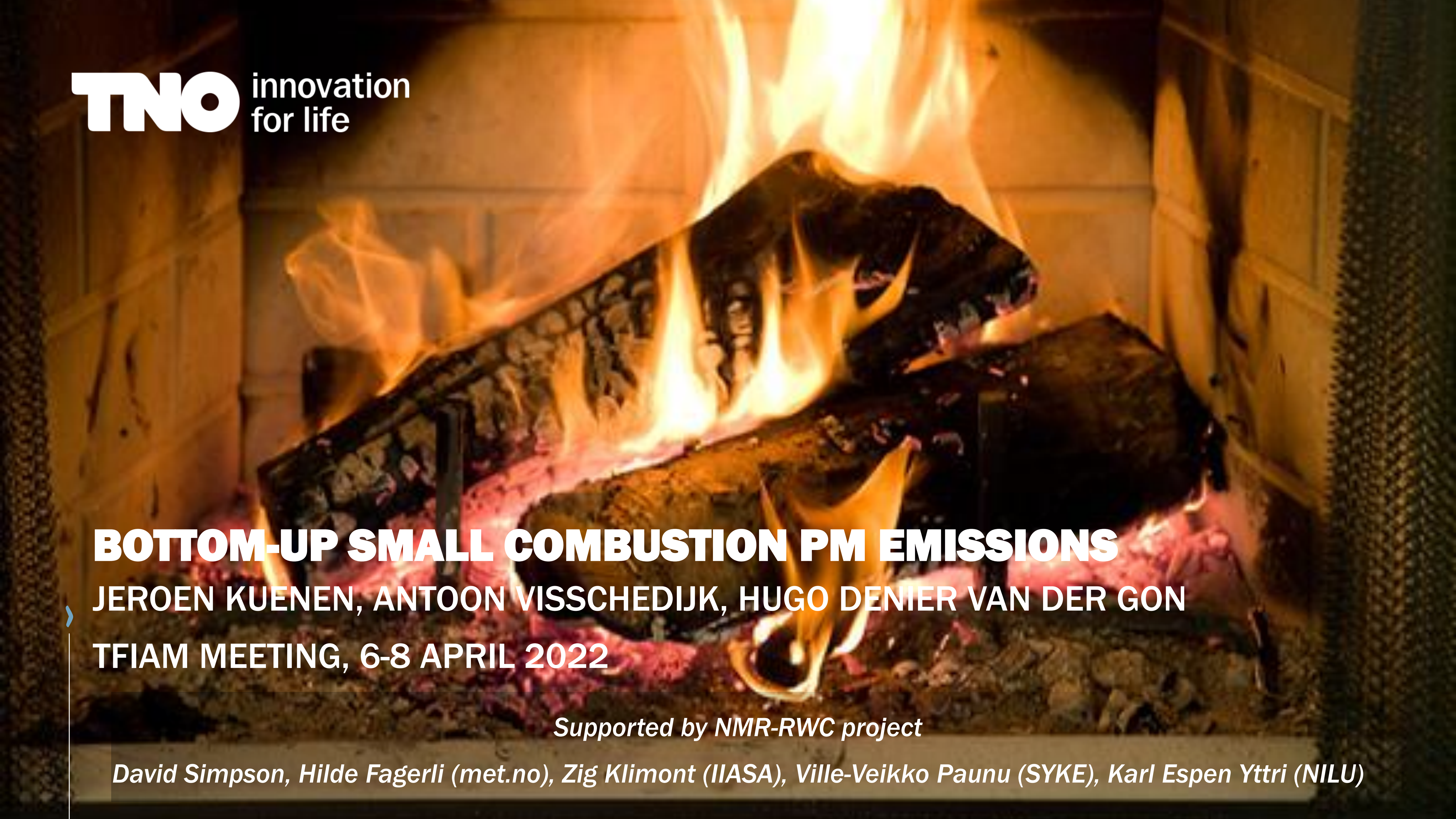

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BOTTOM-UP SMALL COMBUSTION PM EMISSIONS

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David Simpson, Hilde Fagerli (met.no), Zig Klimont (IIASA), Ville-Veikko Paunu (SYKE), Karl Espen Yttri (NILU)

OUTLINE

- Short introduction and history
- Approach for the updated Ref2 inventory
  - Activity data
  - Appliance types and technologies
  - Emission factors
- Preliminary results
- Specific questions / discussion points

INTRODUCTION
WHAT ARE CONDENSABLES?

- FPM = Filterable Particulate Matter
- CPM = Condensable Particulate Matter
- TPM (Total Particulate Matter) is the sum of the two

Component	**C* (at T=298 K)**	Description
VOC	C* >3.2x10^{6} µg m^{-3}	Primary VOCs from fuel combustion, evaporation, vegetation
SVOC	0.32 µg m^{-3} < C* < 320 µg m^{-3}	Semi-volatile compounds, partition significantly between gas and aerosol phase
IVOC	320 µg m^{-3} < C* < 3.2x10^{6} µg m^{-3}	Mixture of organics contributed by both primary emissions and photochemical oxidation of gas-phase organics

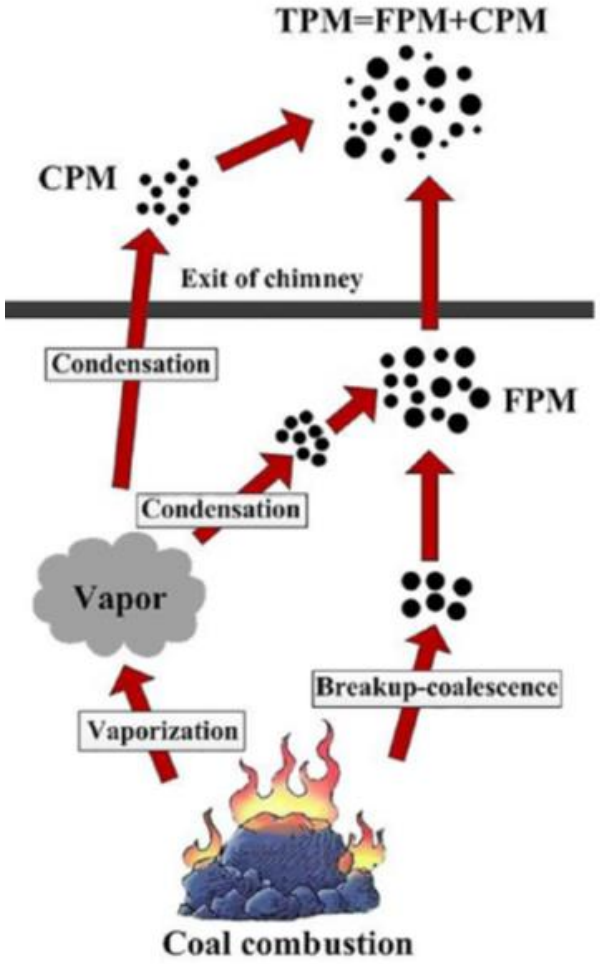

Fig. 1. Particle formation from coal combustion.

