

Implications of scenarios for the Gothenburg Protocol Revision on urban air quality in Europe and EECCA

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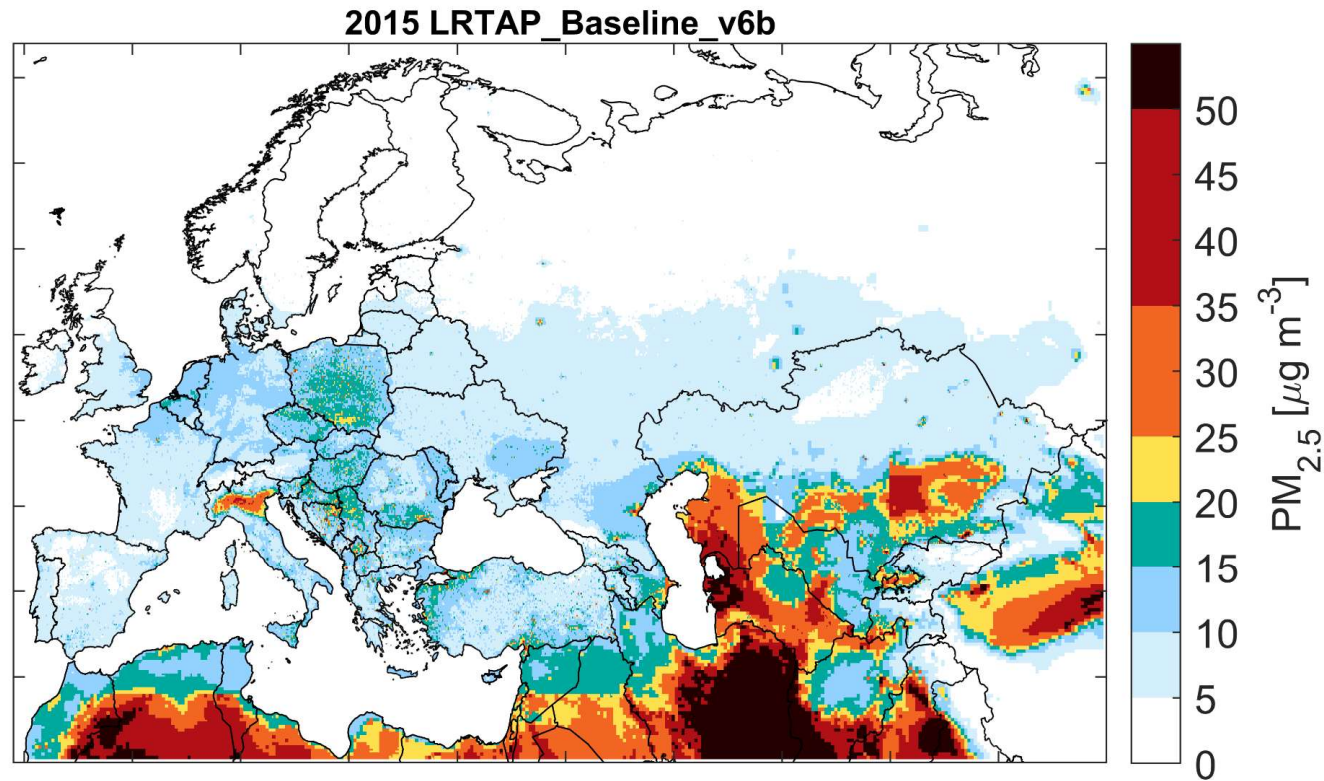
EPCAC Meeting 18 Nov 2025

Part 1: PM_{2.5}

Results from GAINS model simulations for the Gothenburg Protocol Revision

PM_{2.5} : 2015

Total PM_{2.5} incl. natural dust

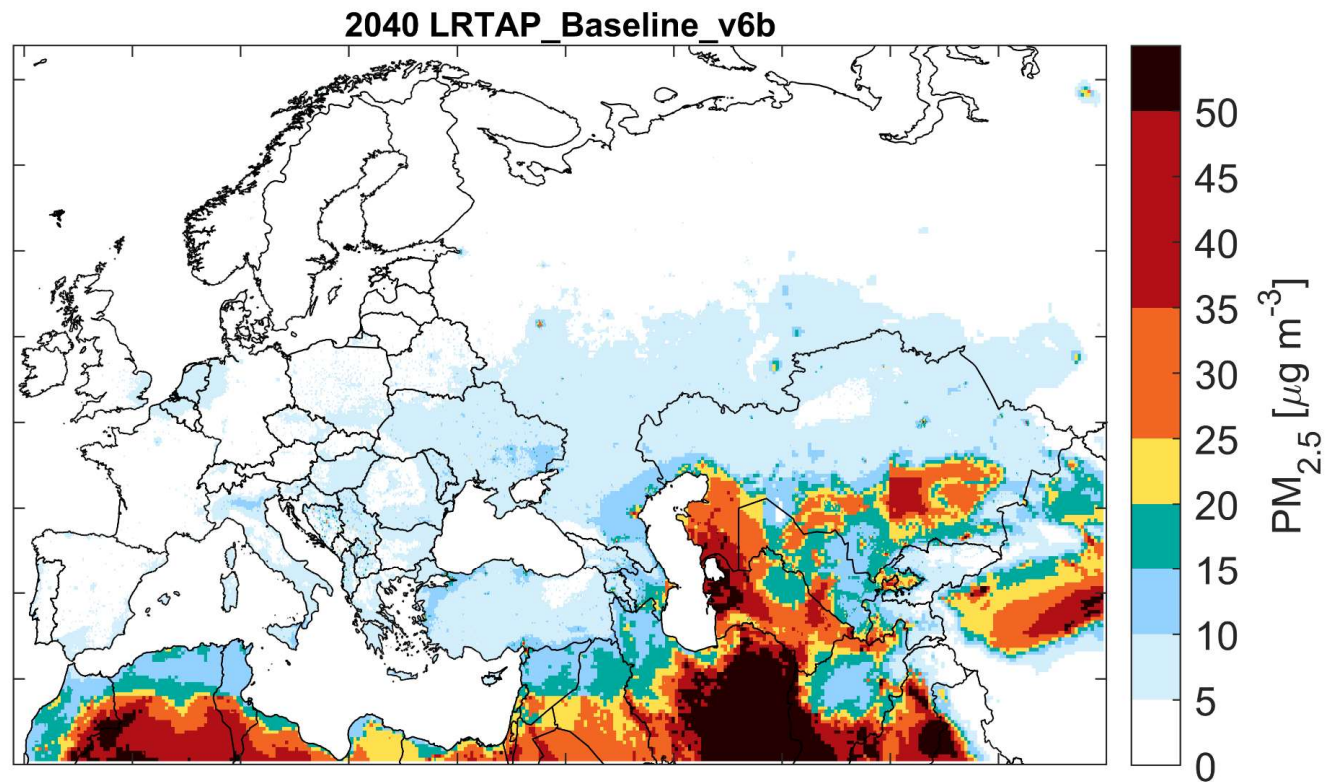


Method: GAINS transfer coefficients (pollutant, sector spec.) at $0.3^\circ \times 0.2^\circ$ (SIA) / $0.1^\circ \times 0.1^\circ$ (PPM) (linear approx. to EMEP CTM) + downscaling to 250m (PPM) emulating the uEMEP model.

