emep

Co–operative programme for monitoring and evaluation of the long–range transmissions of air pollutants in Europe

UNECE

Convention on Long-range Transboundary Air Pollution

MSC-W Modelling work in support of the Gothenburg Protocol review & revision

Model results from MSC-W using the GAINS emission scenarios

Hilde Fagerli, Bruce Denby, Willem van Caspel, Peter Wind, Agnes Nyiri, Svetlana Tsyro, David Simpson, Gunnar Lange & rest of the EMEP/MSC-W team + CIAM team

TFMM & TFHTAP Joint Session, Potsdam, 7th May 2025

Norwegian Meteorological Institute

Content

EMEP MSC-W model results in support of GP review & revision using the GAINS emission scenarios

1. EMEP MSC-W regional model runs for the ex-post analysis using latest (consistent with TFHTAP) GAINS emission scenarios
2. Global/regional EMEP MSC-W results using a slightly earlier version - focusing on CH_4
3. Multi-scale modelling for Europe (down to 100m resolution) for GP review
   (will also be done for ex-post analysis)

What has MSC-W done with the most recent GAINS scenarios?

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- So far this work has focused on providing data for the so-called ex-post analysis
- Ex-post analysis = the **extra analysis done on the EMEP MSC-W model data**, mostly by WGE - ongoing since January, to be presented at EMEP SB in September). Mostly ecosystem specific deposition and POD/AOT
    - ICP Vegetation (Ozone POD/AOT)
    - ICP Waters (Deposition)
    - ICP M&M (Deposition)
    - CCE (Deposition)
    - CDM (Deposition)
    - ICP IM (Deposition)
    - ICP Materials (SO_2, NO_2, O_3, HNO_3, PM_{10})
    - ICP Forest (Ozone POD/AOT)
- In addition, MSC-W will do fine scale (uEMEP) analysis

WGE : Working Group of Effects
ICP : International Cooperative Program
CCE : Coordination Centre for Effects
CDM : Centre for Dynamic Modelling

EMEP MSC-W runs for ex-post analysis

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- Focused on EMEP domain and what European countries possibly can achieve in terms of improving air quality: CLE and MFR is spanning the possible outcomes (plus the OPT scenario)
- Regional scale modelling (focused on EMEP domain, 0.1 degree resolution), providing modelled global boundary conditions ourselves (EMEP model)
- (Almost) Fully consistent with TFHTAP runs except
  - Regridding of EU emissions using EMEP emission gridding
  - Forest fires (FINN v2.5 with MODIS and VIIRS)
- Reduced complexity climate modelling of CH_4 concentrations (similar to TFHTAP)
- 5 meteorological years (2016-2020)

Emission scenarios

Future reduction scenarios apply only to the EMEP countries, with the rest-of-world (global) following Current Legislation (CLE) emissions.

- 2015 baseline emission year
- 2040 CLE represents ‘business as usual’ for the target year
- 2040 MTFR applies Maximum Feasible Technical Reductions with CLE activity data
- The optimized 2040 OPT scenario achieves a reduction of premature mortality (attributable to ambient PM2.5) in 2040 by 50% compared to 2015

International shipping follows CLE in all scenarios. Emissions from soil-NOx follow climatological conditions.

