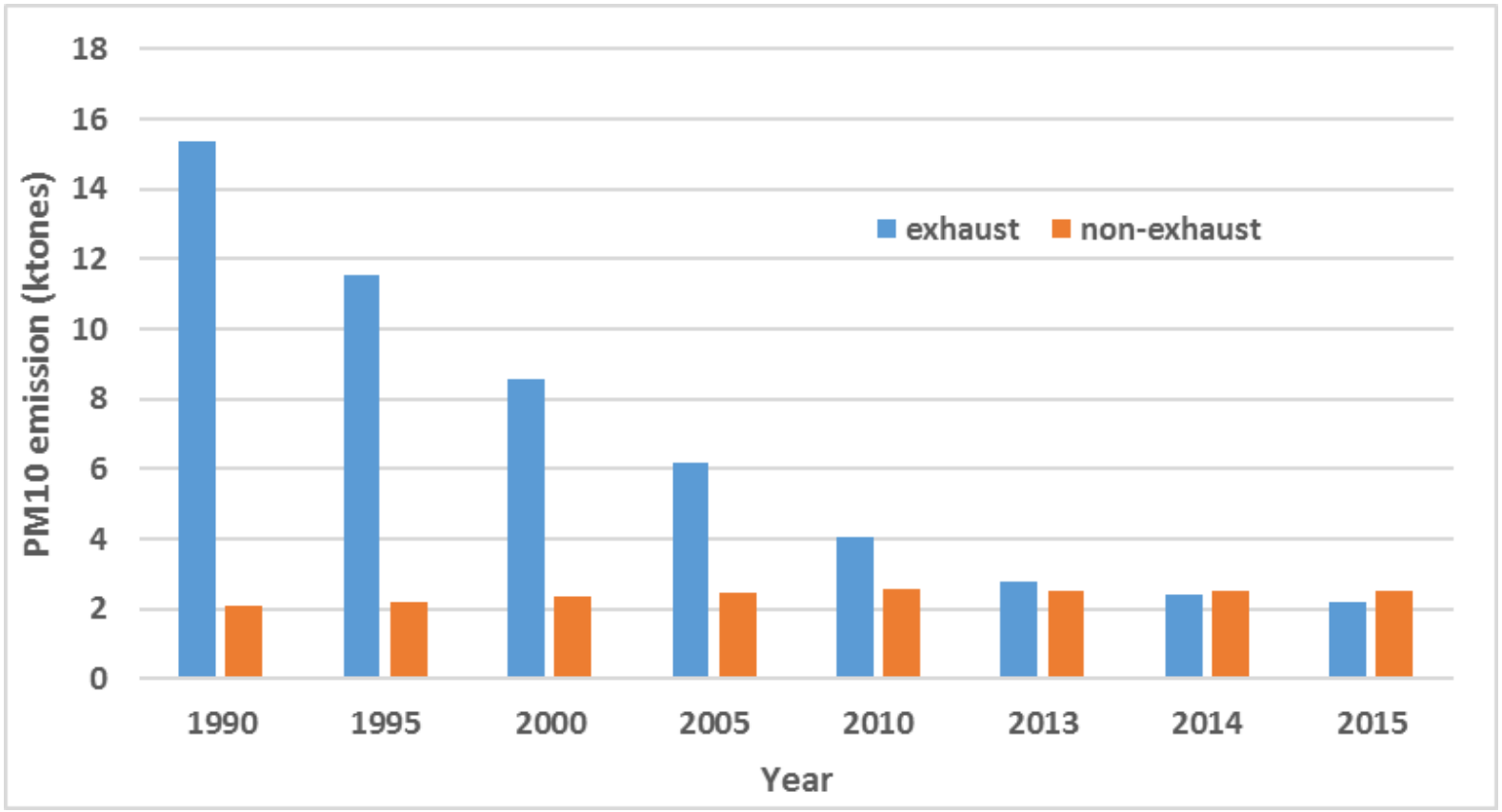
Riediker et al. 2004. Part Fib Toxicol. 1:2.

METAL CONTENT (% M/M) OF SELECTED BRAKE PAD SAMPLES BY XRF ANALYSIS



Hulskotte, J.H.J., G.D. Roskam, H.A.C. Denier van der Gon, Elemental composition of current automotive braking materials and derived air emission factors, Atmospheric Environment, 99, 436–445, 2014

TREND IN ROAD TRANSPORT PM EMISSIONS IN THE NETHERLANDS 1990-2015



A major change in composition – from combustion to wear dominated…..

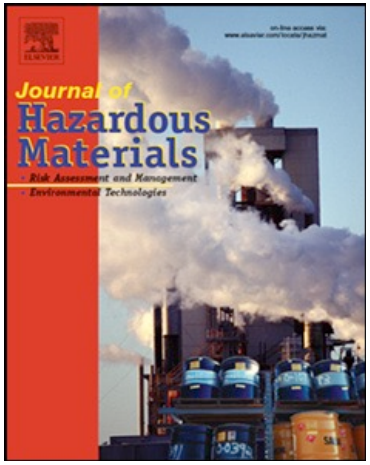
MORE ON NON-EXHAUST EMISSIONS....

REVIEW PAPER

The Policy Relevance of Wear Emissions from Road Transport, Now and in the Future—An International Workshop Report and Consensus Statement

Hugo A.C. Denier van der Gon,[1,*] Miriam E. Gerlofs-Nijland,[2] Robert Gehrig,[3] Mats Gustafsson,[4] Nicole Janssen,[2] Roy M. Harrison,[5,6] Jan Hulskotte,[1] Christer Johansson,[7,8] Magdalena Jozwicka,[1] Menno Keuken,[9] Klaas Krijgsheld,[10] Leonidas Ntziachristos,[11] Michael Riediker,[12] and Flemming R. Cassee[2,13]

Journal of the Air & Waste Management Association, 63(2):136–149, 2013.



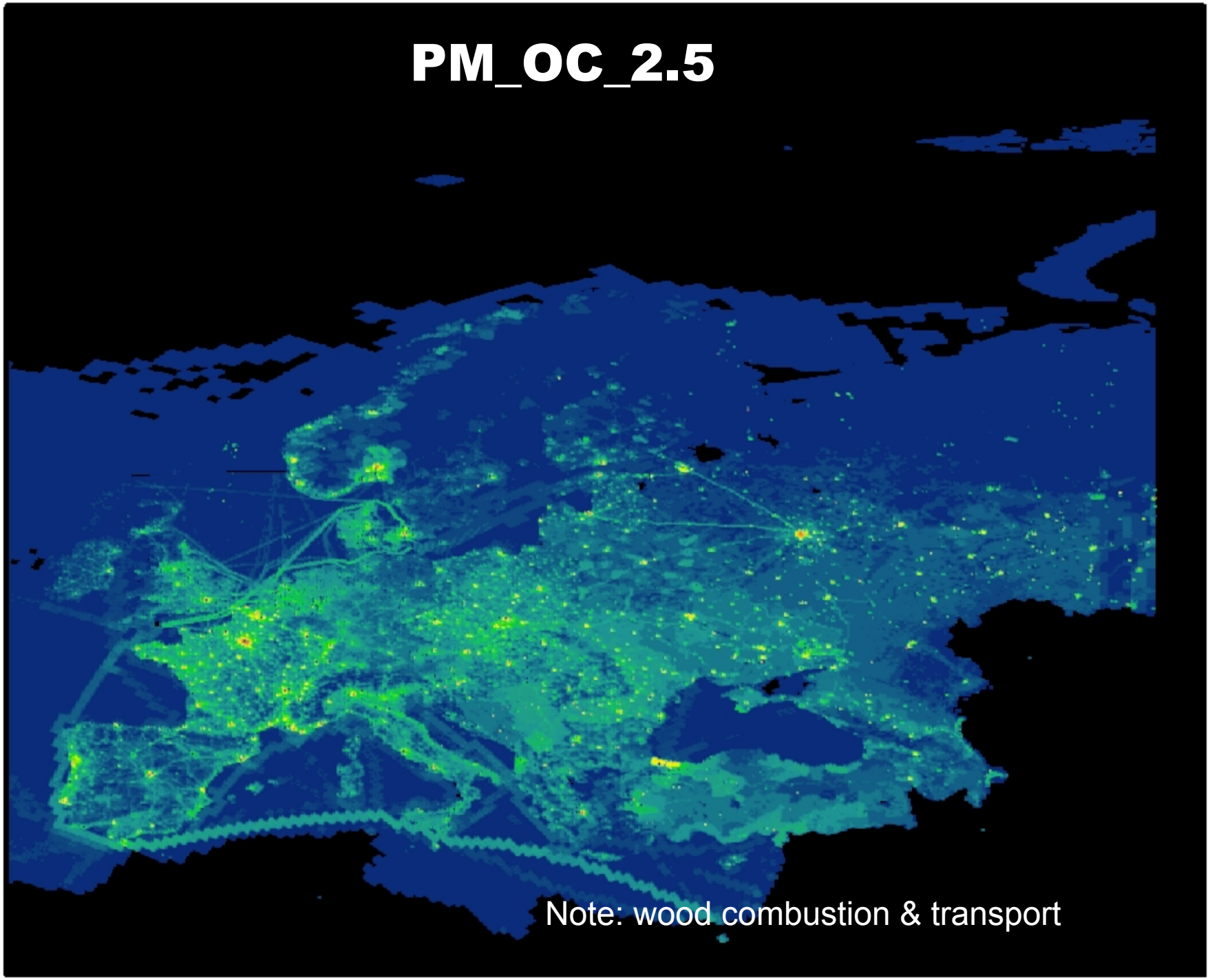
Review

Urban air quality: The challenge of traffic non-exhaust emissions

Fulvio Amato[a,*], Flemming R. Cassee[b,l], Hugo A.C. Denier van der Gon[c], Robert Gehrig[d], Mats Gustafsson[e], Wolfgang Hafner[f], Roy M. Harrison[g,k], Magdalena Jozwicka[c], Frank J. Kelly[h], Teresa Moreno[a], Andre S.H. Prevot[i], Martijn Schaap[c], Jordi Sunyer[j], Xavier Querol[a]