CPM consists essentially of primary SVOC and IVOC and occurs from organic matter being volatilised by heat and subsequently only partly combusted

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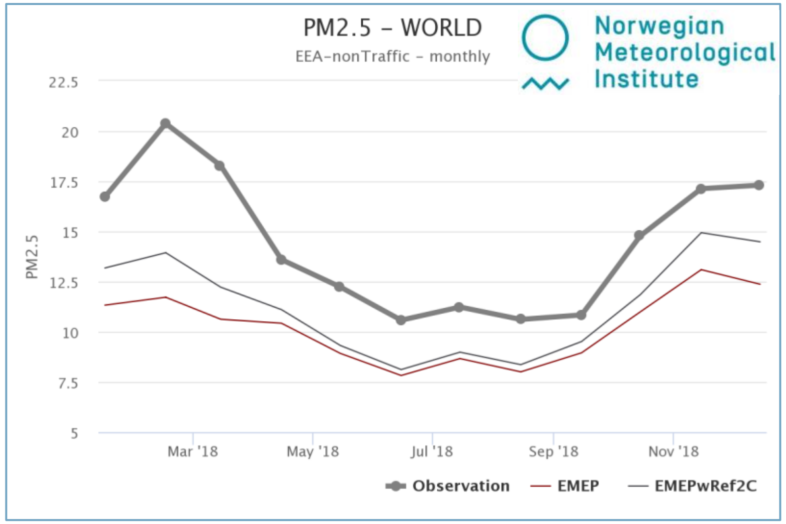
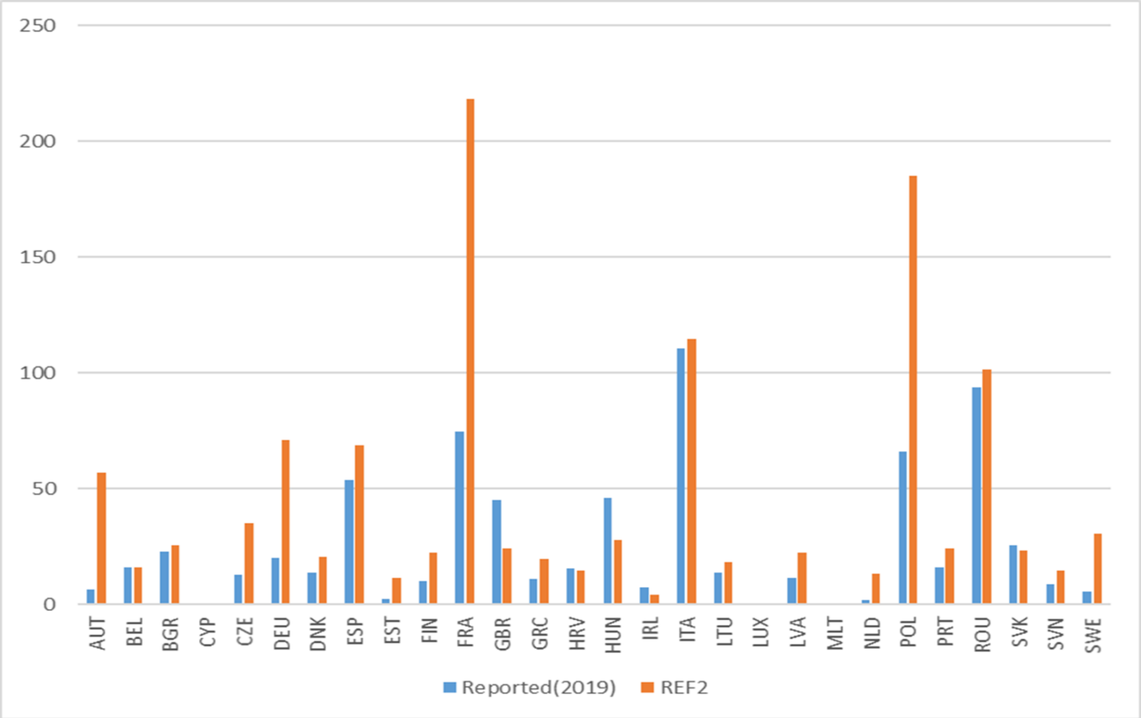
PROBLEMS IN CURRENT INVENTORIES
RATIONALE FOR DEVELOPING REF2

- Condensable PM needs to be included in models that assess the (health) impacts of "real world" ambient PM *(this is what we are all exposed to!)*
- Current emission inventories (in Europe as well as in individual countries) are a mix of "different PM's" – dependent on measurement type or emission factor source, it may or may not include condensables
  - No agreed common standard for measuring PM emission factors in Europe, hence different countries adopted their own standards
  - Increasing recognition for the important role of condensables as part of ambient PM
  - Increasingly countries start to include condensables as part of their official emission inventory
- Necessary information is not always readily available, implementation takes time. Including condensables is not simply multiplying your emission inventory with a fixed factor but technology and cultural dependent
- Politically also sensitive, large changes PM2.5 emissions will affect the pathway to reach NEC/Gothenburg ceilings and impact the distribution of abatement efforts across countries

INTRODUCTION AND HISTORY

- First Ref2 inventory was set up for 2010 in 2016 to investigate potential role of condensables
  - Rather simple approach (see what it does to AQ modelling) – originally part of Copernicus policy (CAMS71) project
  - Using activity data (Eurostat), appliance type split (GAINS), emission factors [Denier van der Gon et al., ACP, 2015]
  - Leads to better results (bias between model and measurements reduced) at overall European level (but not necessarily in each country)