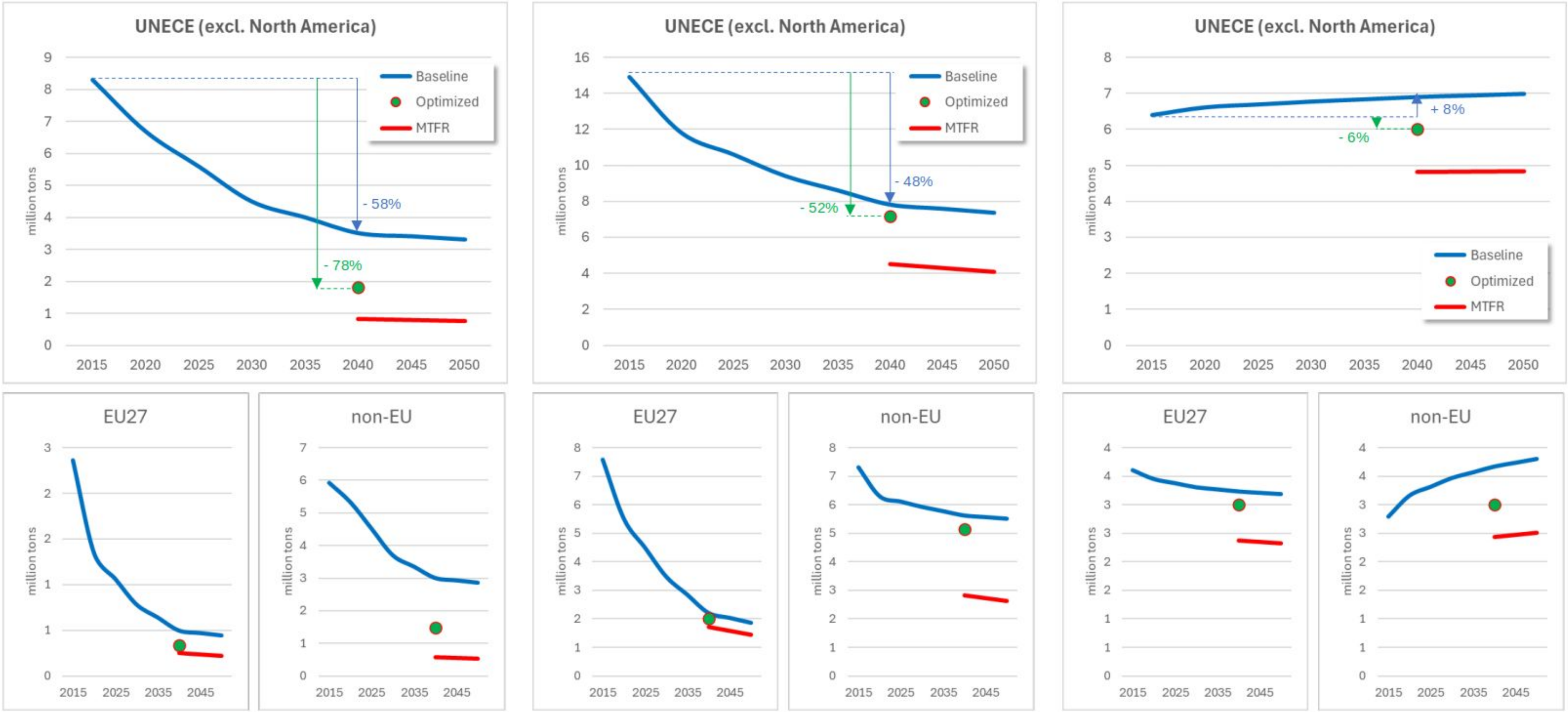
Global CLE emissions are used to calculate background (specified) CH_4 concentrations using the MAGICC7 earth system model emulator.

2015 [CH_4] = 1834 ppb **2040 CLE [CH_4]** = 2107 ppb

Sulfur and nitrogen emissions in the current scenarios (V5a)