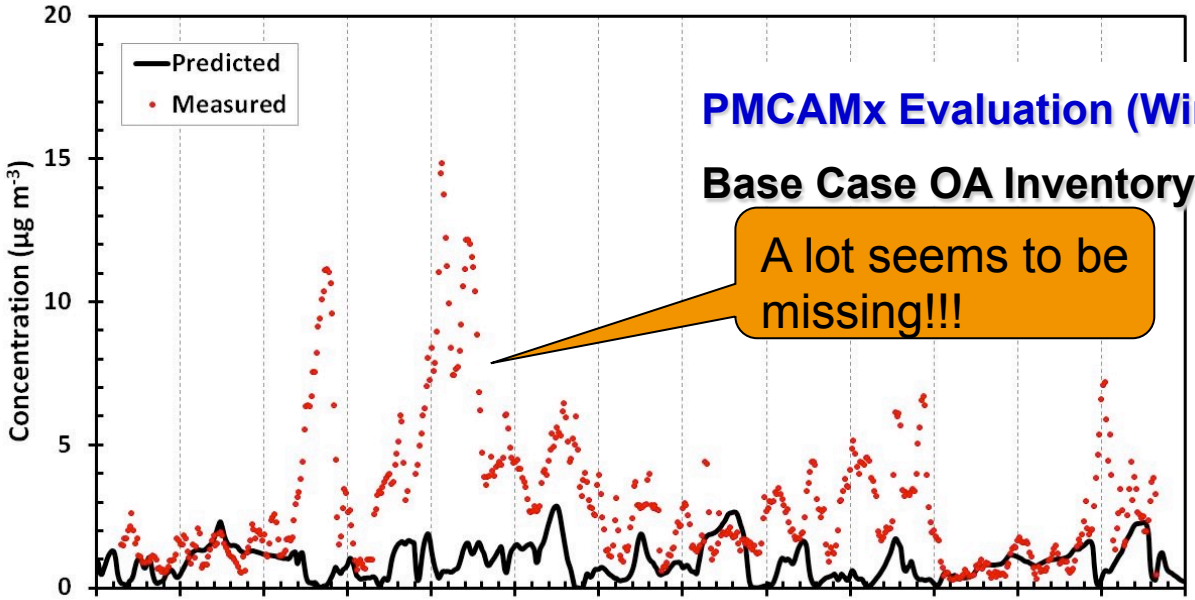
Journal of Hazardous Materials 275 (2014) 31–36

PM_OC_2.5



WHY RETHINK PM FROM WOOD COMBUSTION?

- In 2010 good results EUCAARI EC / OC inventory but….major model vs observed discrepancies during episodes influenced by residential wood combustion (RWC).



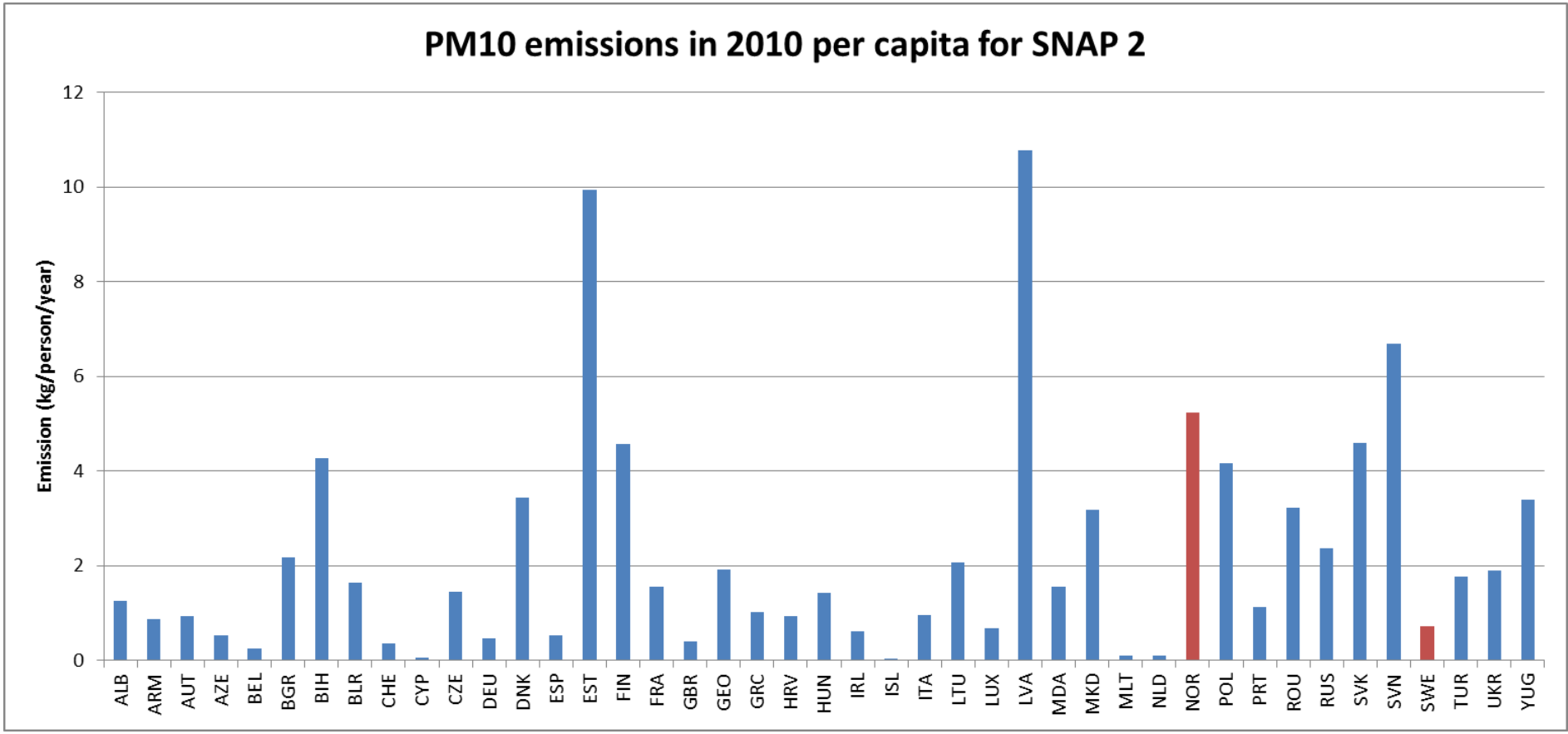
Similar performance in e.g. Payerne, Melpitz

Regional CTMs have a problem with mass closure for PM – mostly an "OC problem". At the time we thought the VBS approach would solve it, now we see it helps but there is still a substantial gap, especially close to the sources……

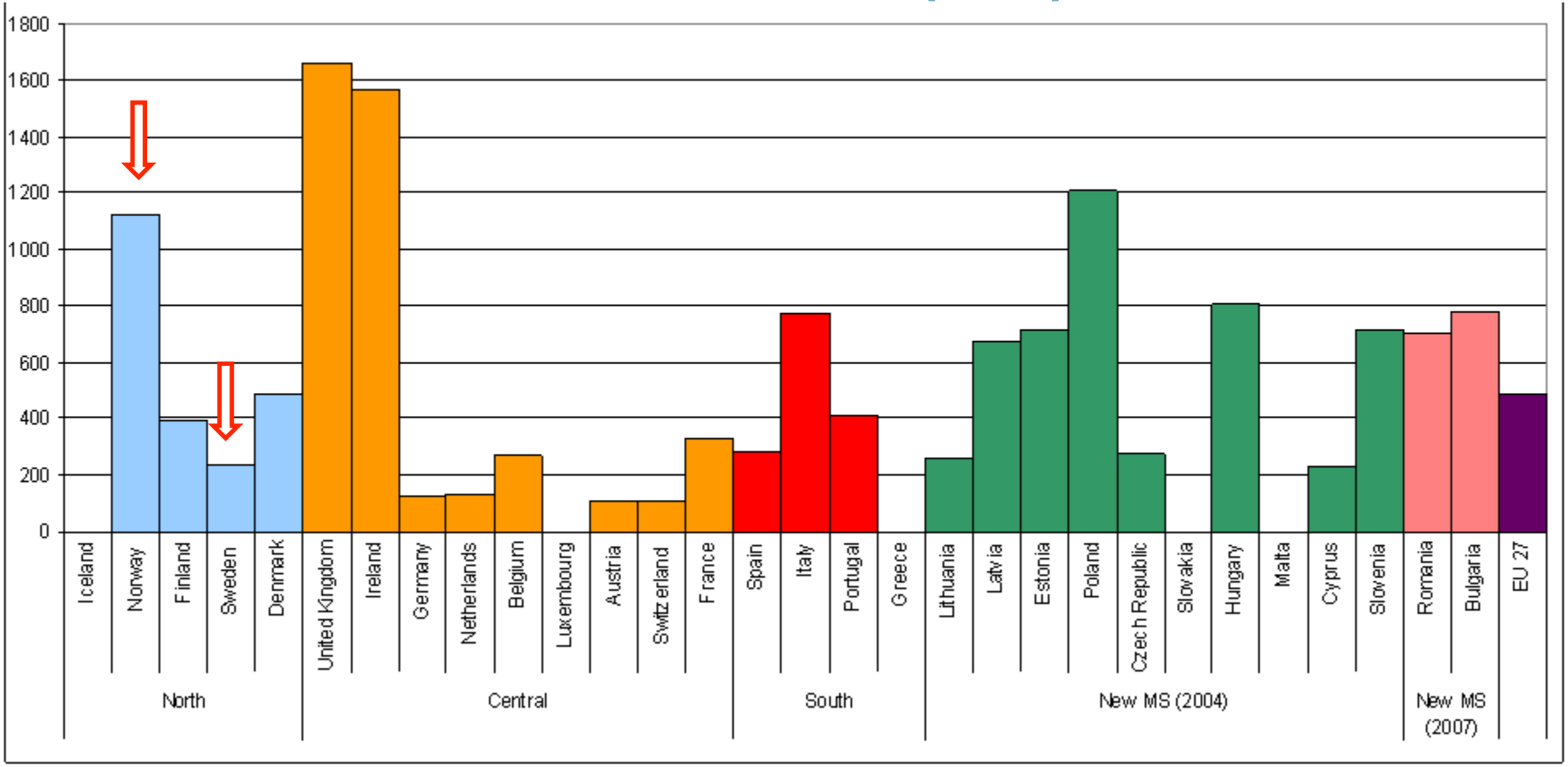
RETHINK THE RWC INVENTORY

- A first comparison/ analysis showed incompatibility of different country approaches (not “right or wrong”)
- Start partly from scratch
- Don’t use national reported data
- Do not define EC and OC as a fraction of PM10 or PM2.5 that should “fit” in the official reported data
- Make a selection of emission factors and apply in a consistent way for all countries