Source: CIAM/IIASA - GAINS model

PM_{2.5} : 2040 CLE

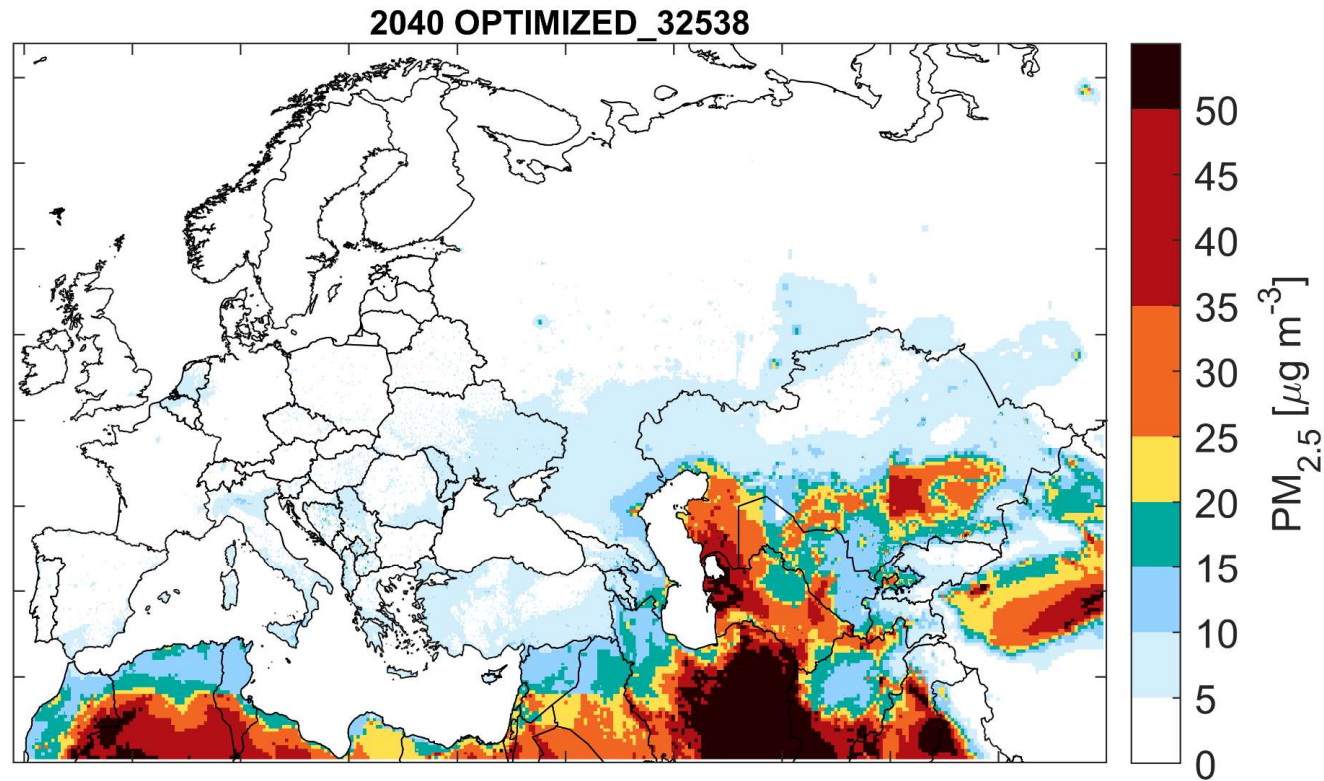
Total PM_{2.5} incl. natural dust



Scenario following Current legislation in 2040. Substantial reductions.

PM_{2.5} : 2040 OPT (central case)

Total PM_{2.5} incl. natural dust

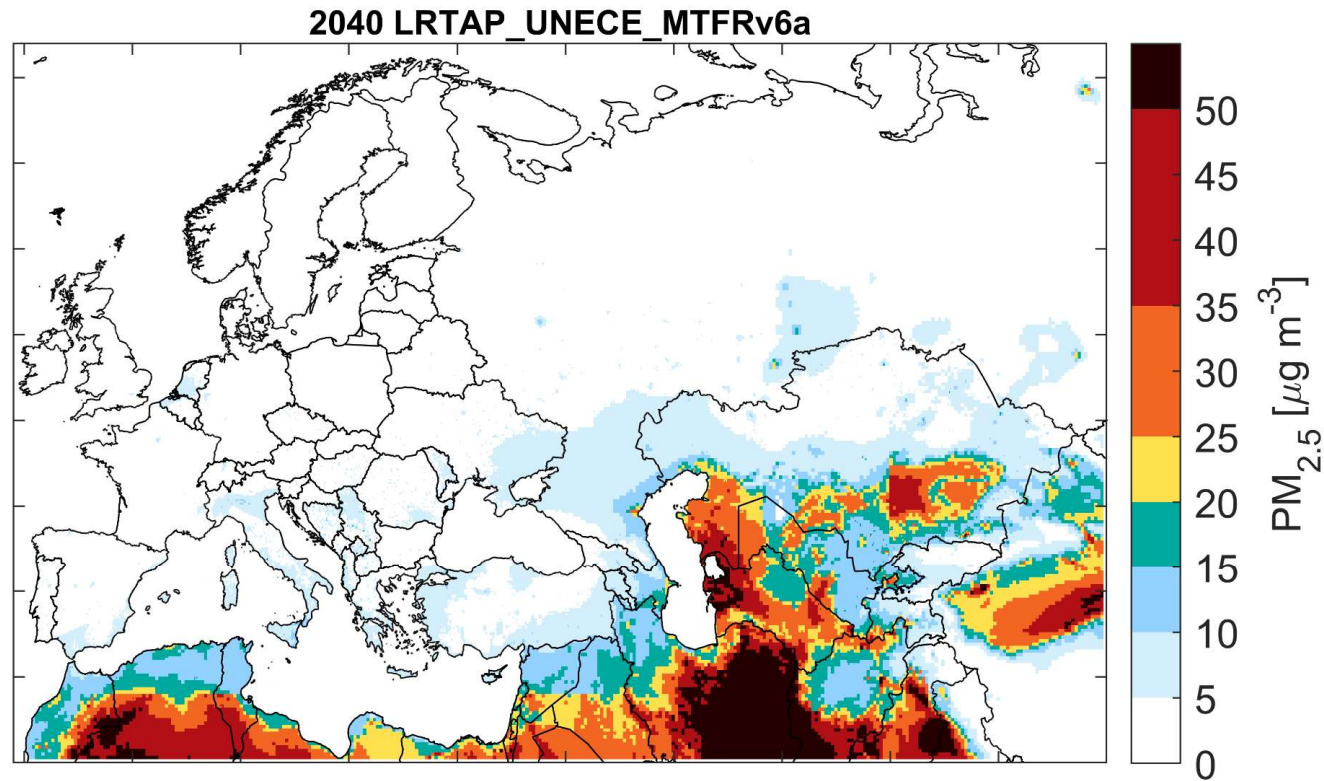


Cost-optimal solution for combined -50% health (mortality from PM_{2.5}) and ecosystem (AAE of CLempN) risks in total UNECE-Europe, compared to 2015.

Source: CIAM/IIASA - GAINS model

PM_{2.5} : 2040 MTRF

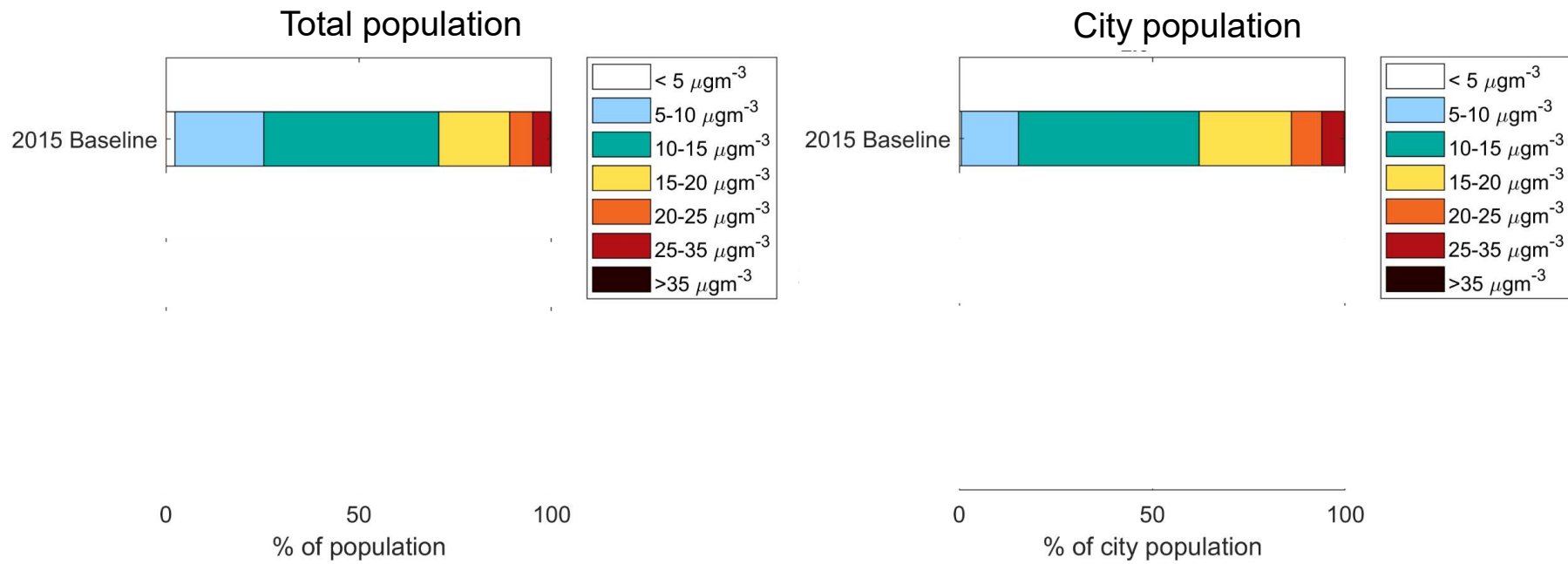
Total PM_{2.5} incl. natural dust



Maximum technically feasible reductions in 2040 (UNECE only).