- Some smaller updates after this

NMR PROJECT
APPROACH AND PREPARATORY WORK

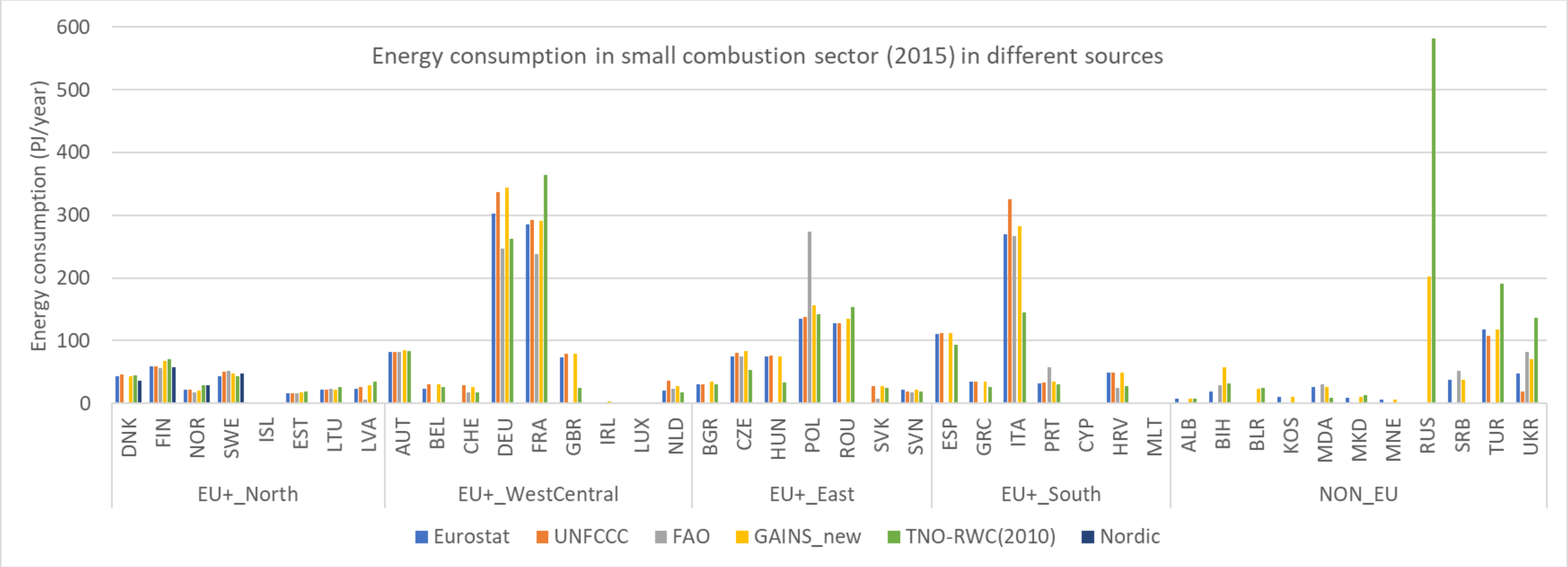
- Goal: Improve reliability of data for integrated assessment within the LRTAP Convention and EU Air Quality assessments – with focus on residential wood combustion
  - Updated emission inventories for 2005-2018/19 (Ref2)
  - Evaluation/improvement of emissions by comparison to other datasets, and of modelled results against observations
  - New model calculations of PM trends and SR matrices

- A full revision of the earlier Ref2 has been performed
  - Activity data
  - Emission factors (both with & without the condensable component to study this effect)
  - Appliance type splits, abatement shares and efficiencies (largely based on GAINS)
  - Developing different scenarios

- **Aim to produce best possible dataset based on currently available European-wide data sources and literature, but will remain uncertain!!**

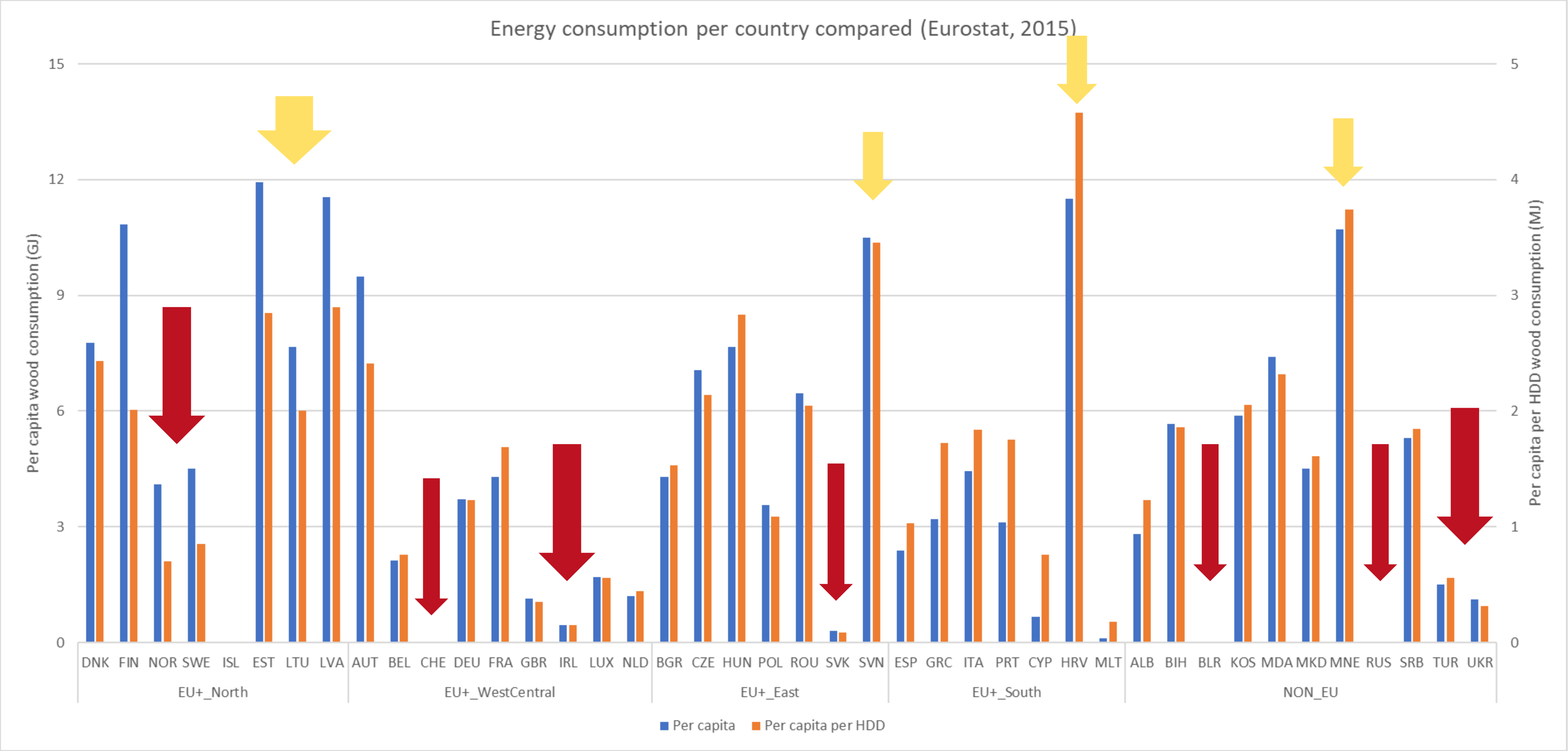
ACTIVITY DATA

- Wood consumption not always well represented in statistics
  - Especially in rural areas, people harvest directly from forests for their own use; these numbers do not always end up in the statistics
  - Assessment of official wood consumption figures needed before use incl. comparison of different sources