PM10 EMISSION PER CAPITA FOR RESIDENTIAL COMBUSTION IN 2010



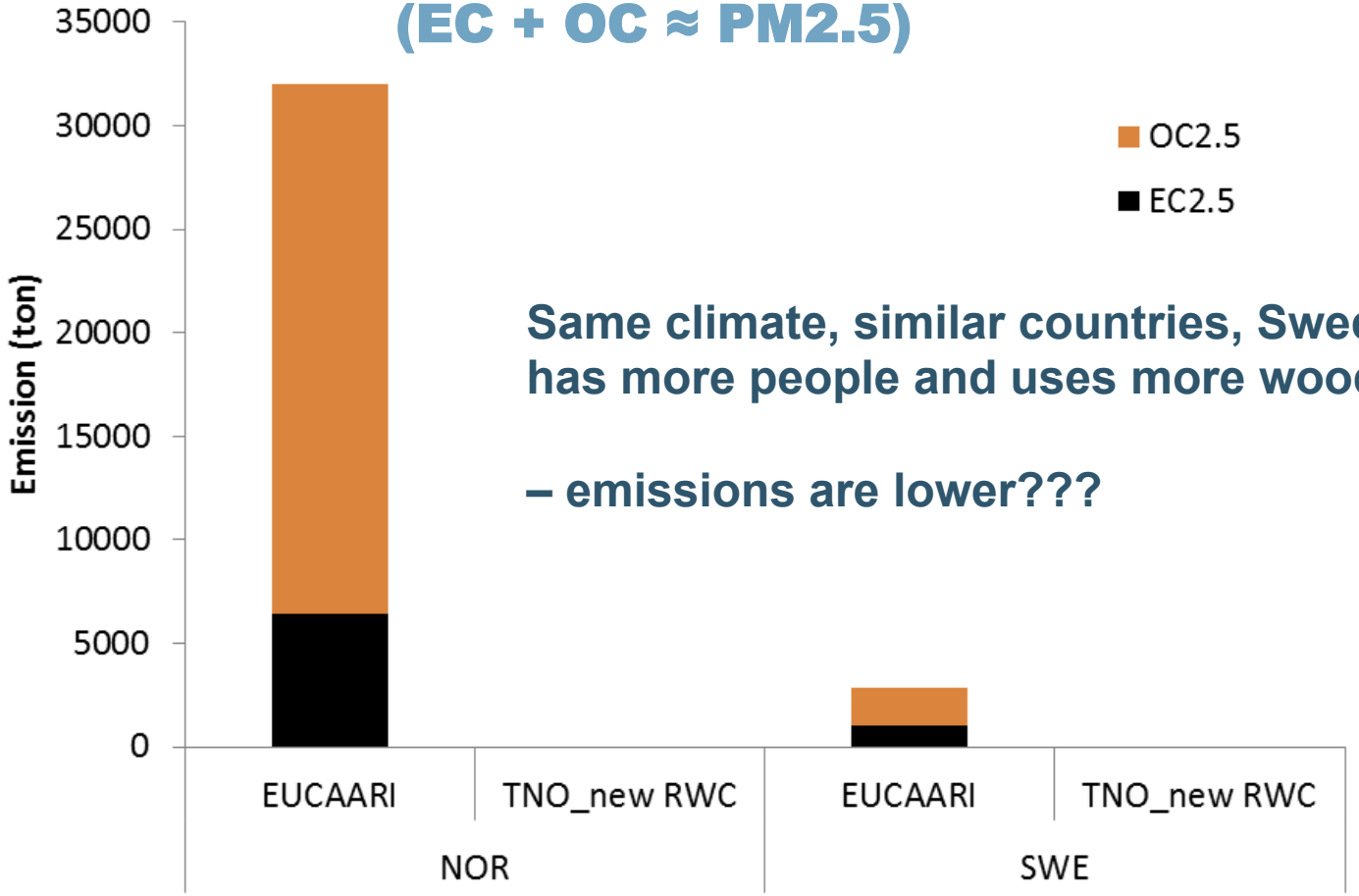
EMISSIONS OF PM10 PER UNIT OF WOOD COMBUSTED IN THE RESIDENTIAL SECTOR IN 2009 (G/GJ)



- **Large differences in "implied" emission factors**

NORWAY & SWEDEN: TOTAL RESIDENTIAL WOOD COMBUSTION EMISSIONS IN 2005

(EC + OC ≈ PM2.5)



Same climate, similar countries, Sweden has more people and uses more wood

– emissions are lower???

EUCAARI inventory approach:

1) Estimate PM2.5

2) use fractions to estimate EC and OC

FILTERABLE PM AND CONDENSABLE PM

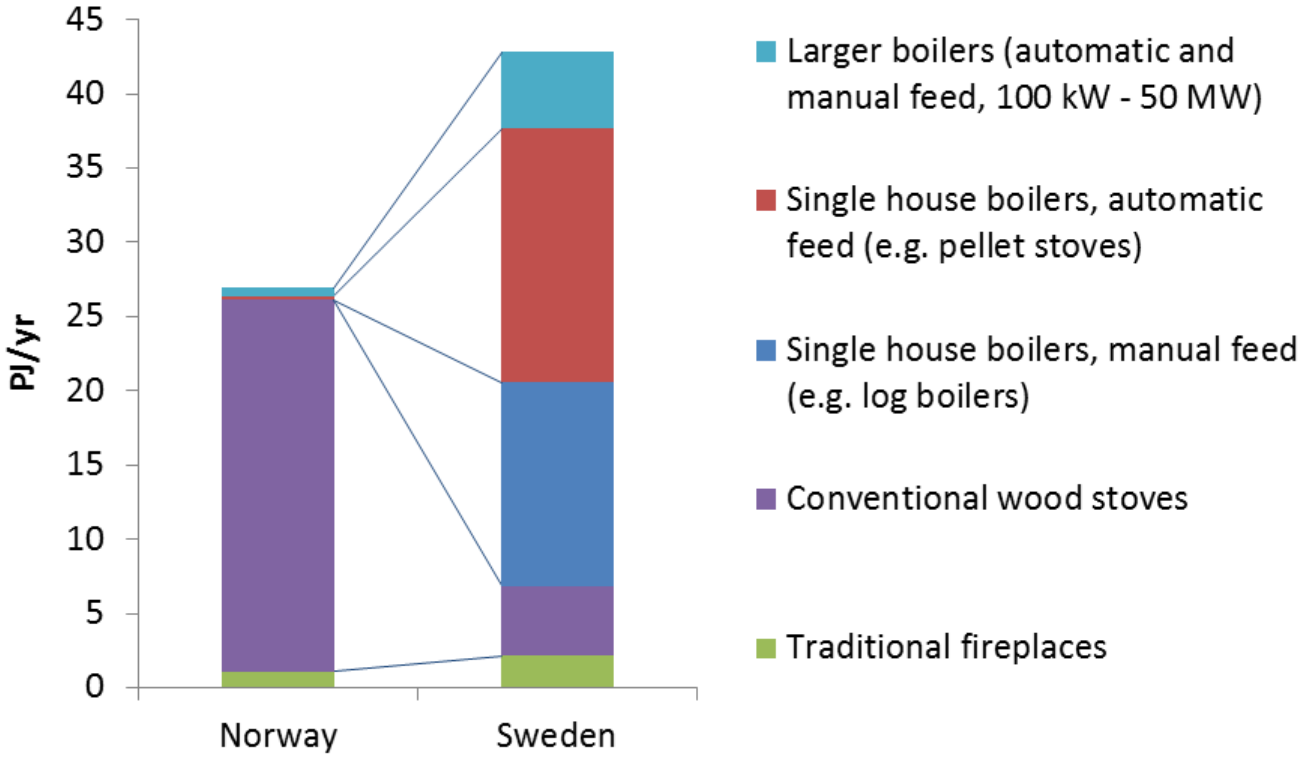
› the US EPA defines particulate matter (PM) as consisting of a filterable fraction (FPM) and a condensable fraction (CPM).

Filterable PM is directly emitted:
- Solid or liquid
- Captured on filter
- PM_{10} or $PM_{2.5}$

Condensable PM is in vapor:
- Reacts upon cooling and dilution
- Forms solid or liquid particle
- Always $PM_{2.5}$ or less

where should the PM mass be that forms almost instantaneously?