PM_{2.5} exposure distribution: EU

Total PM_{2.5} incl. natural dust

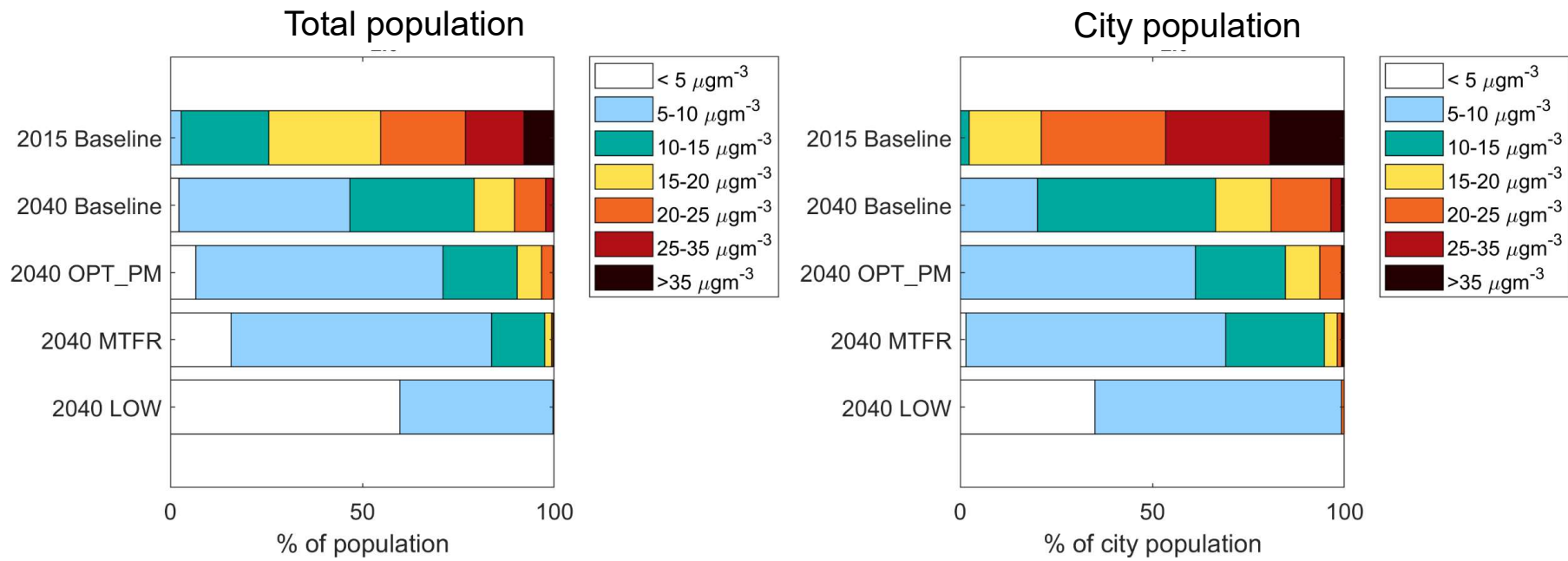


Population: JRC GHSL 250m (R2019), projection according to UN WUP 2018.
 City definition: JRC UCDB urban core polygons

Source: CIAM/IIASA - GAINS model

PM_{2.5} exposure distribution: West Balkan

Total PM_{2.5} incl. natural dust



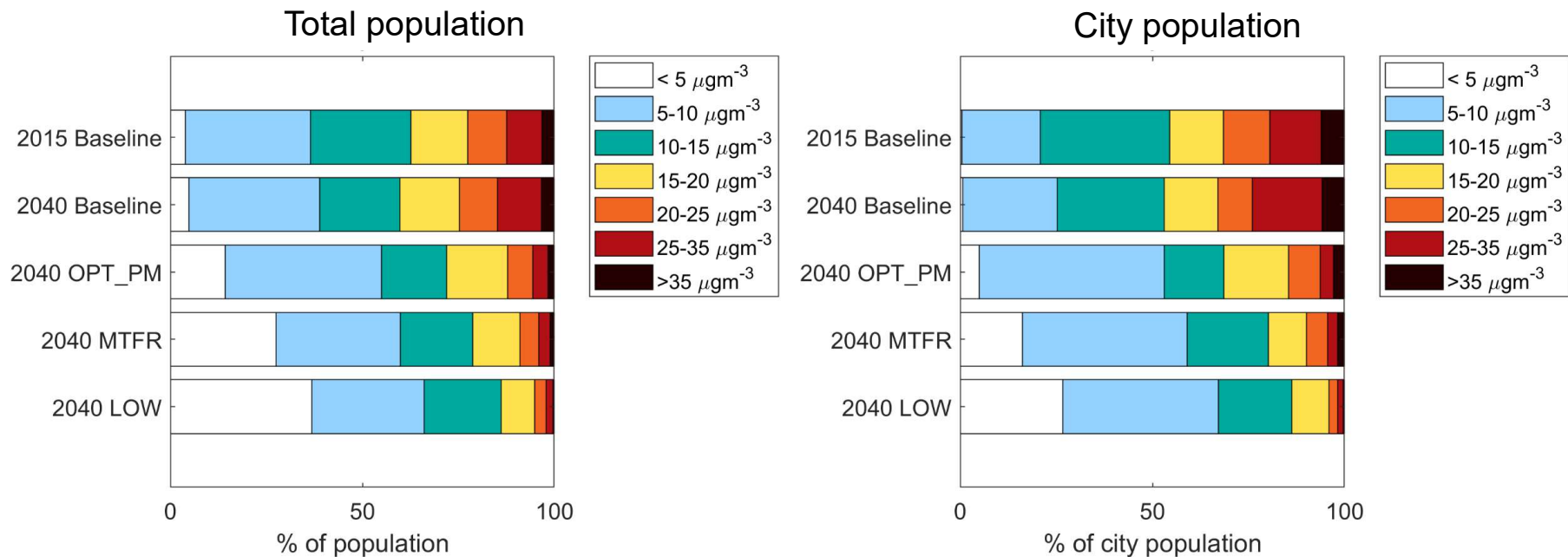
Bigger differences between total and city exposure. Strong decreases in the Baseline, convergence in OPT and MTRF.

Population: JRC GHSL 250m (R2019), projection according to UN WUP 2018.
 City definition: JRC UCDB urban core polygons

Source: CIAM/IIASA - GAINS model

PM_{2.5} exposure distribution: EECCA

Total PM_{2.5} incl. natural dust

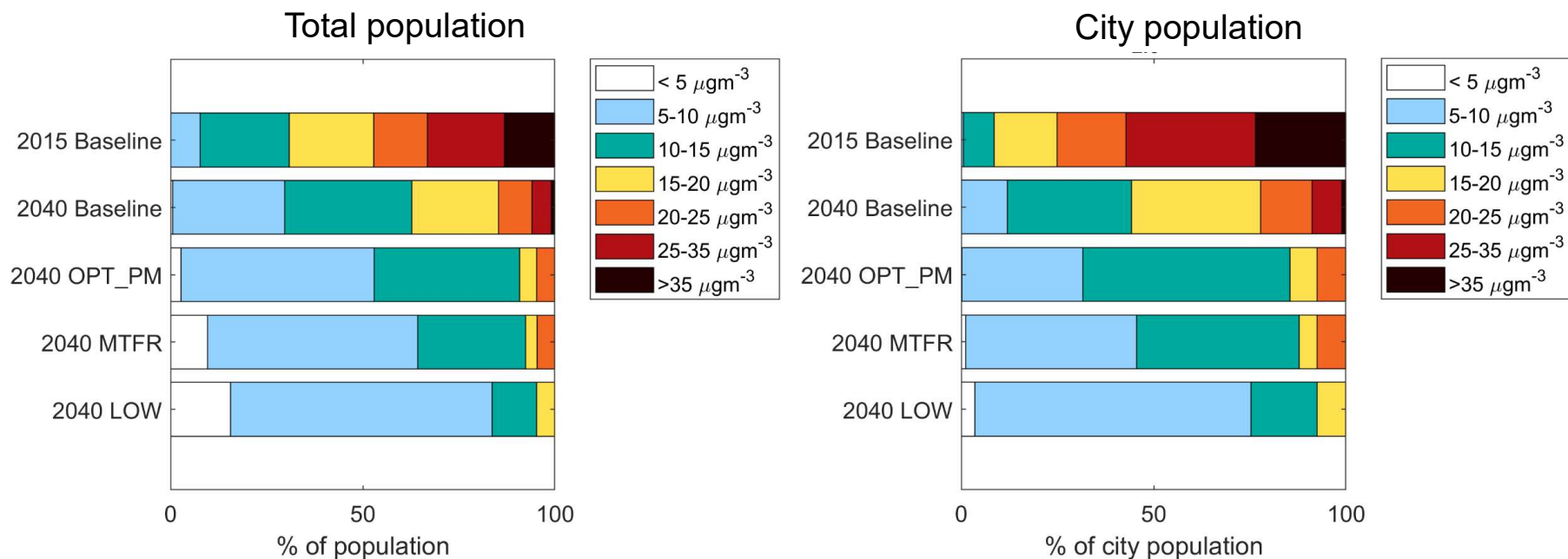


Increases in higher concentration ranges in the Baseline!