WOOD CONSUMPTION PER COUNTRY

ANALYSIS OF WOOD USE



Wood use & population from Eurostat; HDD is country average calculated with CTM LOTOS-EUROS

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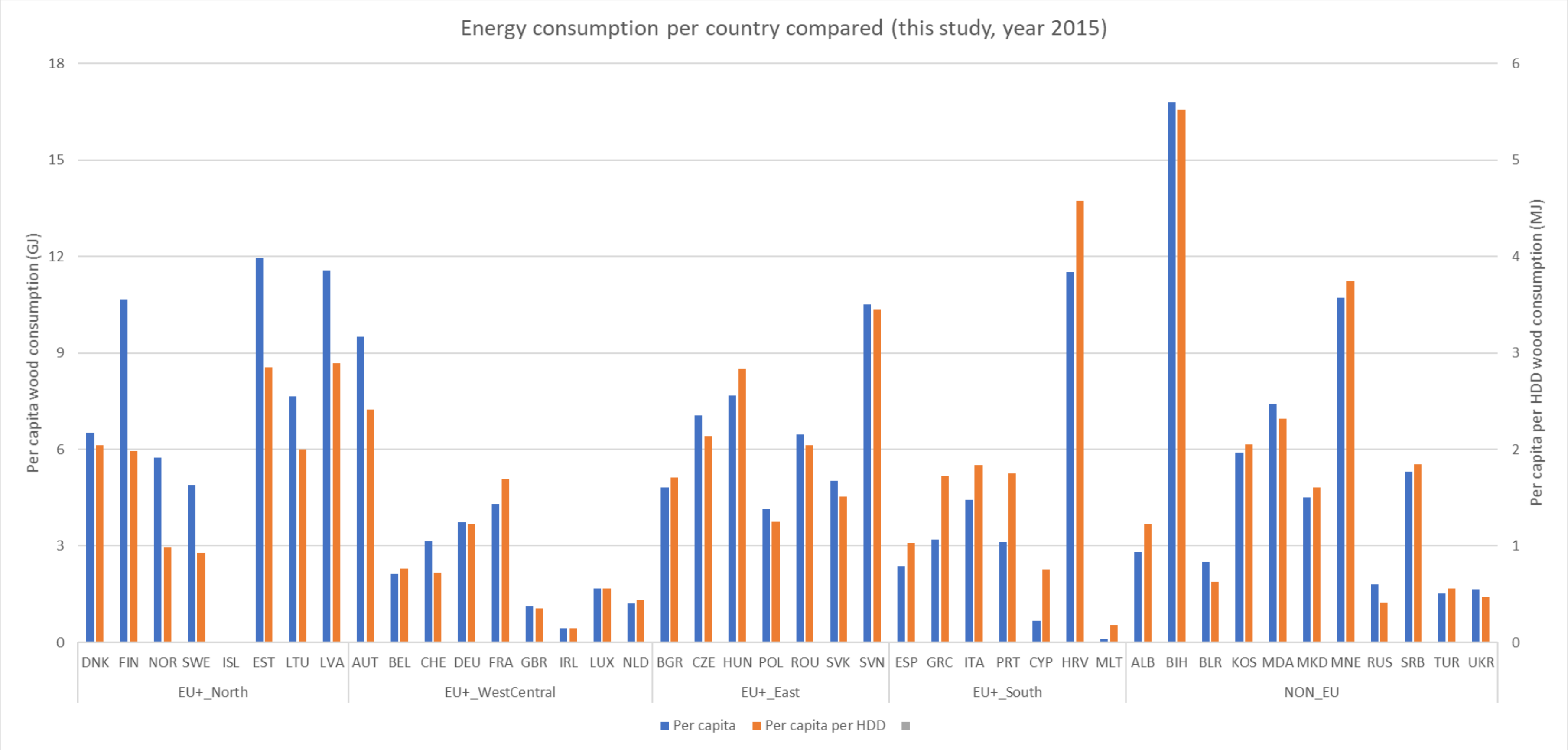
WOOD CONSUMPTION PER COUNTRY
ANALYSIS OF WOOD USE

- For selected countries Eurostat data were replaced with latest GAINS data for wood consumption
- Some further corrections made in specific countries to fix time series consistency
- Resulting energy consumption per country per HDD clearly shows that most of these apparent discrepancies remain – for many there could be good reasons while for others there may be under- (or over-) estimates