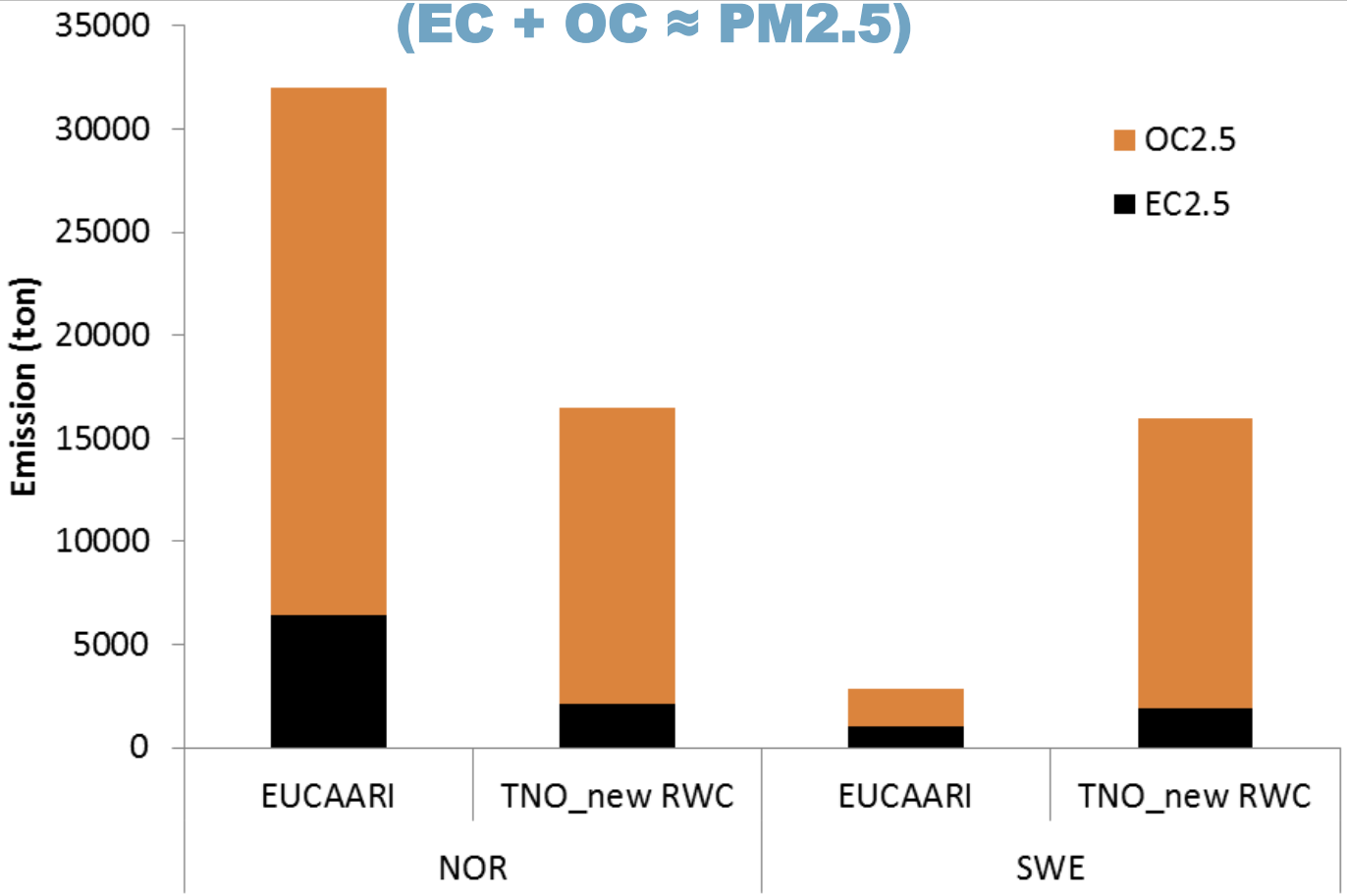
WOOD USE IN NORWAY & SWEDEN



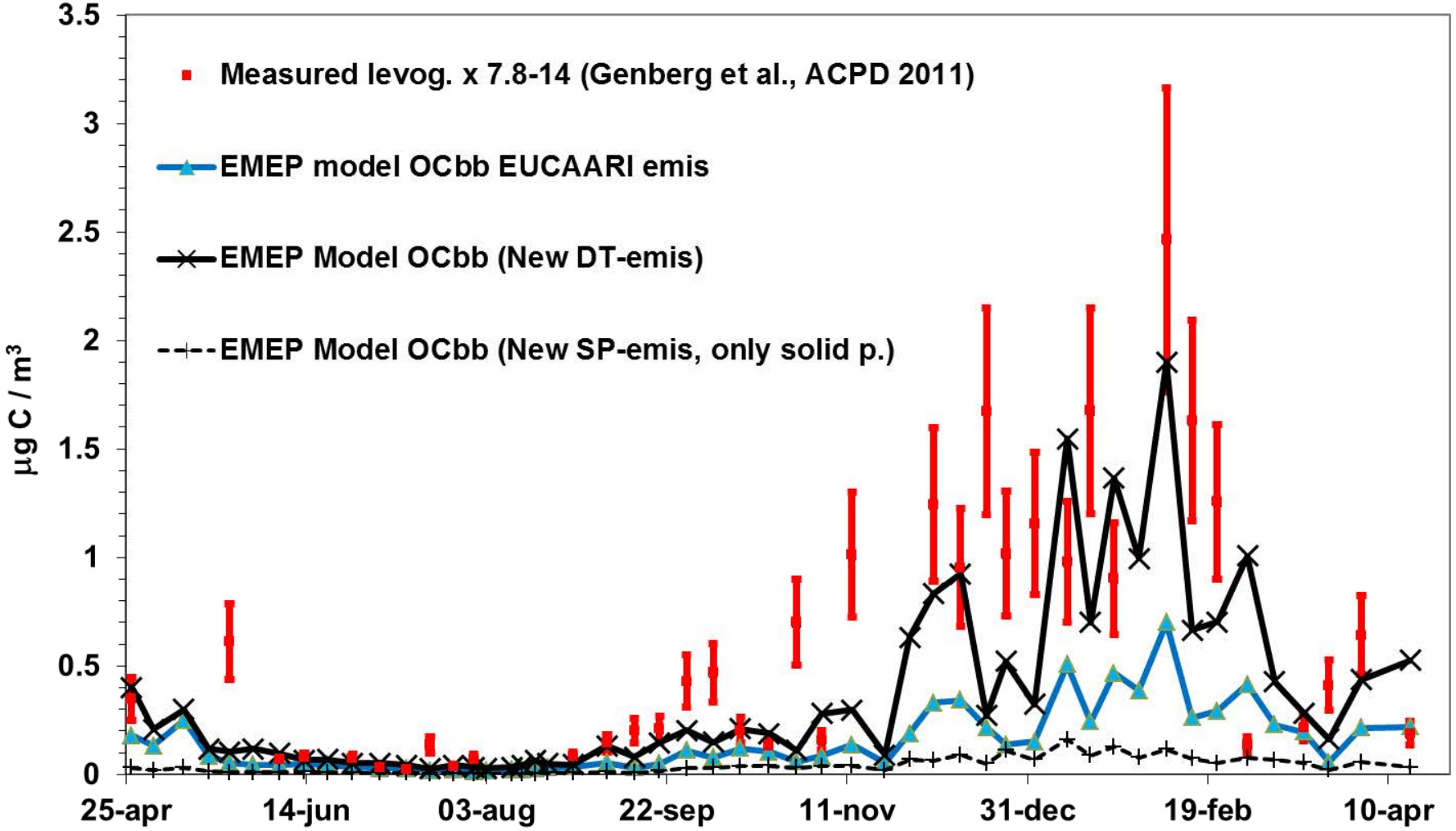
- Wood use in Sweden larger but different appliance
- Countries use their own methods to calculate PM emissions

NORWAY & SWEDEN: TOTAL RESIDENTIAL WOOD COMBUSTION EMISSIONS IN 2005

(EC + OC ≈ PM2.5)



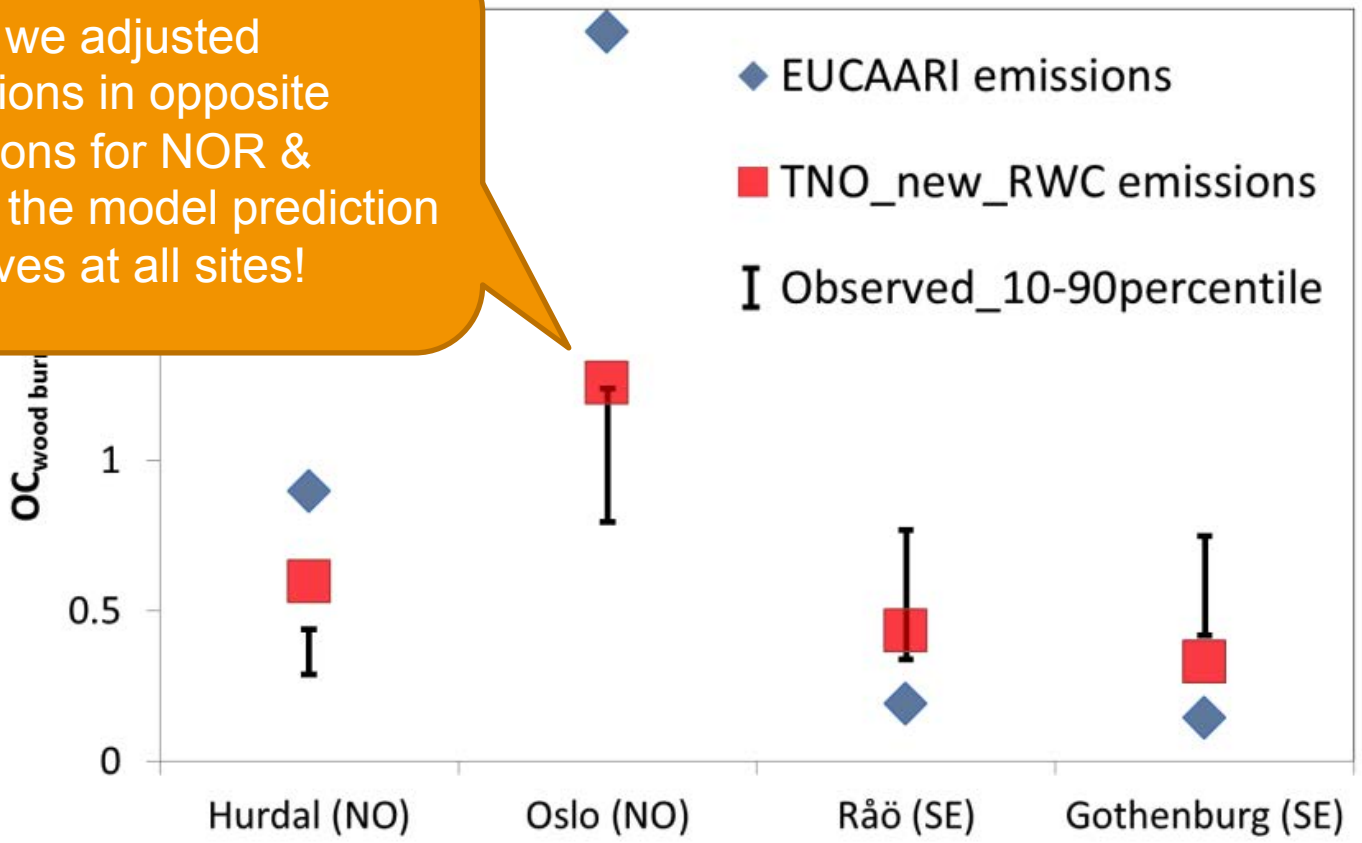
Vavihill OCbb and levoglucosan 2008-2009