Improvements in policy scenarios - remaining elevated concentrations are partly natural dust.

PM_{2.5} exposure distribution: Türkiye

Total PM_{2.5} incl. natural dust

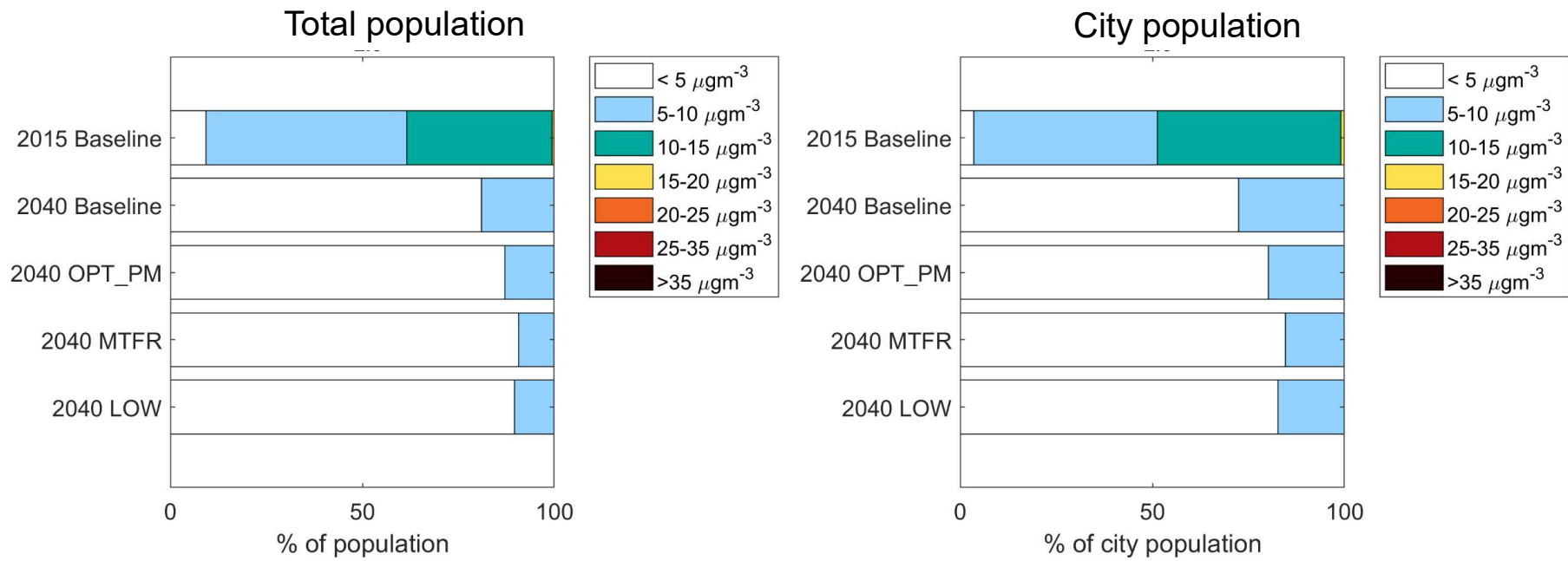


Population: JRC GHSL 250m (R2019), projection according to UN WUP 2018.
 City definition: JRC UCDB urban core polygons

Source: CIAM/IIASA - GAINS model

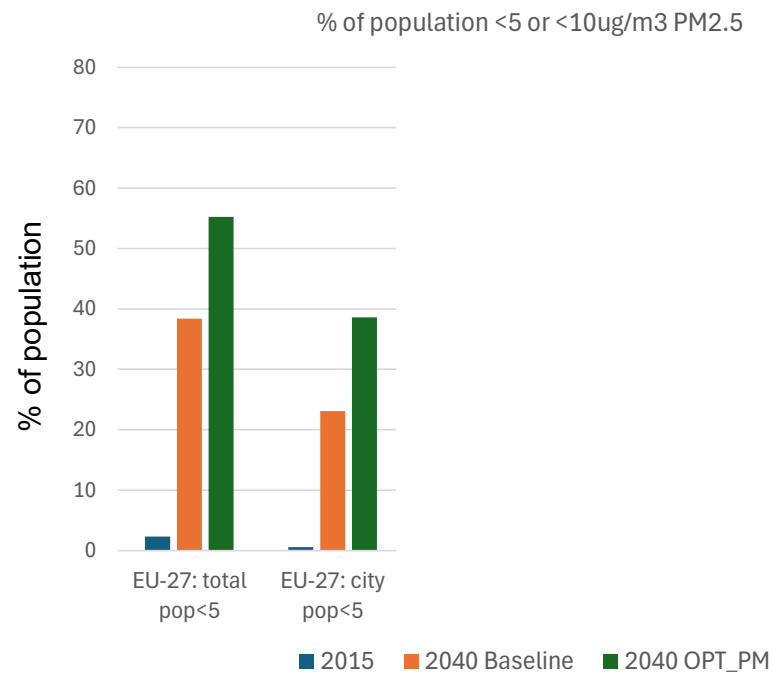
PM_{2.5} exposure distribution: EFTA+UK

Total PM_{2.5} incl. natural dust



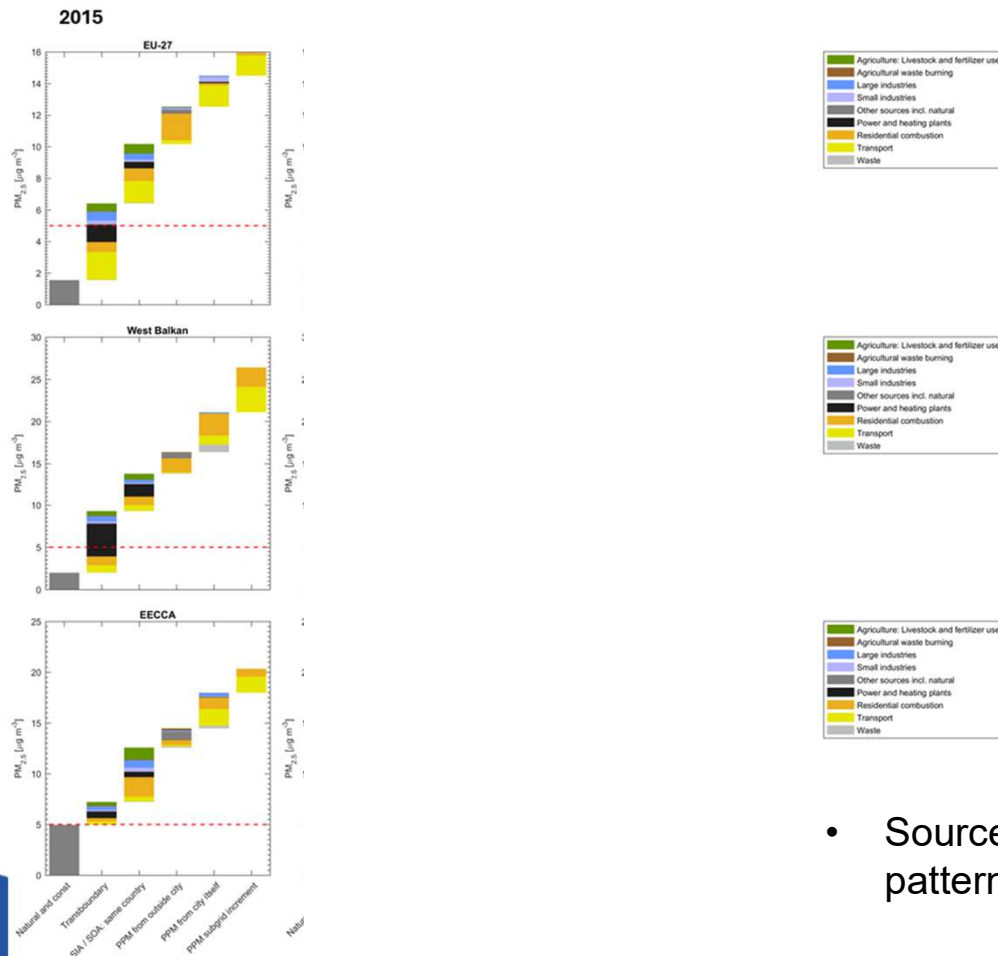
Population: JRC GHSL 250m (R2019), projection according to UN WUP 2018.
 City definition: JRC UCDB urban core polygons

Population shares in (relatively) low PM_{2.5} ranges



Although the target for OPT is set for total population, and measures are implemented at country level, in relative terms the urban population benefits more strongly.