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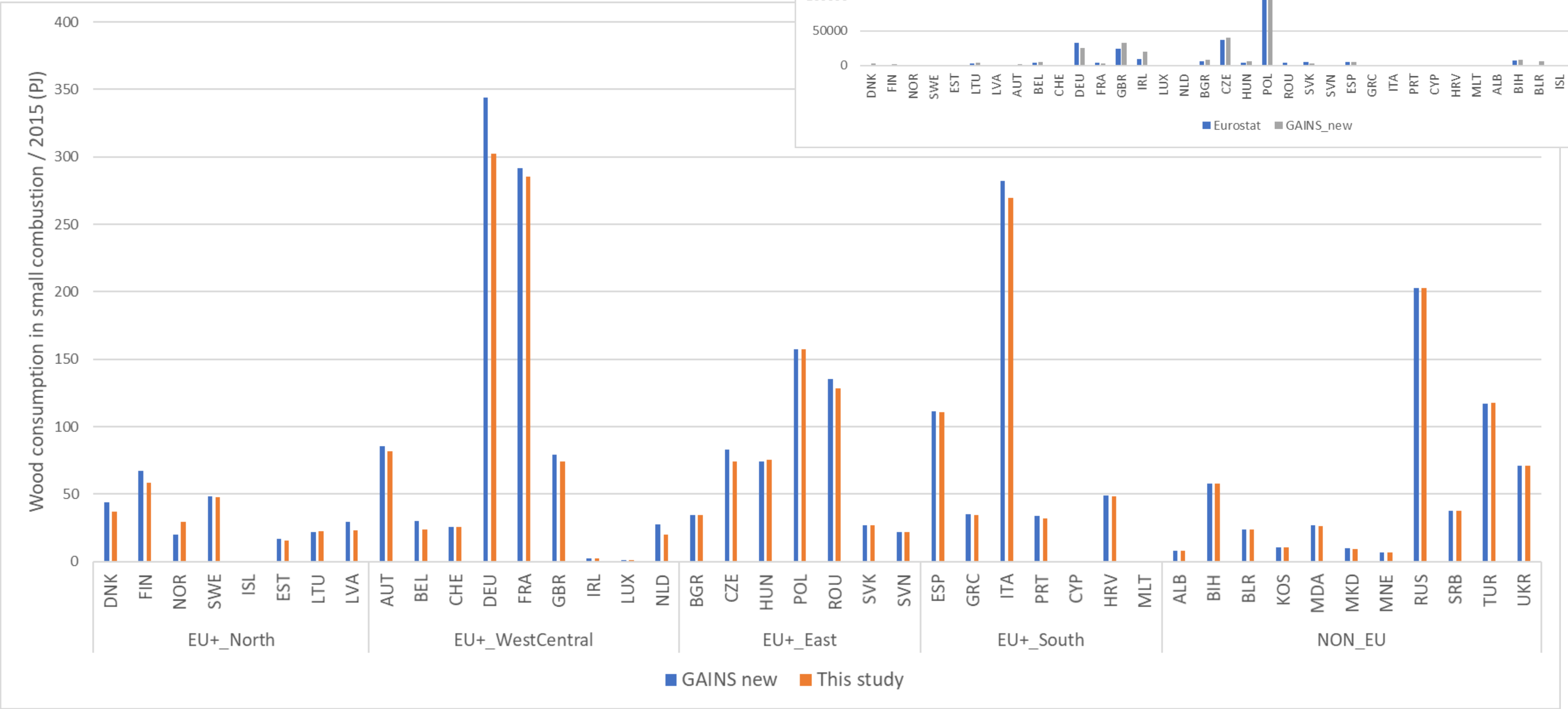
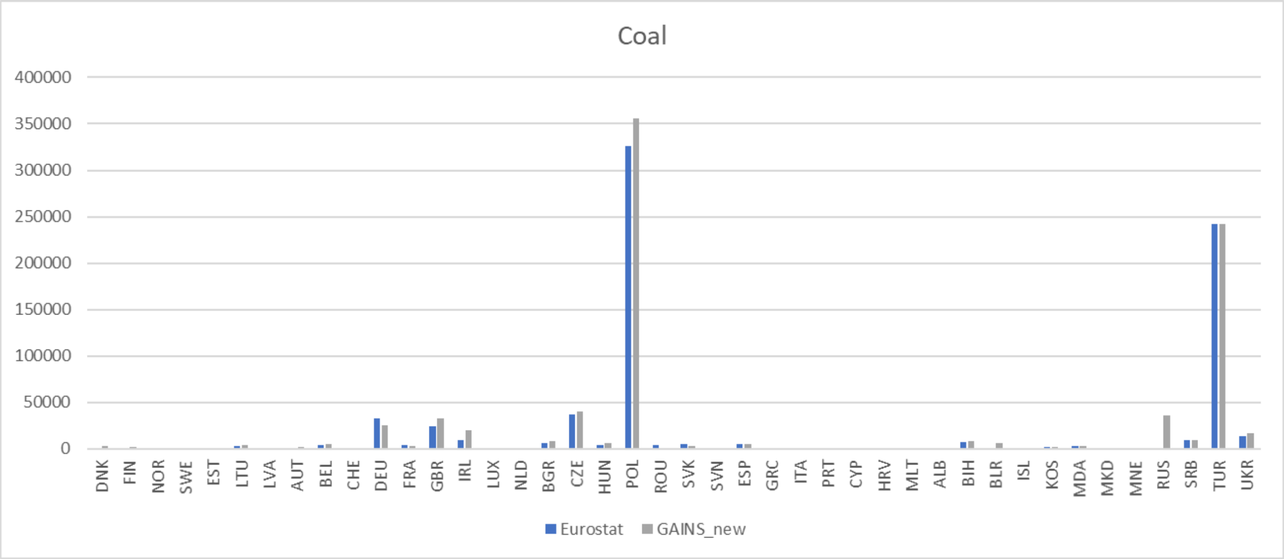
FUEL CONSUMPTION
DIFFERENCES WITH GAINS





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APPLIANCE TYPES

- Appliance type split taken from GAINS model
  - Reflects GAINS estimates including country-specific updates
  - Reviewed and updated in specific cases, e.g. France:

Year	ISO3	Sector	Fuel	Tech	Share
2015	FRA	Fireplace	Wood	Traditional	70%
2015	FRA	Fireplace	Wood	Improved	25%
2015	FRA	Fireplace	Wood	New	5%
2015	FRA	Small boiler	Wood	Improved	80%
2015	FRA	Small boiler	Wood	New	20%
2015	FRA	Small boiler	Hard coal	No control	90%
2015	FRA	Small boiler	Hard coal	New	10%
2015	FRA	Heating stove	Wood	No control	~~1%~~ 22%
2015	FRA	Heating stove	Wood	Improved	~~74%~~ 58%
2015	FRA	Heating stove	Wood	New	~~25%~~ 20%

What are "traditional", "improved" and "new"?