Denier van der Gon et al., 2015

Wood Burning OC - source-apportionment studies
...nter campaigns in Scandinavia

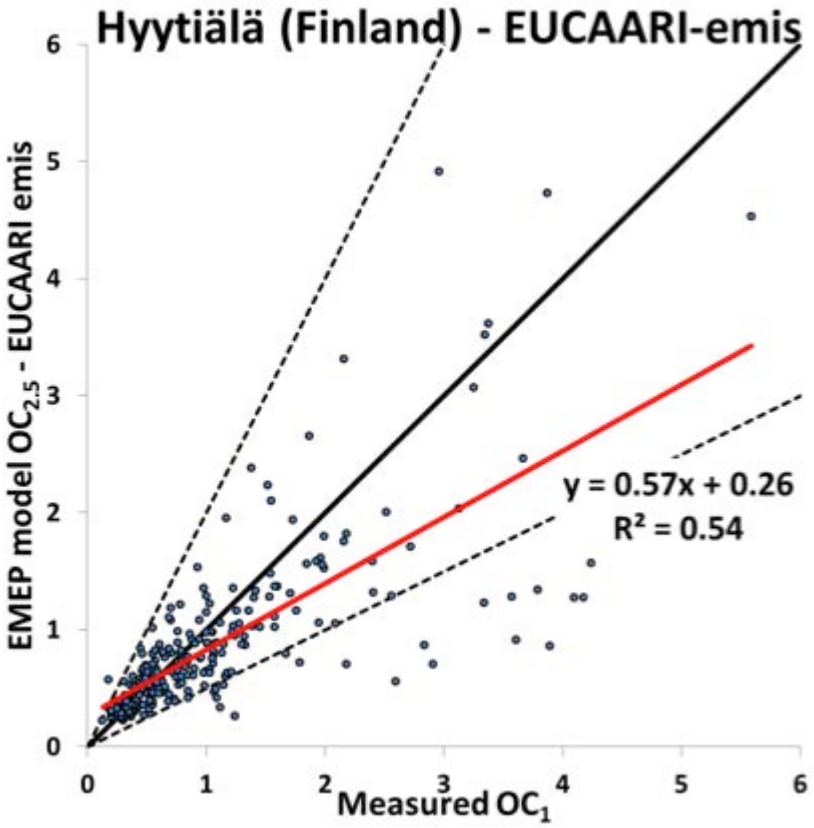
While we adjusted emissions in opposite directions for NOR & SWE, the model prediction improves at all sites!

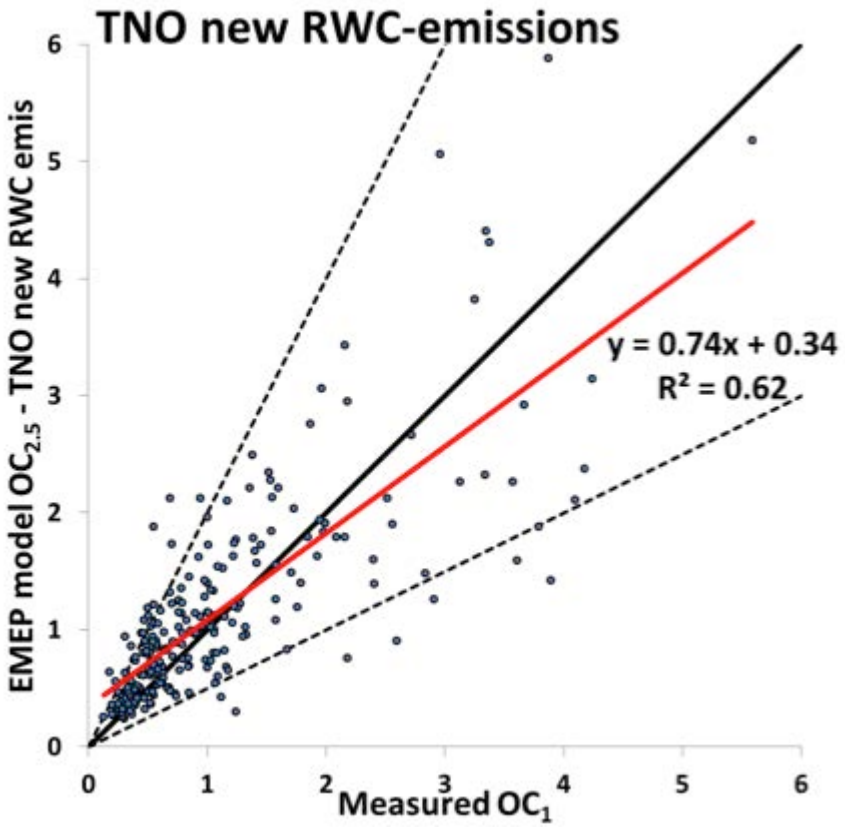


Comparison of model calculated OC from wood burning to source-apportionment data from measurement campaigns during winter in Norway and Sweden
(SORGA, 1 - 8 March 2007, Yttri et al.,2011) (GÖTE, 11 Feb - 4 Mar 2005, Szidat et al., 2009). Unit: μg(C) m^{-3}

Denier van der Gon et al., 2015

MEASURED AND MODELLED PM_OC CONCENTRATIONS WITH THE EMEP MSC-W MODEL





Denier van der Gon et al., ACP, 2015

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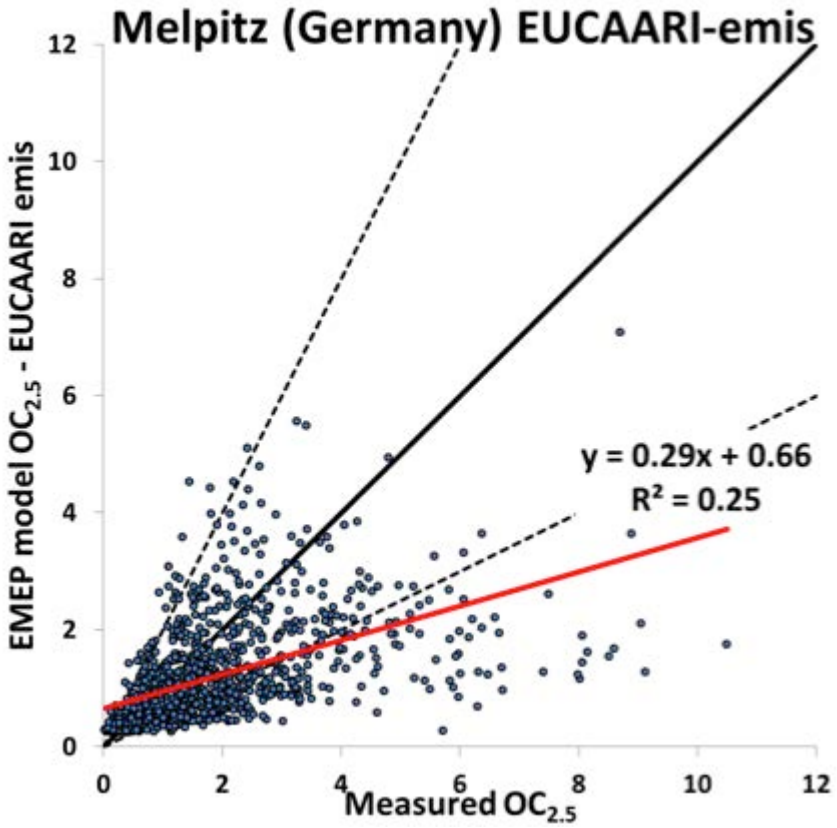
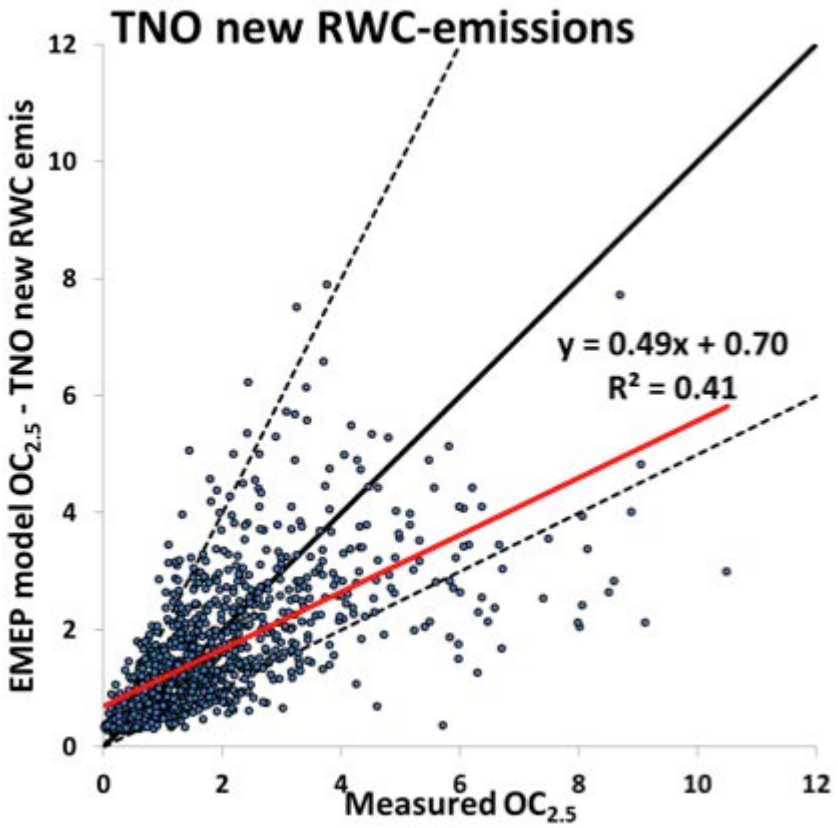
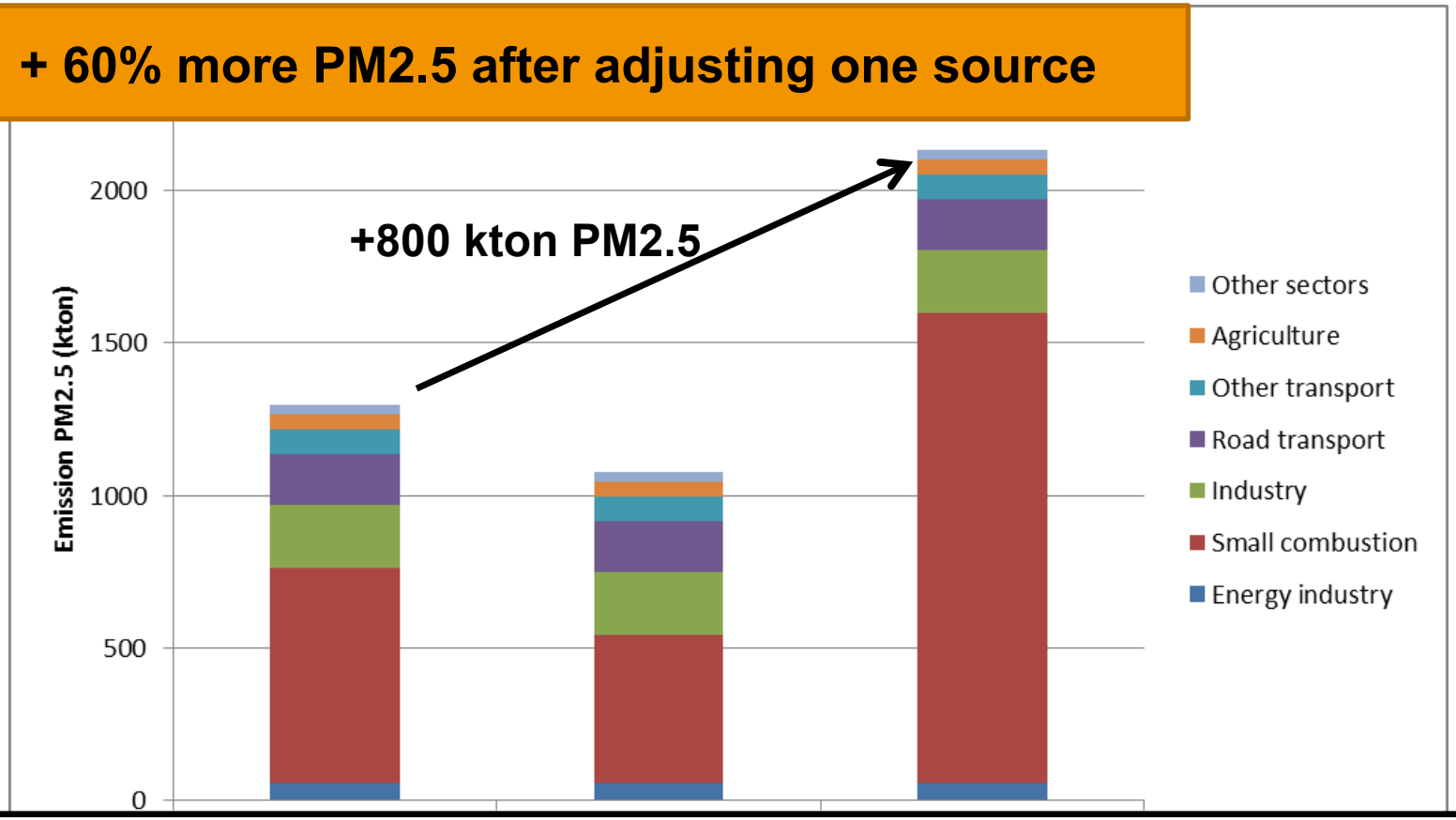