Source attribution to PM_{2.5} in cities in selected regions/scenarios

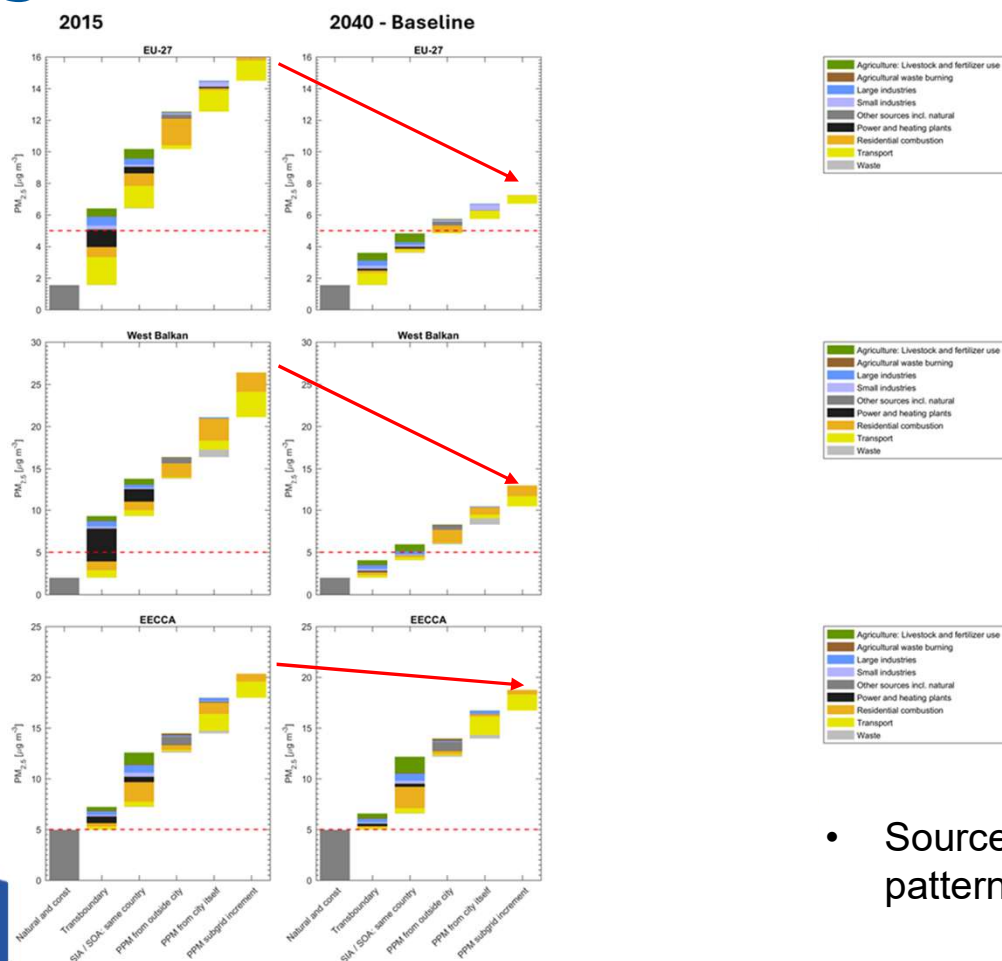


- Residential sector and transport dominate the contribution from the city itself for most cities in 2015 and 2040
- Transboundary and regional contribution is more variable

- Source contributions depend on the emission gridding pattern – IIASA gridding emphasizes traffic in cities.

Source: CIAM/IIASA - GAINS model

Source attribution to PM_{2.5} in cities in selected regions/scenarios



- Residential sector and transport dominate the contribution from the city itself for most cities in 2015 and 2040
- Transboundary and regional contribution is more variable
- Strong reductions expected from implementation of current policies
- Measures available to reduce exposure further, bringing contribution of anthropogenic PM_{2.5} to below WHO AQG

- Source contributions depend on the emission gridding pattern – IIASA gridding emphasizes traffic in cities.

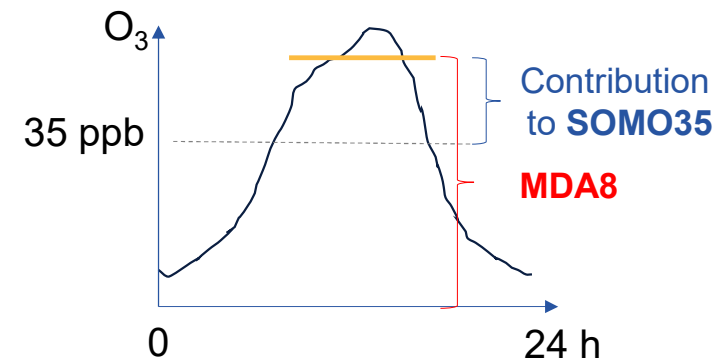
Source: CIAM/IIASA - GAINS model

Part 2: Ozone

Results from EMEP model simulations for the Gothenburg Protocol Revision
(GAINS scenarios as before, slightly earlier version – Dec 2024)

Options for ozone impact calculations

Historically, GAINS focused on all-cause mortality from short-term exposure to O_3 , expressed through the **SOMO35** metric (sum of daily max 8-hour running mean >35 ppb).

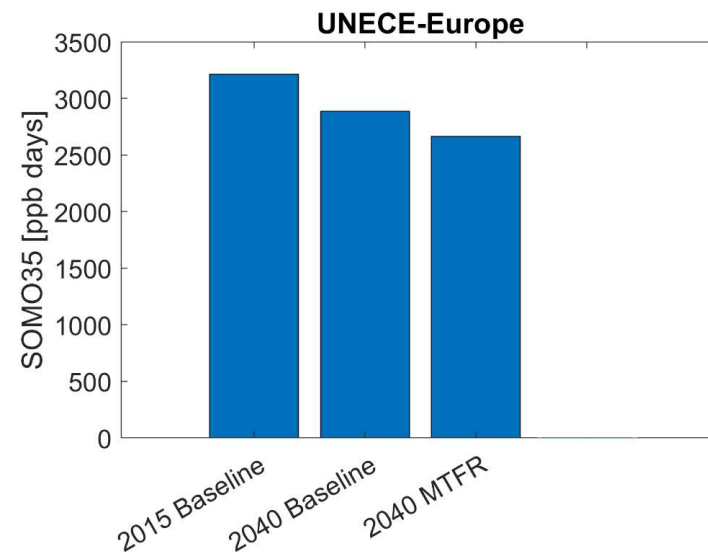
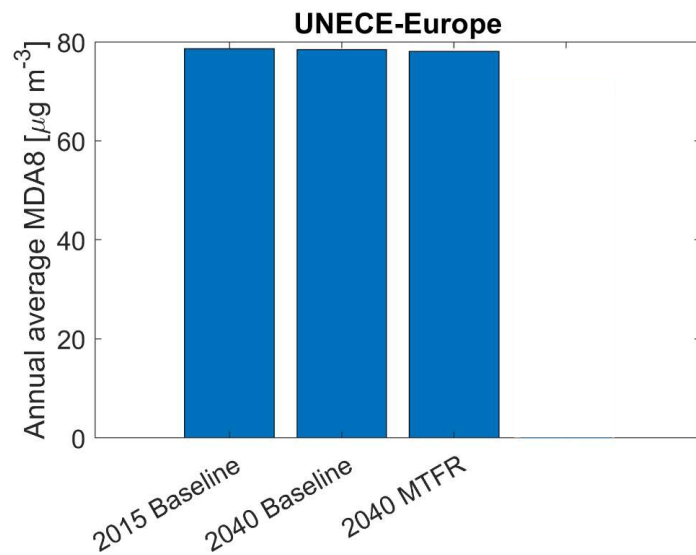


Recent epidemiological evidence:

- Long-term exposure:
 - Peak-season average **MDA8**: significant in systematic review for AAQ Guidelines (Huangfu & Atkinson, 2020) but not anymore by Kasdagli et al (2024)
 - Annual average MDA8: found significant for respiratory mortality by Kasdagli et al (2024), but not for all-cause mortality.
- Short-term exposure:
 - Orellano et al (2020): significant for all-cause mortality, $RR=1.0043/10\mu\text{g}\text{m}^{-3}$
 - Vicedo-Cabrera et al (2024): significant for all-cause mortality, $RR=1.0018/10\mu\text{g}\text{m}^{-3}$

O₃ exposure trends (total UNECE-Europe)

In EMEP model simulations for WGE (Jan 2025)