All traditional boilers replaced

All traditional stoves replaced?
~ 20% No control is lowest in Europe

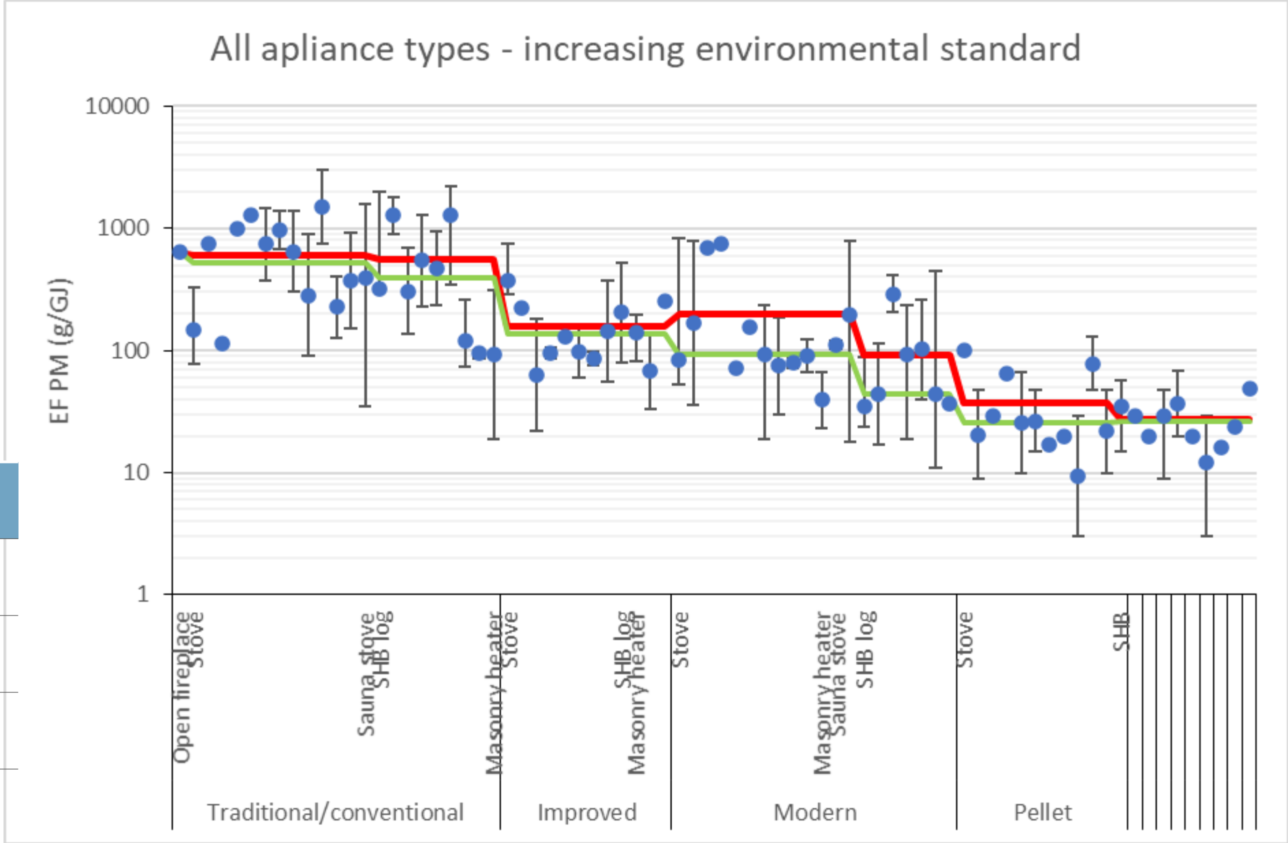
EMISSION FACTORS

- Coal – use assessment of emission factors used in GAINS model as this is only really important in a couple of countries
- For wood a new set of emission factors was developed
- Literature values put together, median value taken

- Improved/new fireplaces treated as improved/new stoves (no data)
- Improved & new are not well-defined, so need to choose emission factors to span the range

PM2.5 emission factors (g/GJ) for wood

Technology	Heating stove	Small boiler
Traditional	519	395
Improved	192	158
Modern	103	79
Pellet	26	35
Pellet + ESP	4	4



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SCENARIOS

- Goal of these scenarios is to allow the modelling study to see which would compare best to measurements (perhaps also country dependent), which might be useful to further refine emissions

- Three scenarios defined

1. Use of emission factors directly, with “ideal” conditions (full load, dry wood)
2. Use for “typical” conditions (taking into “bad combustion”, explained in next slide): this is considered the most representative for real-world; the (default) Ref2 scenario
3. Use of higher emission factors (back to literature survey: median of top-5 EFs [or top-3 if <10 sources])), in this scenario also the “typical” conditions are taken into account

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BURNING CONDITIONS ("BAD COMBUSTION")

- Wood burning will not always follow best practice, especially when applied in small installations and with less-experienced users
- Literature shows that the impact of using wood that is not completely dried, or partially loading of the combustion chamber may have a large impact on the emissions
  - Especially for newer technologies, bad combustion practices may bring emission levels back to uncontrolled
- Assessment of different literature sources for amounts of wet wood/part load was made
- Impact on emission factors: up to ~80% higher for non-traditional stoves, for boilers lower impact
- The additional emissions are considered all to be condensables

Appliance	Assumptions
Fireplaces	15% wet wood, 25% part load (only for new/improved)
Single house boilers	15% wet wood, 10% part load
Stoves	15% wet wood, 25% part load

Table 19: Example calculation of emission factors (EF, mg/MJ) including bad combustion conditions where it is assumed that 70% is combusted under normal conditions (N:S), 5% use moist fuel and 25% is fired at part load

Traditional log wood boilers	EF N:S mg/MJ	ratio M/S Moist fuel / Standard fuel	ratio P/N Part load / Nominal load	Emission factors, including "bad combustion" according to example assumptions
$PM_{2.5}$	320	1.5	4	568
EC	25	1.5	1	26
OC	120	1.5	4	213
CH_4	75	1.5	3	114
NMVOC	470	1.5	3	717
CO	3270	1.5	2	4169

Investigation of real life operation of biomass room heating appliances – Results of a European survey

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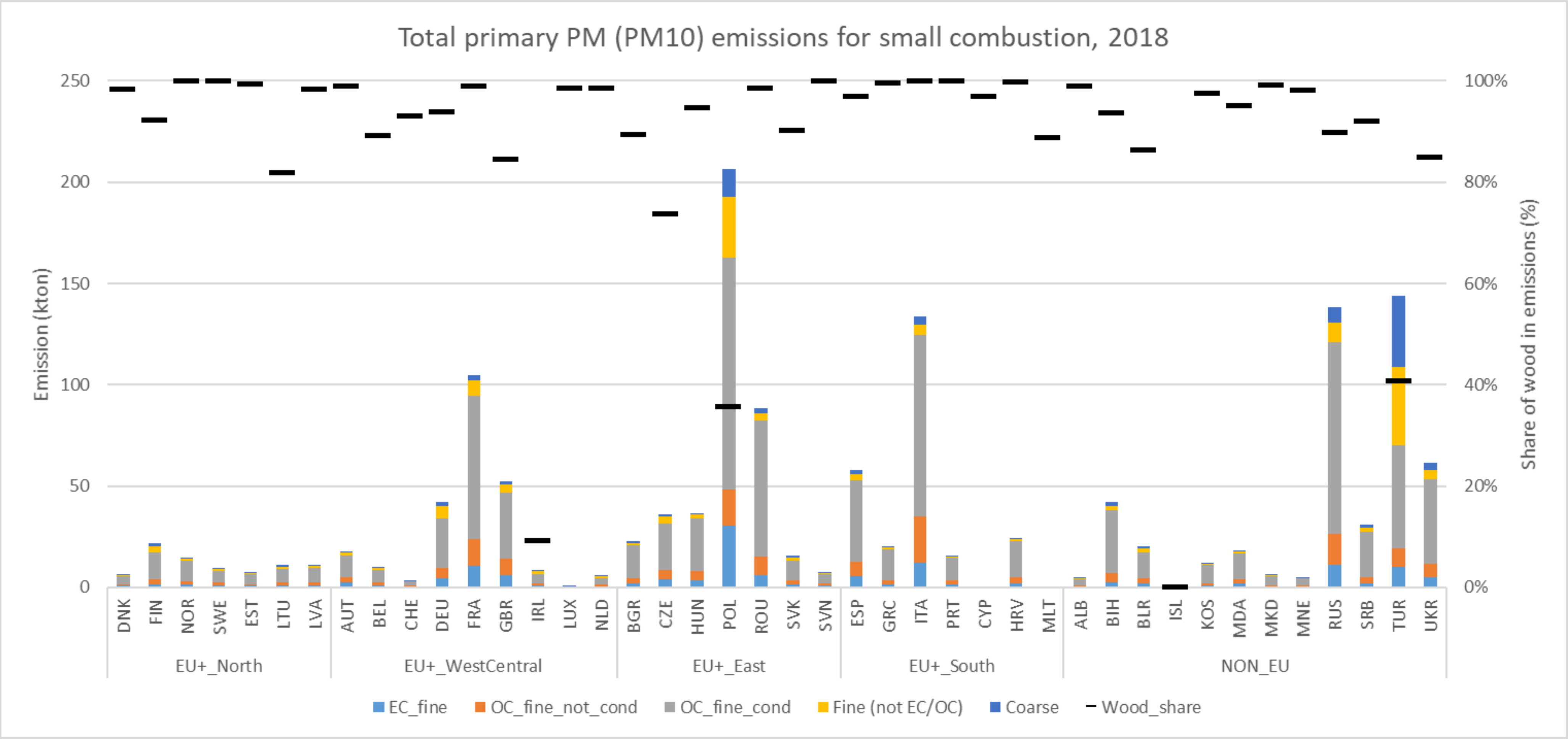
PRELIMINARY RESULTS
TYPICAL SCENARIO