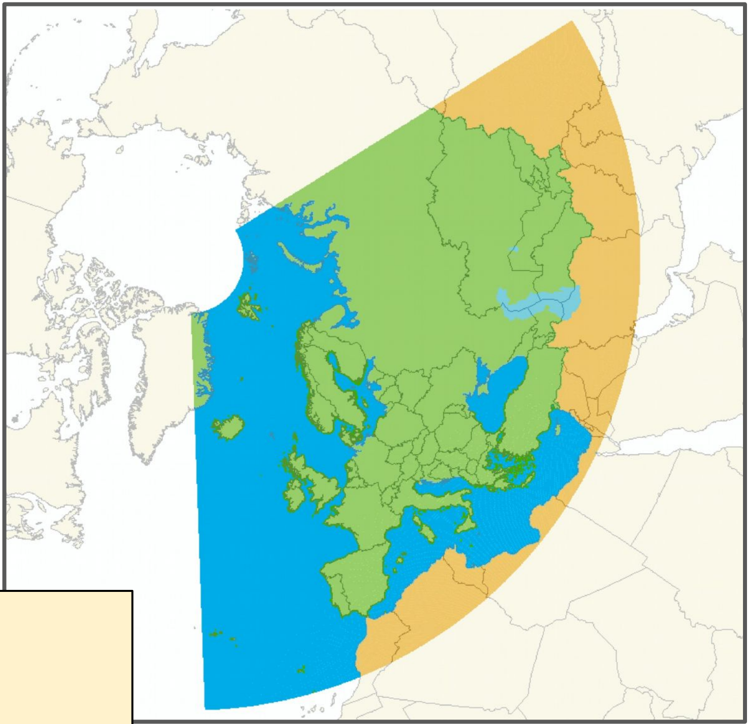
Optimized refers to 50% reduction of premature mortality for UNECE, dynamic population, cost optimal solution

Sulfur Dioxide (SO_2) | Nitrogen Oxides (NO_x) | Ammonia (NH_3)



Source: CIAM/IIASA - GAINS model

EMEP MSC-W regional Model setup



The EMEP domain

Fact sheet:

- 0.1 x 0.1 degree (~10 km) EMEP domain simulations
- 20 vertical levels up to 100 hPa (~12 km altitude)
- Driven by 3-hourly ECMWF IFS reanalysis meteorology (winds, temp, humidity)
- 3-hourly IFS model-top boundary conditions for ozone
- **6-hourly boundary conditions from global EMEP simulations**
- **6-month spin-up from global simulations**
- **All scenarios simulated for five meteorological years between 2016-2020**
- Specified background methane concentrations based on 2015 baseline observed values and 2040 CLE scenario calculations

Regional model runs in TFHTAP compared to model runs for ex-post analysis

	Boundary conditions from global model			
Regional model simulation	CLE2015	CLE2040	MTFR2040	HILO2040
CLE2015	x			
CLE2040		x		
MTFR2040			x	
HILO2040				x
CLE2040glob-HILO2040reg		x		
CLE2040glob-MTFR2040reg		x		
CLE2040glob-OPT2040reg		x		

TFHTAP

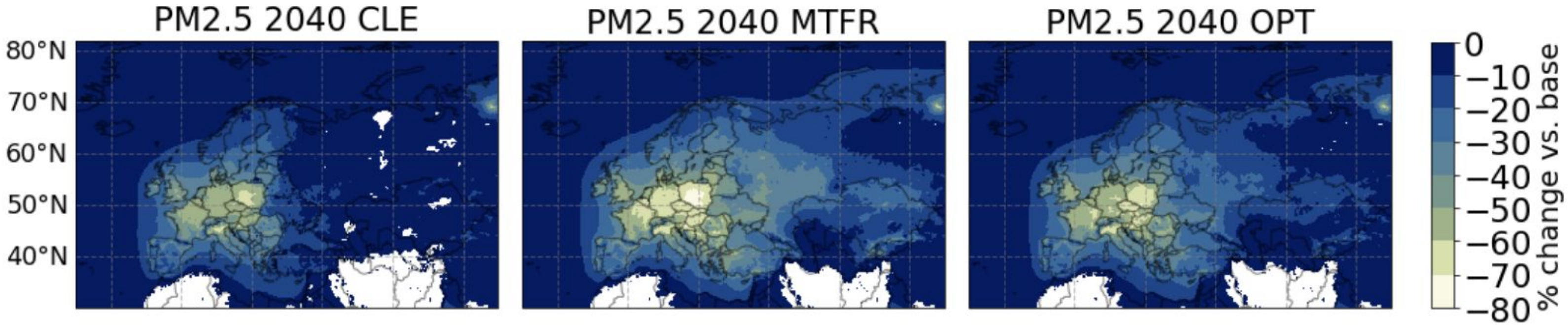
Ex-post analysis = yellow cells

Additional EMEP MSC-W runs

- Focused on European actions (outside of EMEP domain is kept as CLE)
- 5 meteo years