Denier van der Gon et al., ACP, 2015

IMPLICATIONS FOR EU-28 (2013)

+ 60% more PM2.5 after adjusting one source



This is a major impact and needs further investigation and verification!

Research is needed both at

- **the emissions side** (PM condensable by source type, better activity and appliance types information and emission factors)
- **the model side** (PM, NMVOC, SVOC, IVOC and volatility base set approach)

EMISSION TIMING!

- Models need spatial and temporal explicit emissions.
- Impact of temporal variation is underestimated and undervalued.
- Fixed (no year to year variation) default temporal profiles are much better than no temporal profile but…….
- But, especially for episodes the timing of emission can be crucial…..
- Often debated – is it “emission” work or “model” work; - Answer: Both!

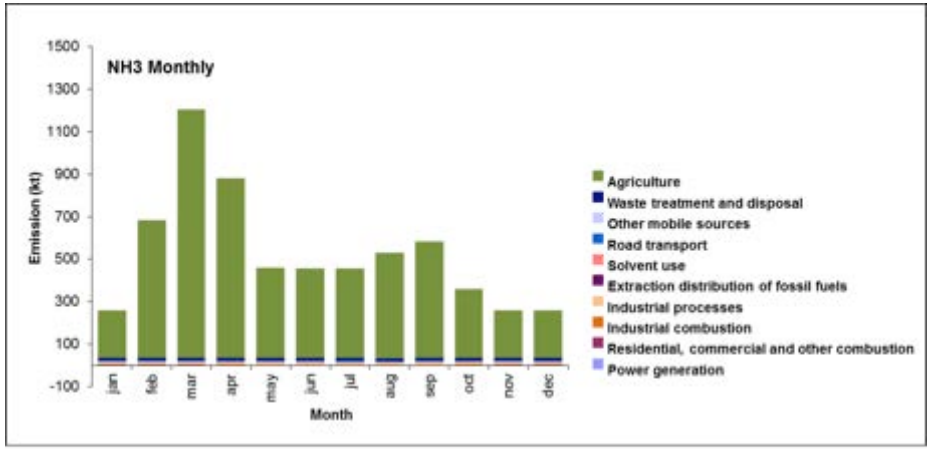
On going work, difficult to get funded and very suitable for collaboration and/or PhD projects because you can learn much about the system…

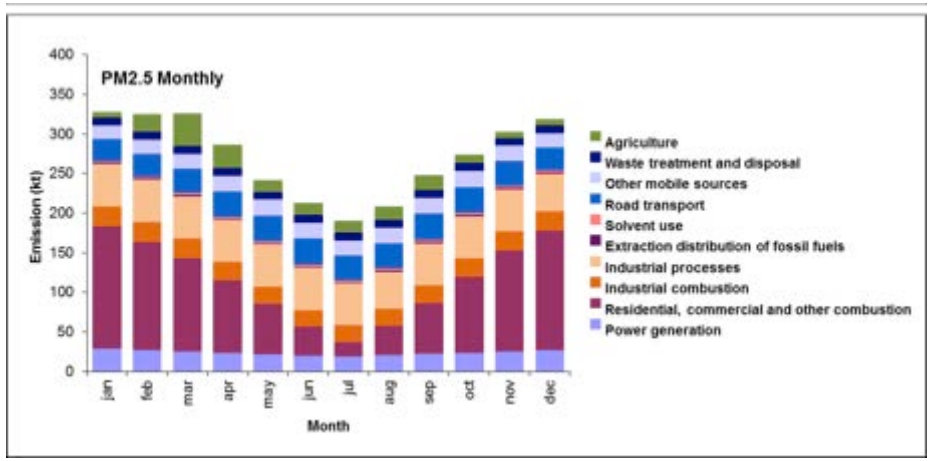
Most prominent examples

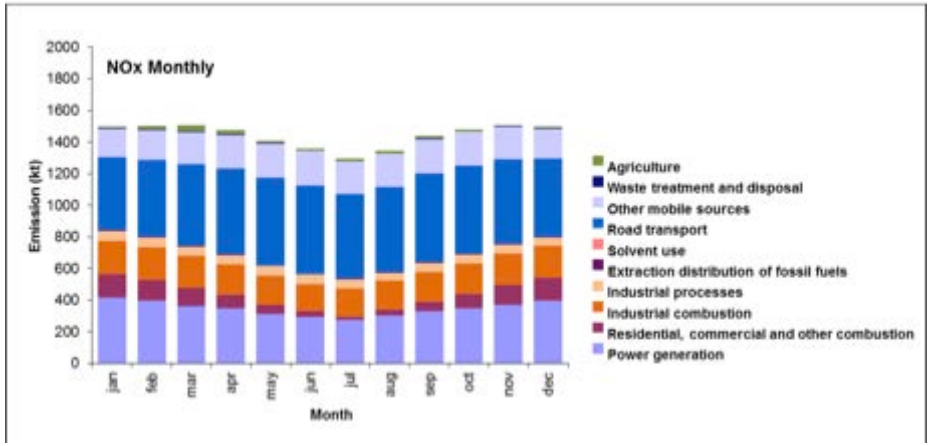
- NH3 volatilization after manure / fertilizer spreading)
- Timing of domestic heating
- Dependencies of traffic on weather conditions

EMISSION TIMING!

DEFAULT TEMPORAL PROFILES







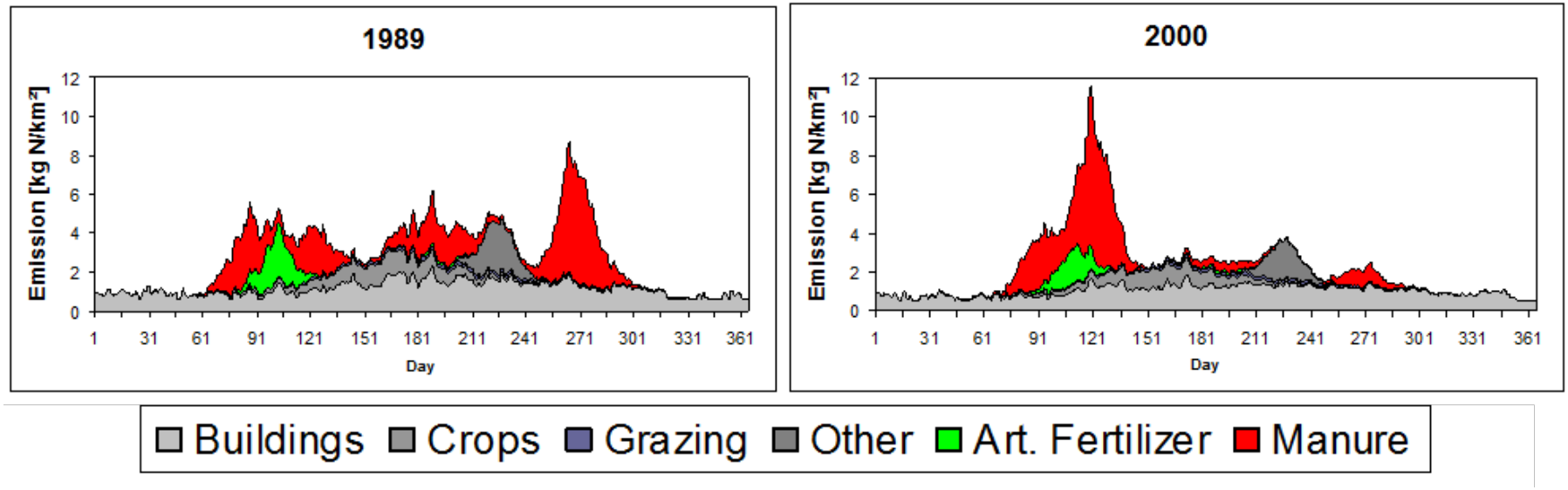
Much better than nothing but…..