- More non-carbonaceous material with higher non-biomass share (mostly coal)
- Organic carbon split in filterable & condensable component

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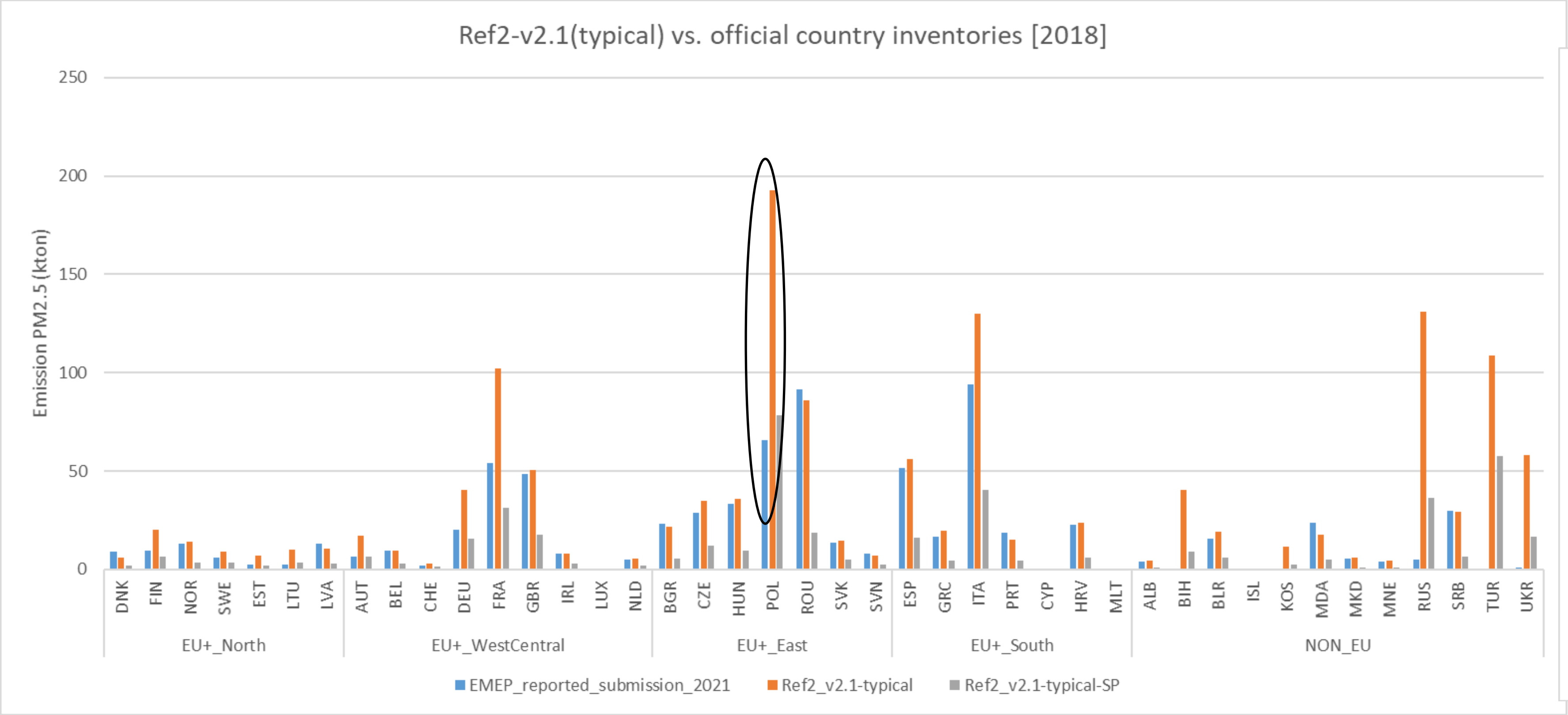
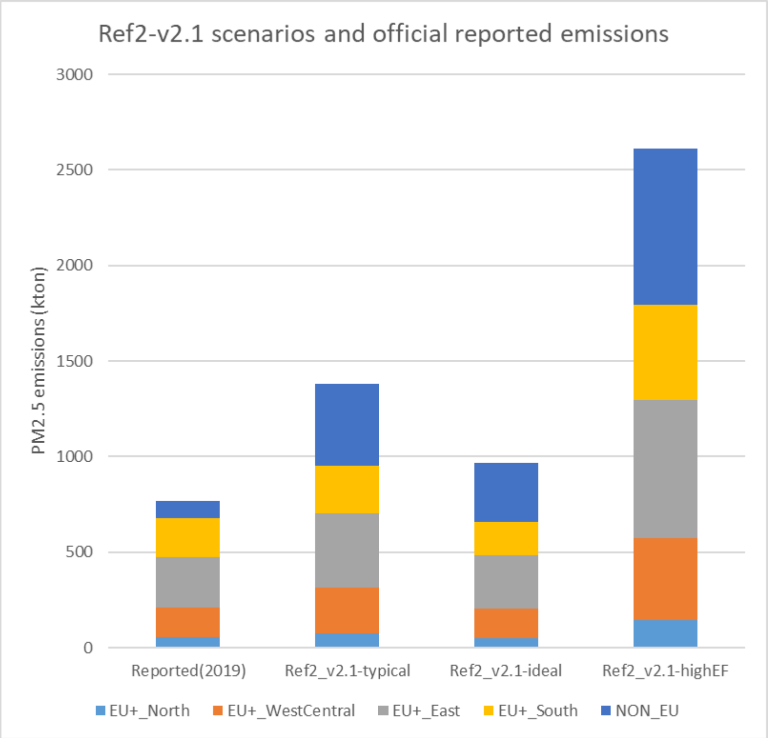
PRELIMINARY RESULTS
SCENARIOS AND COMPARISON TO OFFICIAL INVENTORIES