Results

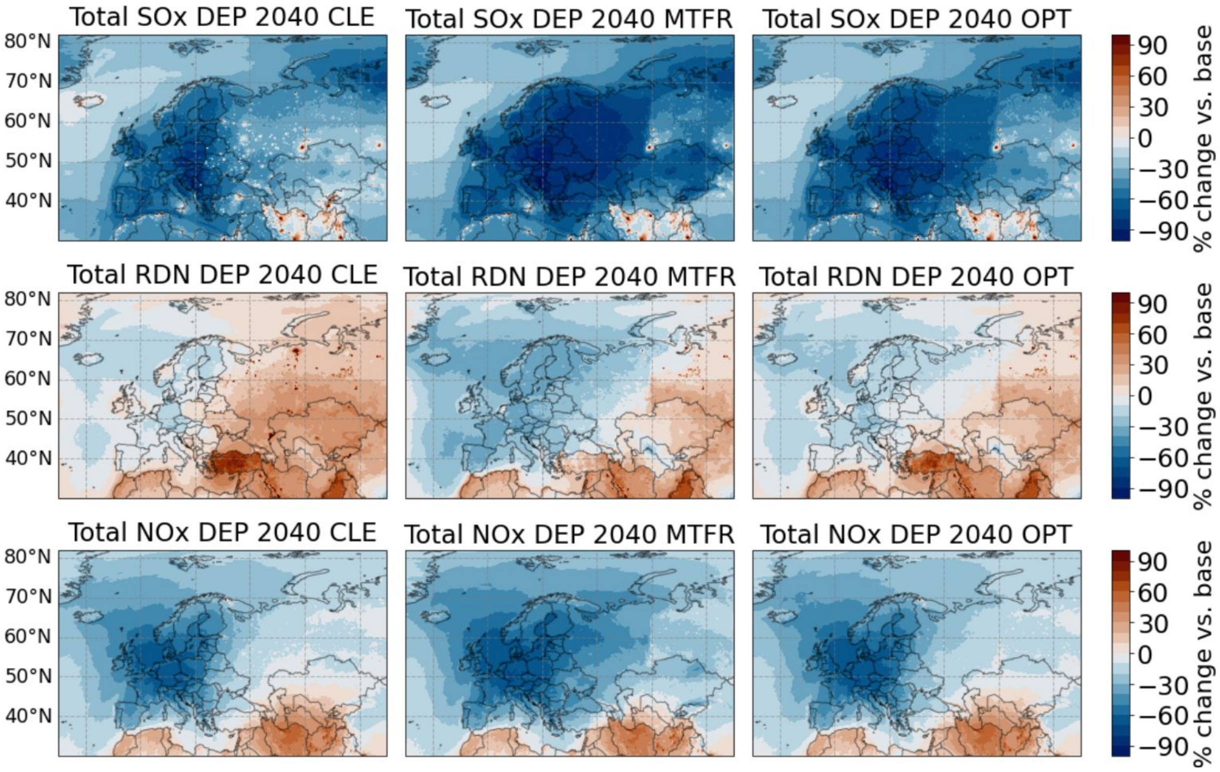
- Model results have been delivered to WGE groups - will be presented in September at EMEP & WGE SB
- EMEP MSC-W has started uEMEP ex-post analysis (example of previous uEMEP for GP review later in the talk)



Changes in $PM_{2.5}$ relative to 2015

Robustness? Multi-model ensemble?

Examples of deposition: relative changes



Robustness? Multi-model ensemble?