- Same for all countries
- Same for all years

Known to be unrealistic

- Impact of improvements on annual average modelled concentrations in general limited

HOURLY AMMONIA EMISSIONS AS A FUNCTION OF TIME FOR 1989 AND 2000 IN DENMARK (SKJØTH ET AL., 2008).

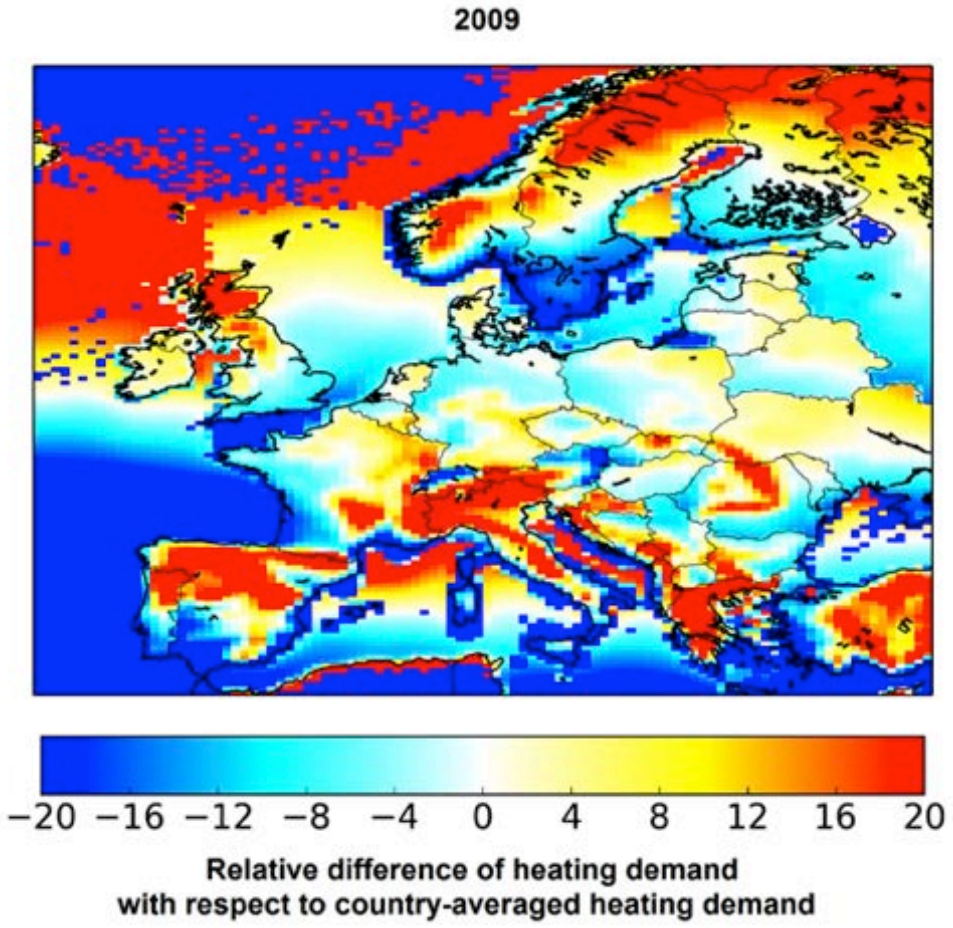


A large shift in emission timing during the year is observed due to a change in the regulation in Denmark and the subsequent change in the agricultural practice

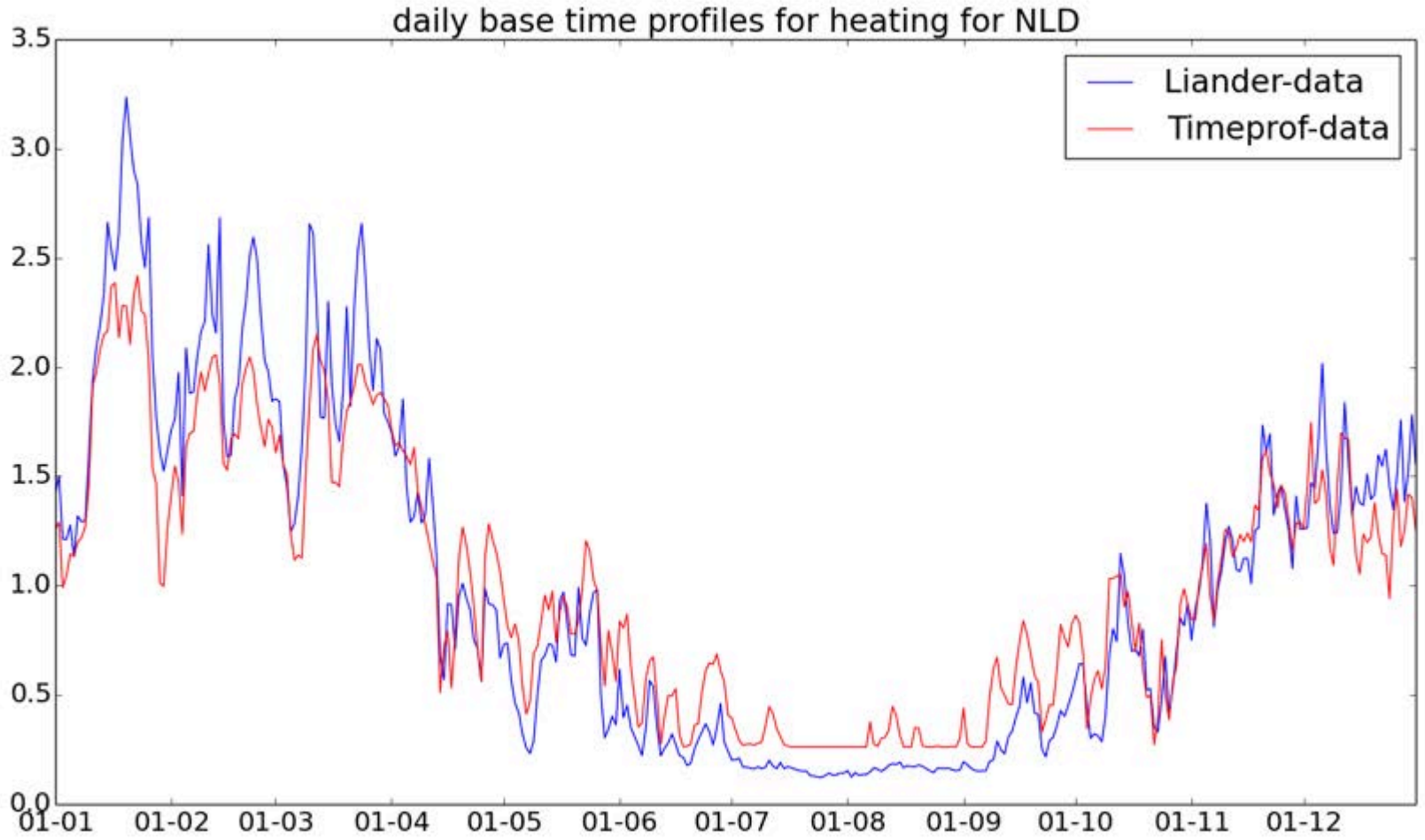
- We know how to implement but several “complications”
- In the model? In the emission database?

RESIDENTIAL COMBUSTION EMISISON TIMING

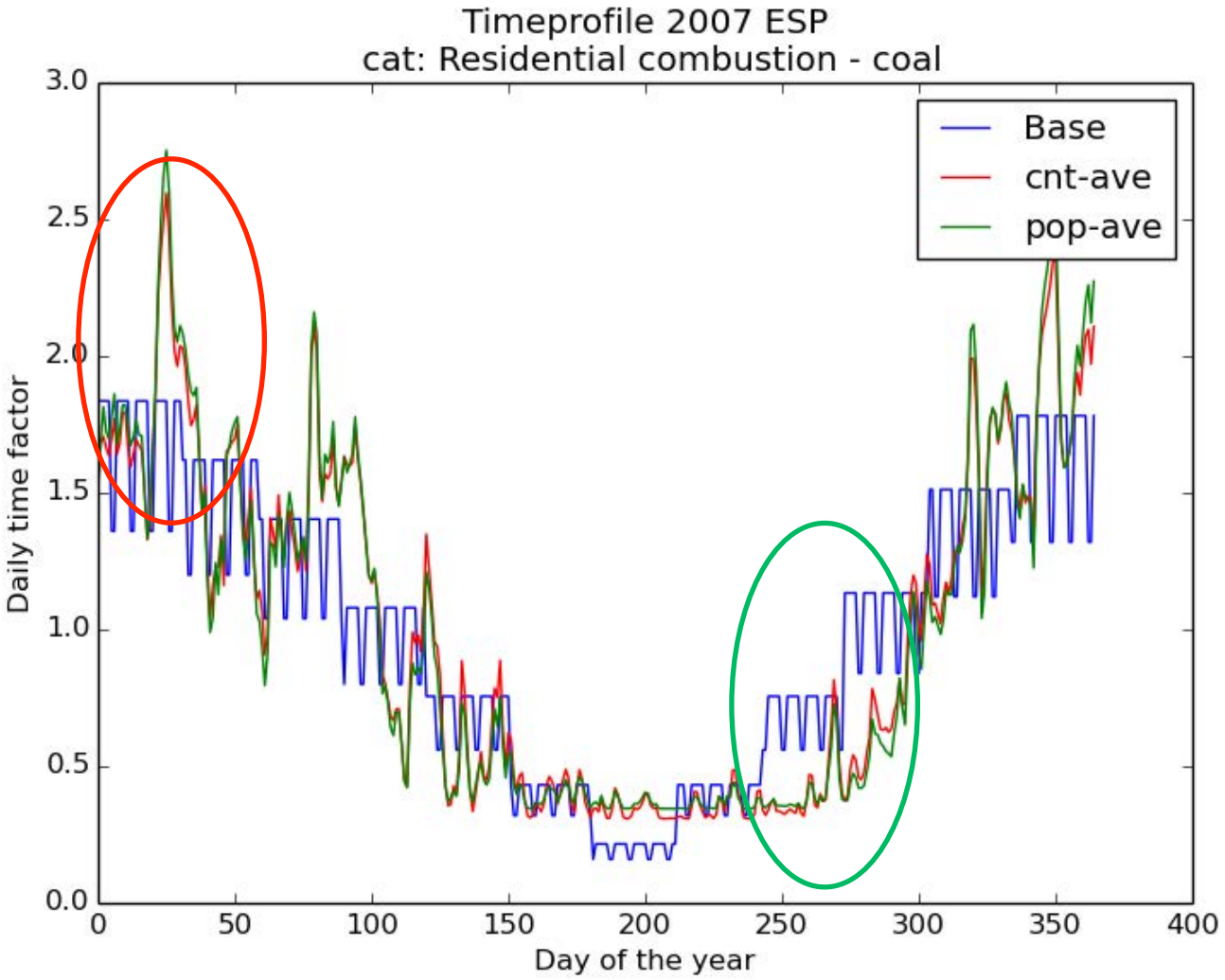
- Heating is related to outside tempera
  purposes)
- The default profile takes seasonal cl
- Changes between years can be larg
  like March, April, October, Novembe
- An alternative approach is to make t
  actual temperature using a “degree
- A 2nd refinement is to do this on a gr
  gradients within the country (e.g. No