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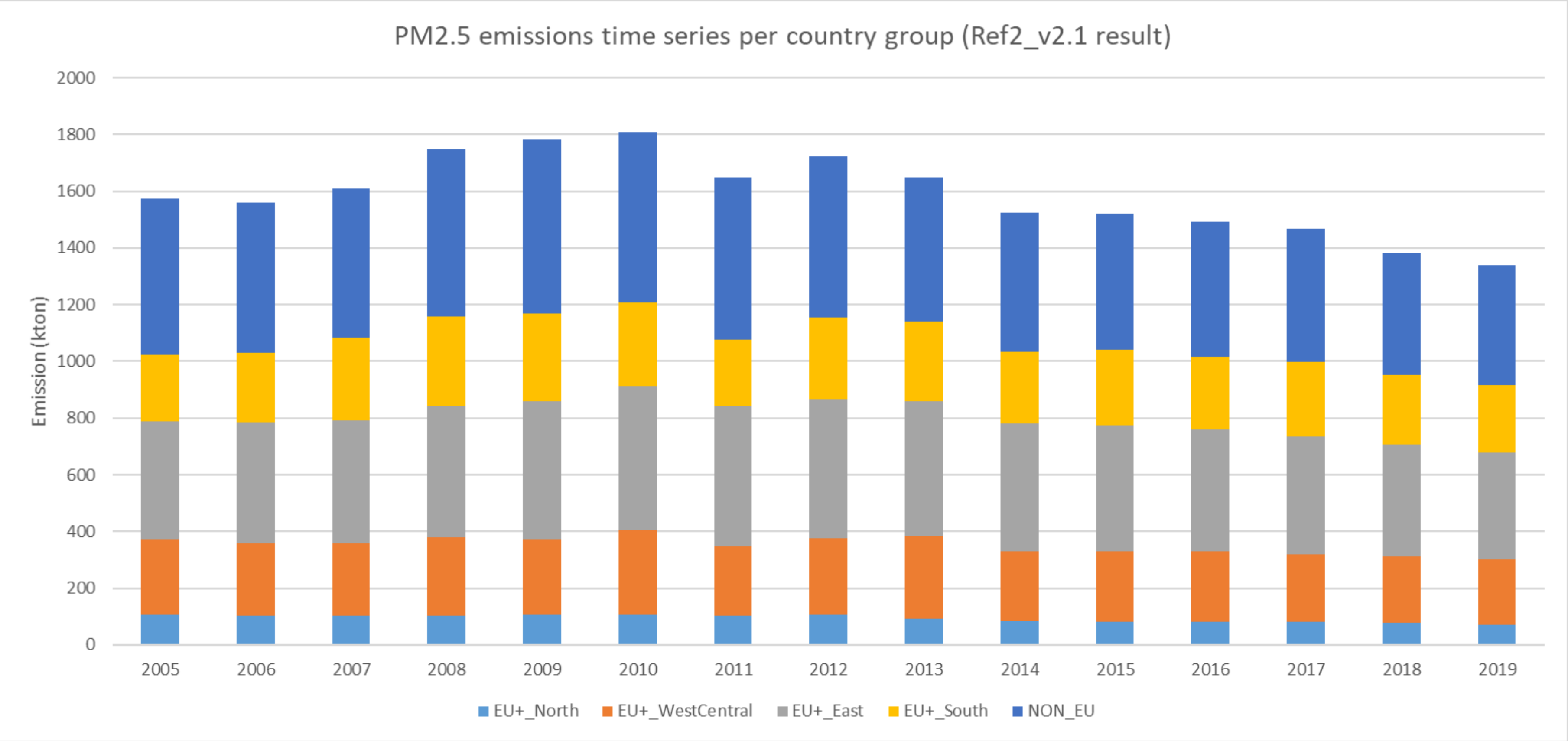
PRELIMINARY RESULTS
TYPICAL SCENARIO - TREND



Emission trend per year	2005-2019	2010-2019
EU+_North	-2.3%	-3.6%
EU+_WestCentral	-1.0%	-2.5%
EU+_East	-0.6%	-2.9%
EU+_South	0.1%	-2.1%
NON-EU	-1.7%	-3.3%
Average	**-1.1%**	**-2.9%**

Reported emission trend per year	2005-2019	2010-2019
EU+_North	-2.7%	-3.9%
EU+_WestCentral	-2.1%	-3.1%
EU+_East	-0.5%	-2.3%
EU+_South	0.2%	-1.8%
NON-EU		
Average	**-1.0%**	**-2.5%**

(based on submission 2021)

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CONCLUSIONS

- Condensables is an important topic for PM2.5, and it is important to account for condensables when assessing the impact of PM2.5 pollution => here focus on small combustion sector (but other sectors may be relevant!)
- Literature emission factors are very variable (ranging over an order of magnitude is not uncommon)
  - Related in part to local circumstances (fuel quality, burning conditions)
- "Bad combustion" effect has a large impact on the emission factors (typical scenario ~ 40% higher compared to ideal case)
- Comparison to countries shows a very diverse picture, in part related to the inclusion of condensables in the country inventories but also activity data/emission factors used
- Trend shows an increase in emissions until ~ 2010, with decreasing emissions afterwards
  - Trend in reported emissions is larger in North & West EU, but overall not very different for EU+ as a whole – but at country level this may be different
- Updated emissions finalised just now, modelling simulations ongoing (D. Simpson, next talk!)
- Results will be used to inform the Gothenburg Protocol review discussions but also to learn more about the issue itself
- However… large ambition to resolve this, but this NMR-RWC project has limited effort & limited budget
  - Progress is there, but significant uncertainties remain and much more improvements can be made…

THANK YOU FOR YOUR TIME

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