EMEP MSC-W contribution to TFHTAP exercise

Convention on Long-range Transboundary Air Pollution

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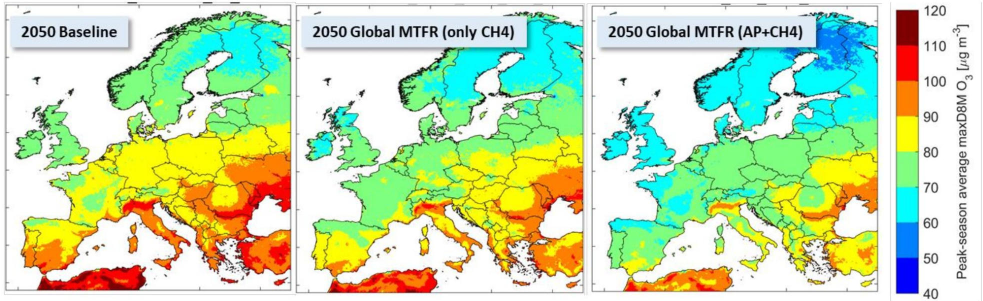
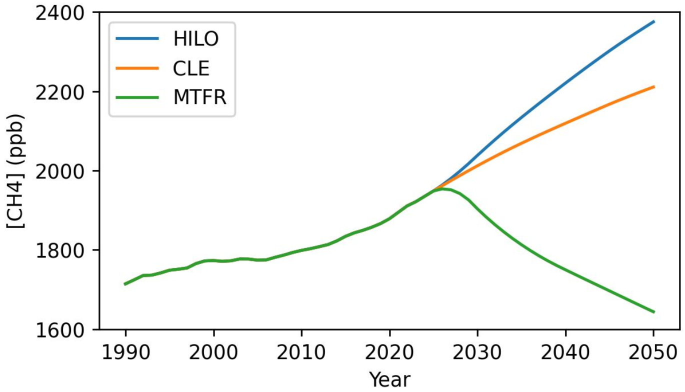
- Global model runs from EMEP MSC-W model
- Regional model runs from EMEP MSC-W model
- Provide CH4 concentrations for the exercise based on the GAINS emission scenarios
- Provide boundary conditions for regional models

Background CH_4 projections

- ➢ Model for the Assessment of Greenhouse Gas Induced Climate Change v7.5.3 (MAGICC7)
  - Reduced complexity climate model
  - Based on global HTAP3-OPNS emissions (NO_x, VOC, CO, CH_4)
  - Probabilistic 600-ensemble member average
  - Fixed biogenic emissions based on budget closure with observations
  - Time series of global average (CLE, MTFR, HILO) tropospheric CH_4 concentrations up to 2050



2050 MTFR anthropogenic pollutant vs. CH_4 impacts. Figure adjusted from the Clean Air Outlook 4 (CAO4) development support document.



CH_4 concencentrations available from https://zenodo.org/records/14980850

HILO NO_x/VOC increases CH_4 lifetime

Delivering boundary conditions from the EMEP MSC-W model to the regional models

- 4 sets of BICs: 2015 CLE, 2040 CLE & MFR, 2040 HILO (MFR + CH4 emissions as in CLE) - all with 2015 meteorology
- 6h (?)
- Species ?
- EMEP or CAMS domain BICs ?

Recent global/regional work from MSC-W

Norwegian Meteorological Institute

- What is the ozone mitigation potential in UNECE?
- How much of that comes from CH_4 emission reduction?

EMEP MSC-W modelling work based on recent emission scenarios from **CIAM** (including recent work on CAO4) and building upon previous work by **TFHTAP**

+ Use recent scenarios from CIAM (but slightly older than TFHTAP)

5-year meteorological average

Included ozone variables such as POD_{crop}, SOMO35, Peak season MDA8/MDA8

-- Only one model (will be followed up by **TFHTAP**)

2050 not 2040

LRTAP Long-range Transboundary Air Pollution

How?