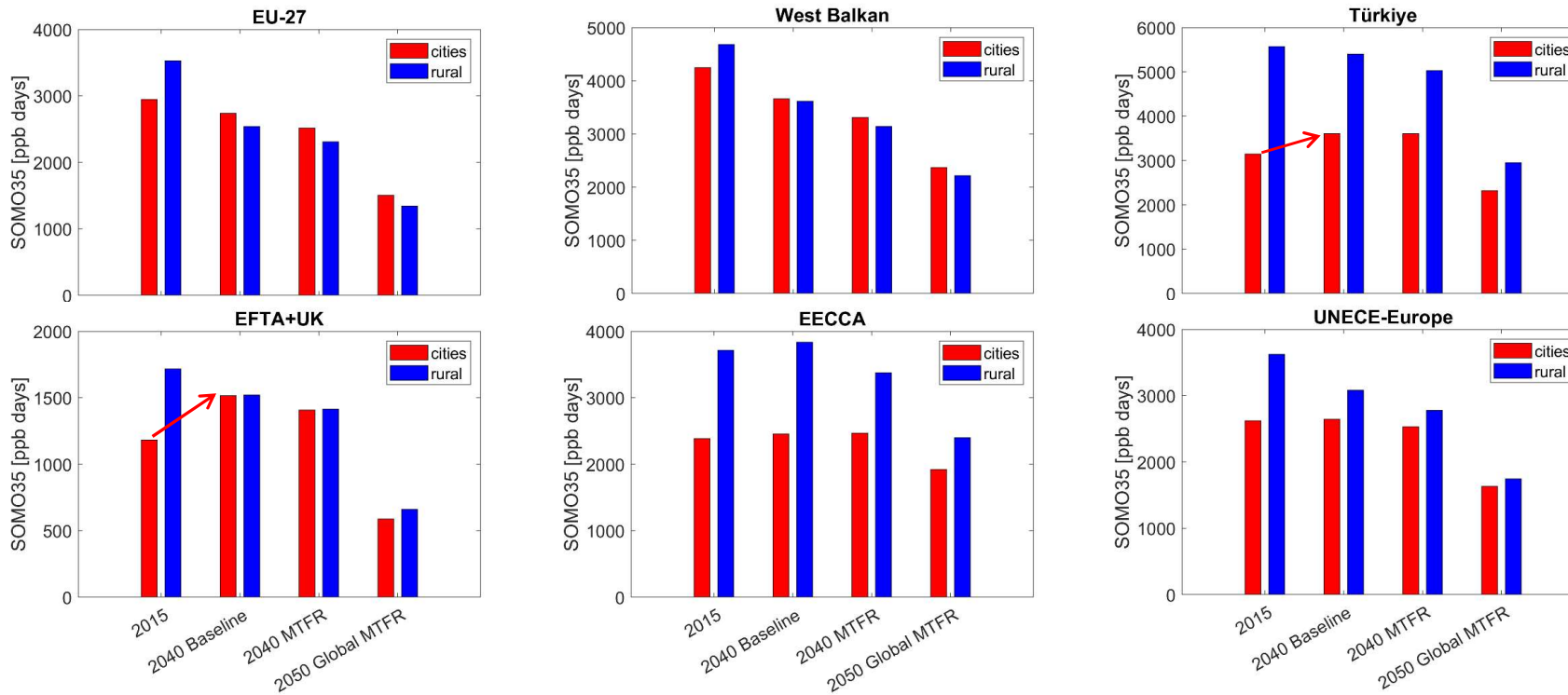
Annual mean MDA8 is very insensitive to emission changes within the UNECE domain

SOMO35 shows more sensitivity

Global MTRF includes CH₄, NO_x, VOC mitigation outside of UNECE-Europe and is from v5 scenario set

O₃ exposure trends: cities vs rural areas

In EMEP model simulations for WGE (Jan 2025), using the GAINS scenarios



Rural areas face higher concentrations than cities.

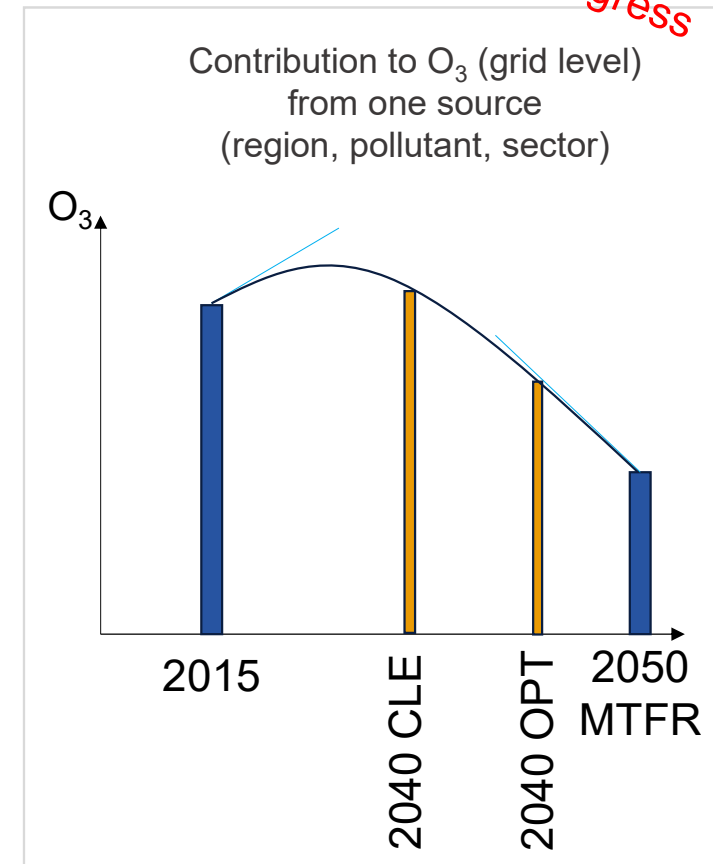
Changes are small in cities, partly increases due to NO_x titration. Differences to rural decrease.

Action beyond UNECE would be needed for more substantial decreases.

Implementing O₃ in GAINS: State of progress

Work in progress

- The EMEP model now allows to quantify the sensitivity of ambient O₃ to a large set of emission sources simultaneously.
- Approach: calculate sensitivities of all relevant O₃ metrics at 0.3°×0.2°
 - to emissions of NO_x and VOC
 - from all UNECE-Europe source countries + 10 sea regions
 - for 3 aggregate sectors (power & industry, low-level, agriculture) separately
 - for a high (2015) and a low (2050 global MTRF) case
- use a quadratic fit to determine the derivative at a given emission level
- Progress: Simulations by MSC-W done, but the range from 2015 to 2050 MTRF seems too large. Full EMEP model between 2040 CLE → 2040 MTRF not well reproduced.
- Solution: repeating with 2040 CLE as high case. Runs in progress.

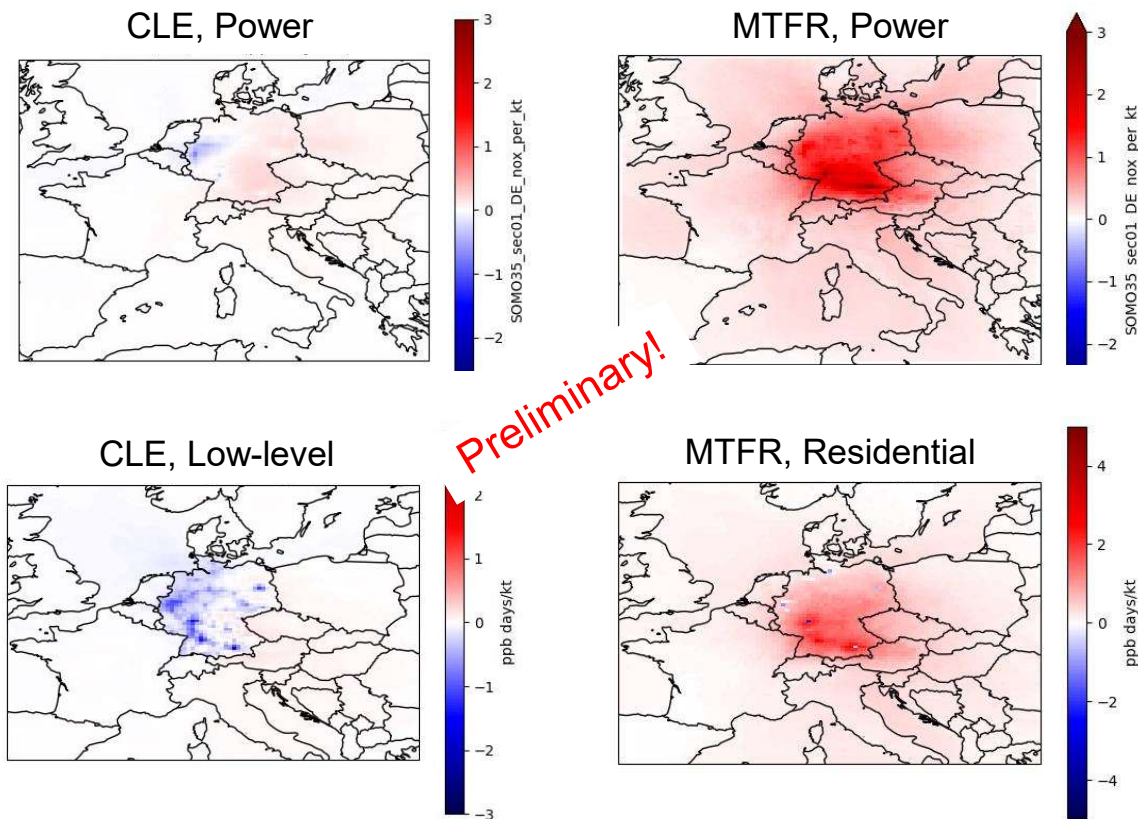


20-11-2025

O₃ transfer coefficients for GAINS

In progress, based on local fraction tracking in EMEP model.