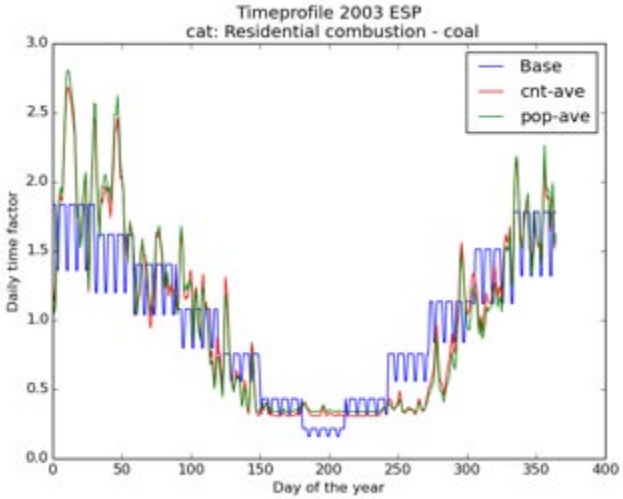
TESTING THE APPROACH USING REAL DEMAND DATA

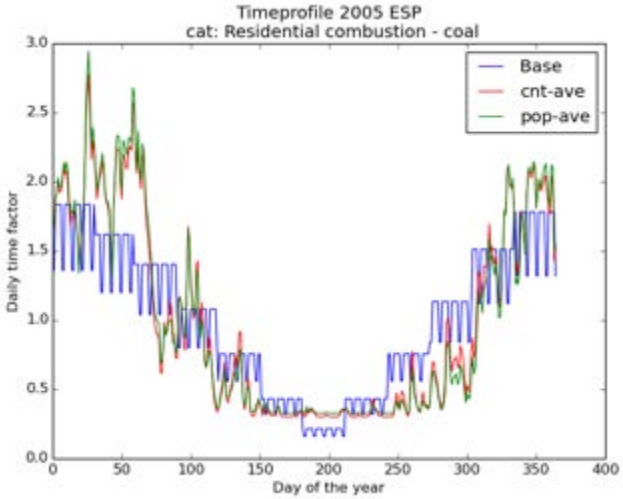


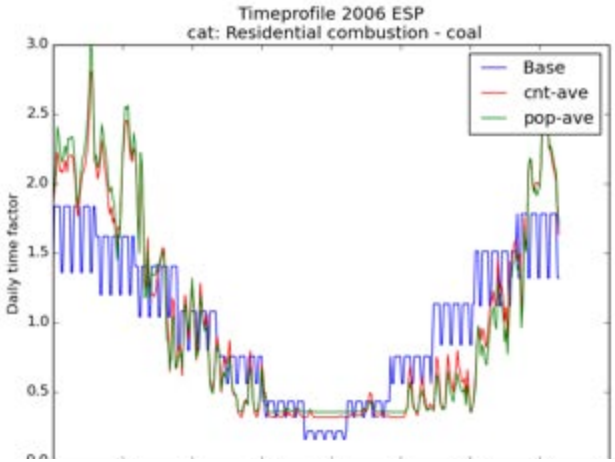
APPLICATION EXAMPLE – SPAIN.

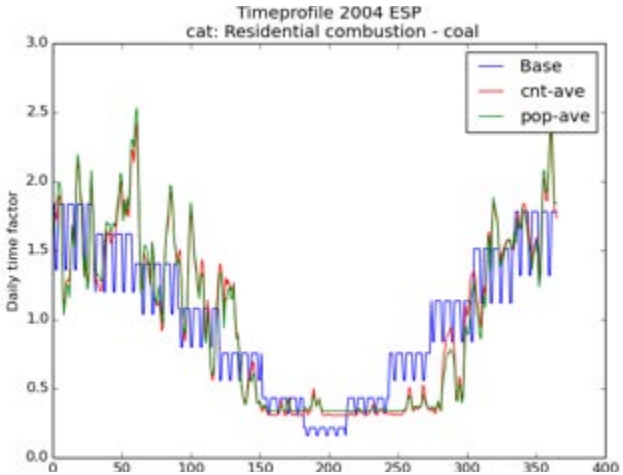


APPLICATION EXAMPLE - SPAIN







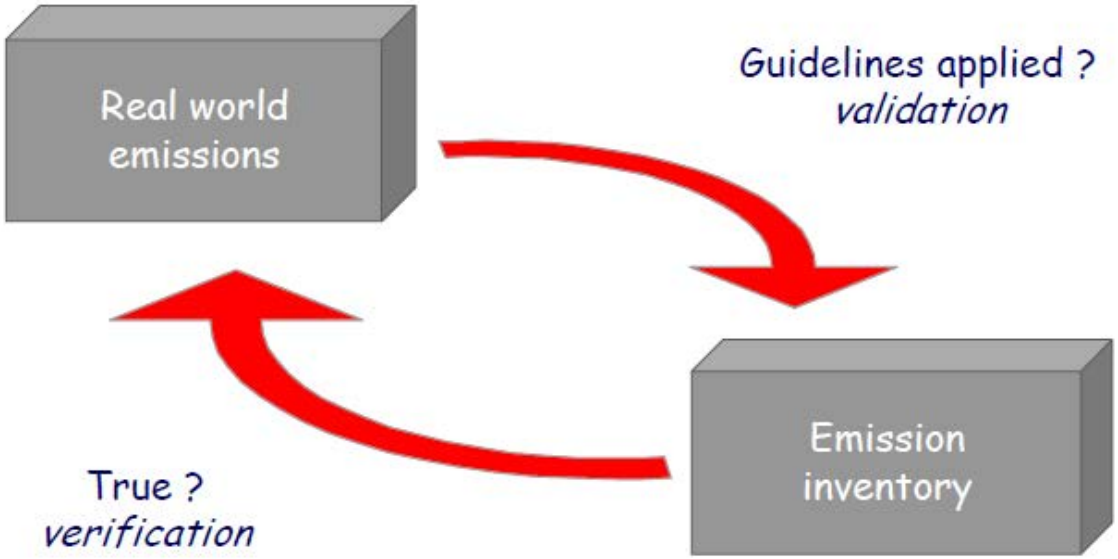


- Degree day approach supports general pattern of default profile
- Episodes can be dramatically different

TO SUMMARIZE….

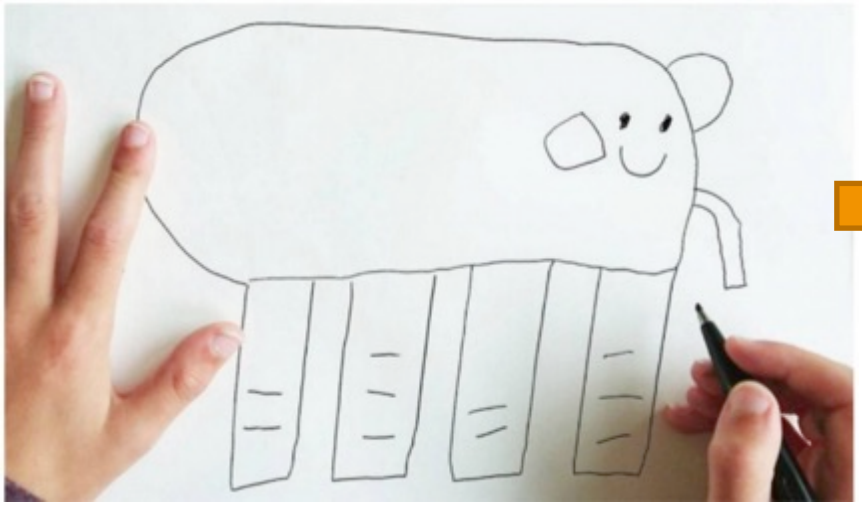
- **Good emission data are crucial**
- Significant room for improvement for every substance but not the same!
- Cooperation model– emission experts can highly beneficial
- Latest year 2011 but updates expected in 2017 (depending on acceptance of CAMS proposal)
- The TNO-MACC data have a country identifier and a SNAPcode in the grid; easy to make adjustments
- Easy to implement your own country data and use TNO-MACC to represent all other countries
- **If you do…. we are interested to learn about your national (gridded) data and you findings**

VALIDATION AND VERIFICATION



- ***Validation*** *checks whether or not the guidelines have been applied, whereas* ***Verification*** *checks whether the data are true*.

A MODEL IS A MODEL….



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To Summarize:

Yes!
Emissions can be fun science!

Thank you for your attention

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Hugo.deniervandergon@tno.nl