Example: Effect of 1kt NO_x sectoral emission increase from Germany on SOMO35:



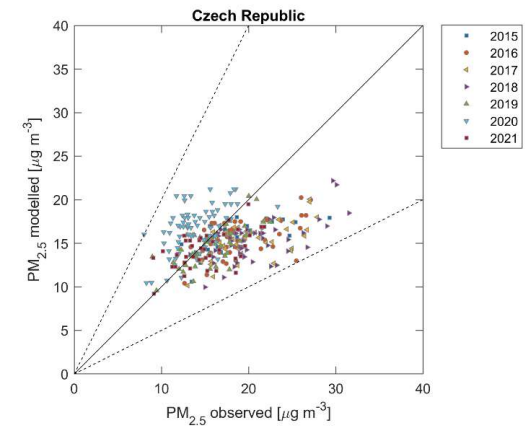
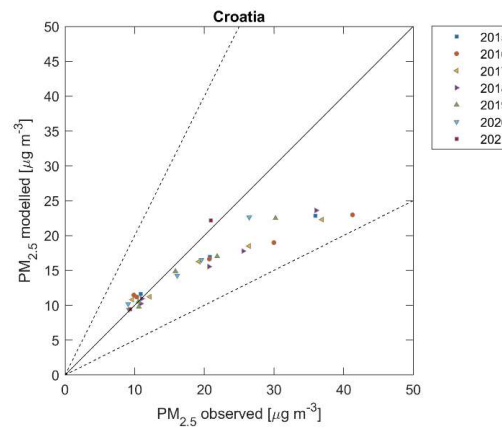
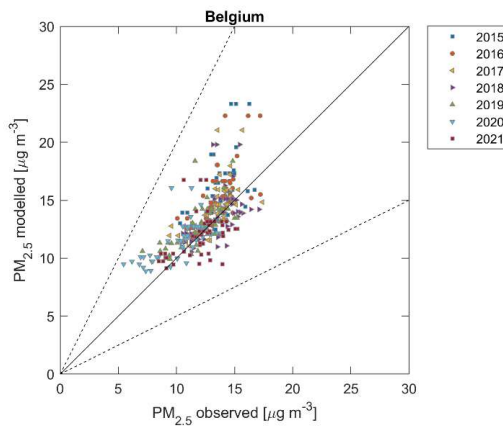
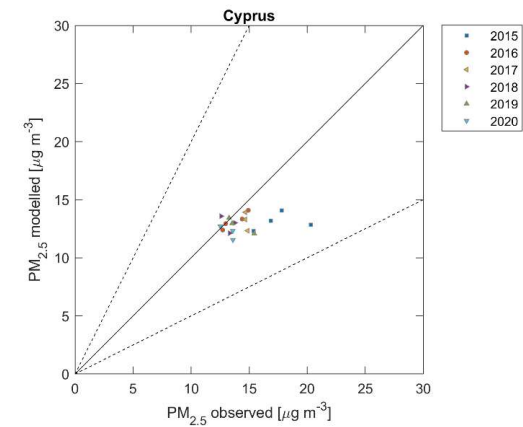
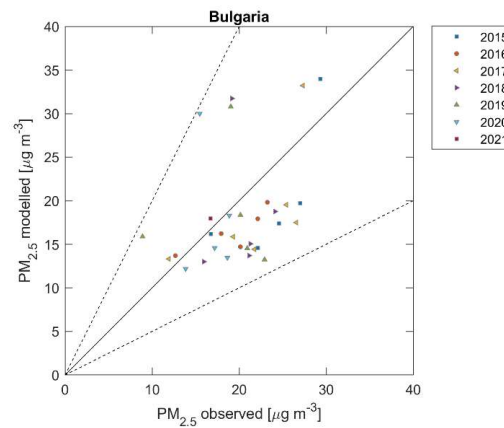
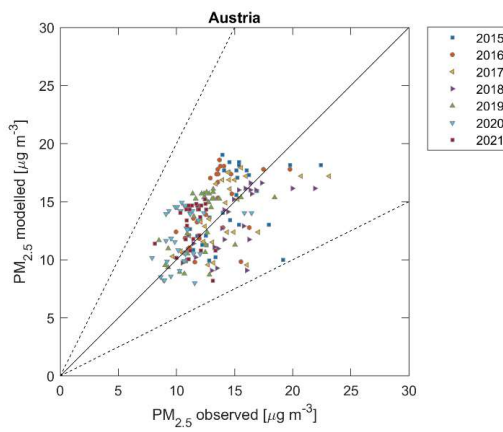
Conclusions – PM_{2.5}

- West Balkan, EECCA, TR:
 - urban populations are exposed to higher concentrations (residential combustion!)
 - While current policies are expected to reduce exposure by 2040, disparity remains
 - Optimized scenarios for community-wide health targets provide more equitable distribution of exposure
 - To reduce remaining disparities, further measures targeting cities would need to be implemented
- EU, EFTA, and UK
 - Less pronounced difference in exposure of total and urban population
 - Important reductions achieved in the Baseline
 - However, larger difference remains in exposure to levels above WHO AQG
- Source contribution estimates to cities depend on emission gridding. IIASA's current gridding pattern emphasizes traffic in cities – more than others. Intercomparison and possible updates needed.

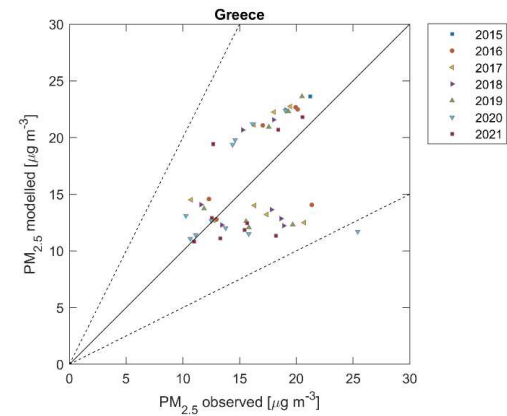
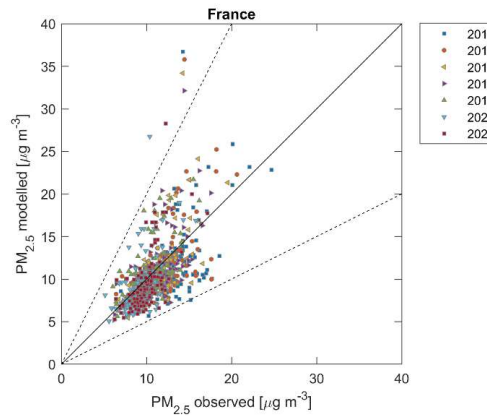
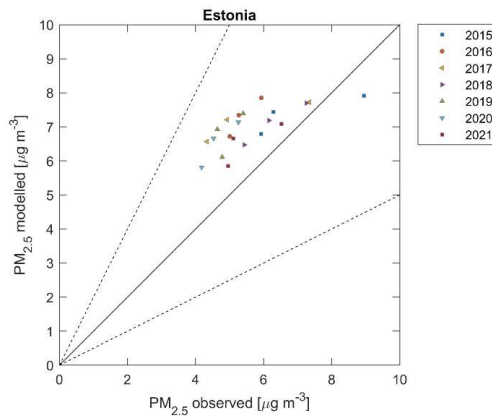
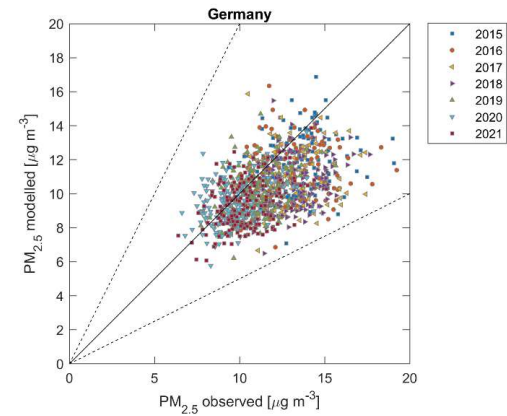
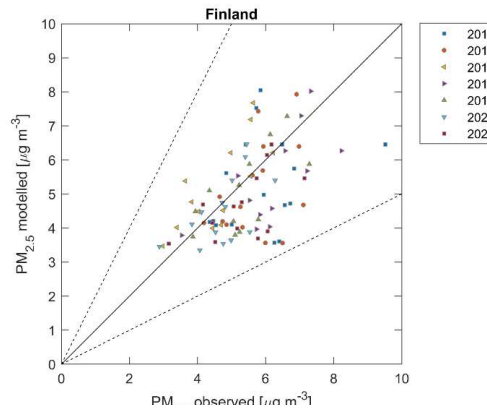
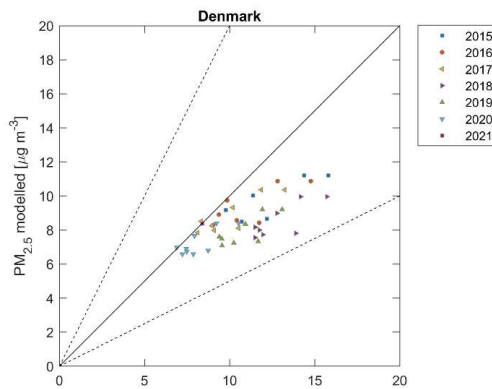
Conclusions – O₃

- O₃ concentrations are less sensitive to precursor emission changes
- Urban populations are exposed to lower O₃ than rural
- Concentrations in cities are expected to change only slightly under Baseline. Some areas will experience increases even under MTFR 2040.
- For more substantial changes, reductions outside UNECE are needed (NO_x, VOC, CH₄)

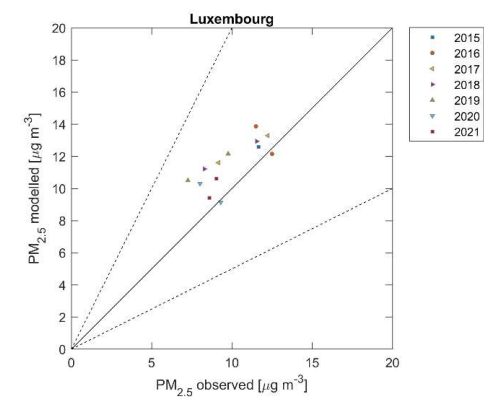
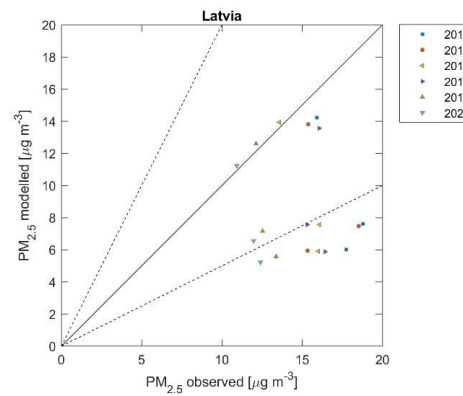
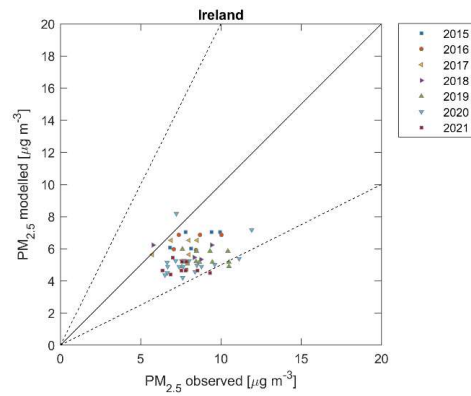
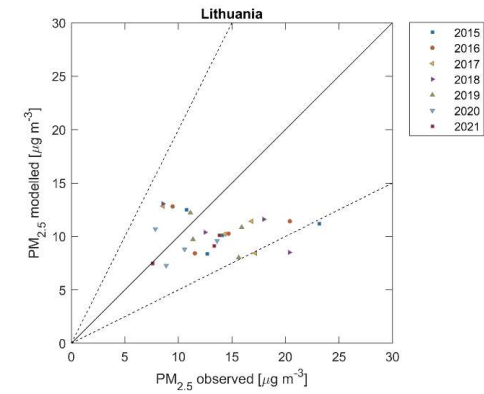
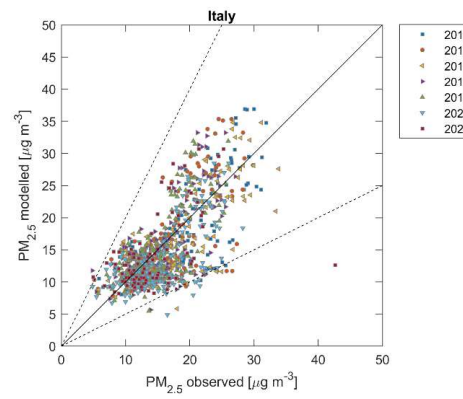
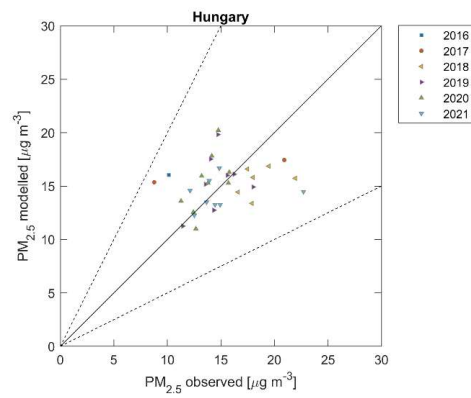
PM_{2.5} validation (EU cities)



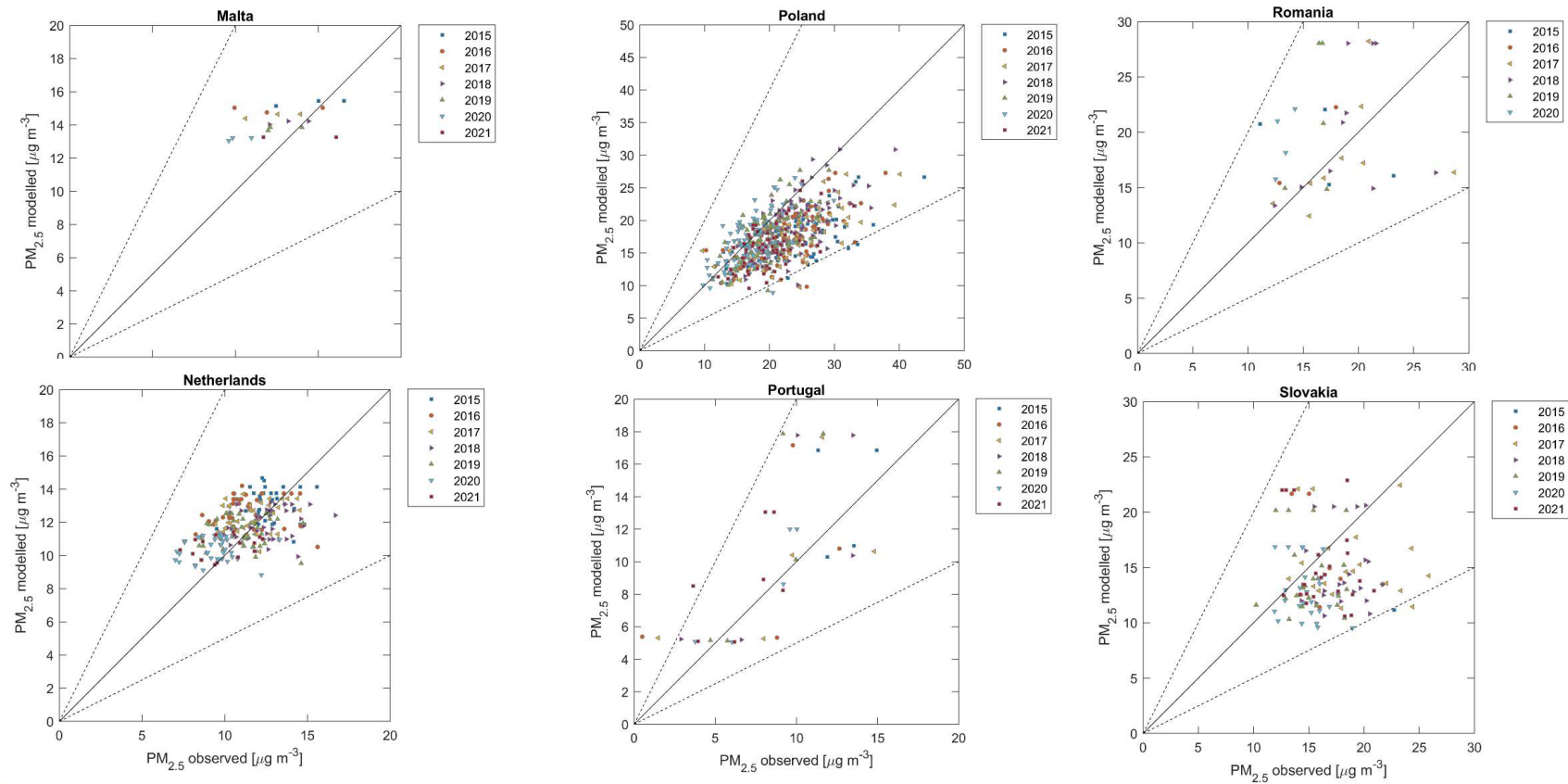
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