- Emissions from CIAM/IIASA scenarios
- EMEP MSC-W model calculations in 0.1x0.1 degree for EMEP domain
- Nested to global EMEP MSC-W simulations in 0.5x0.5 degree
- Average of 5 meteorological years
- A range of different global and regional simulations (with different perturbations, incl. CH_4)
- Extension of the work described in van Caspel et al, 2024 (e.g. to be able to add up to UNECE contributions)

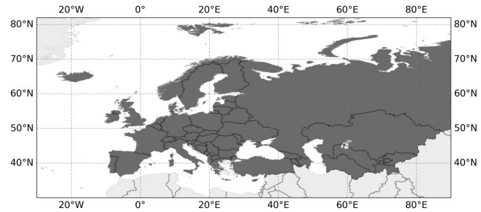


Figure S1. Dark-grey shaded region marks the EMEP region within the 0.1° × 0.1° regional EMEP modelling domain.

Meteorological variability and model performance

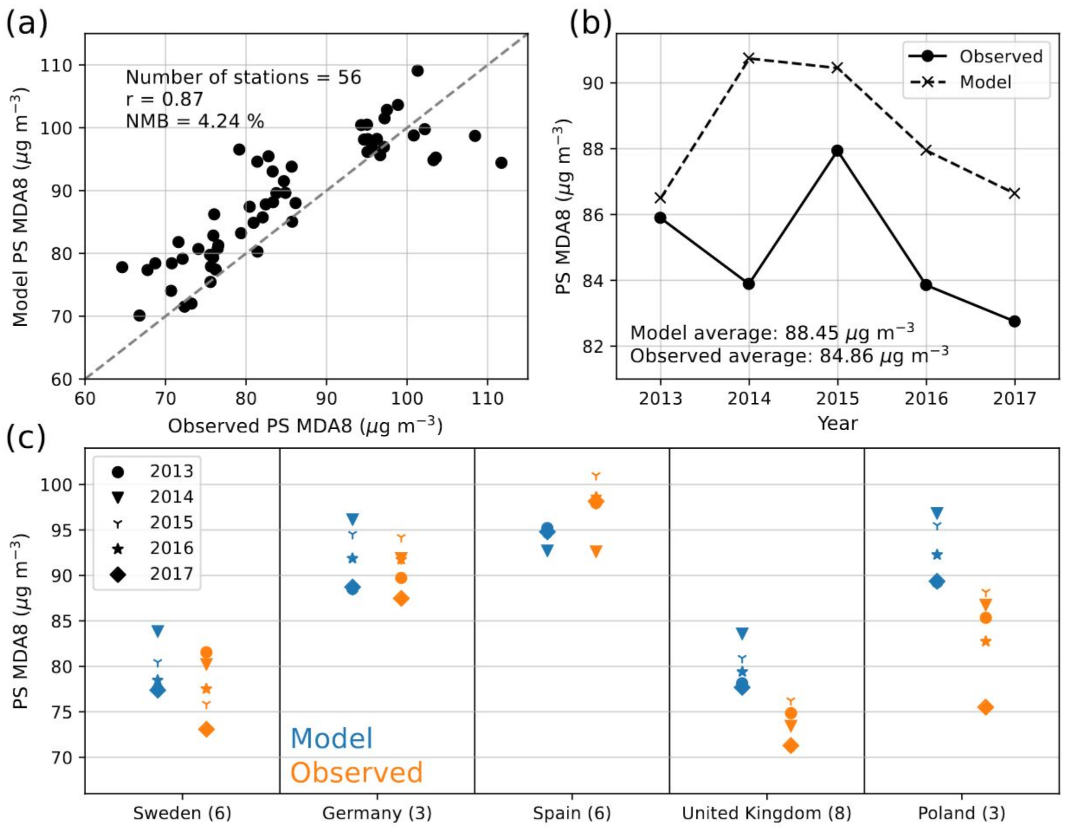
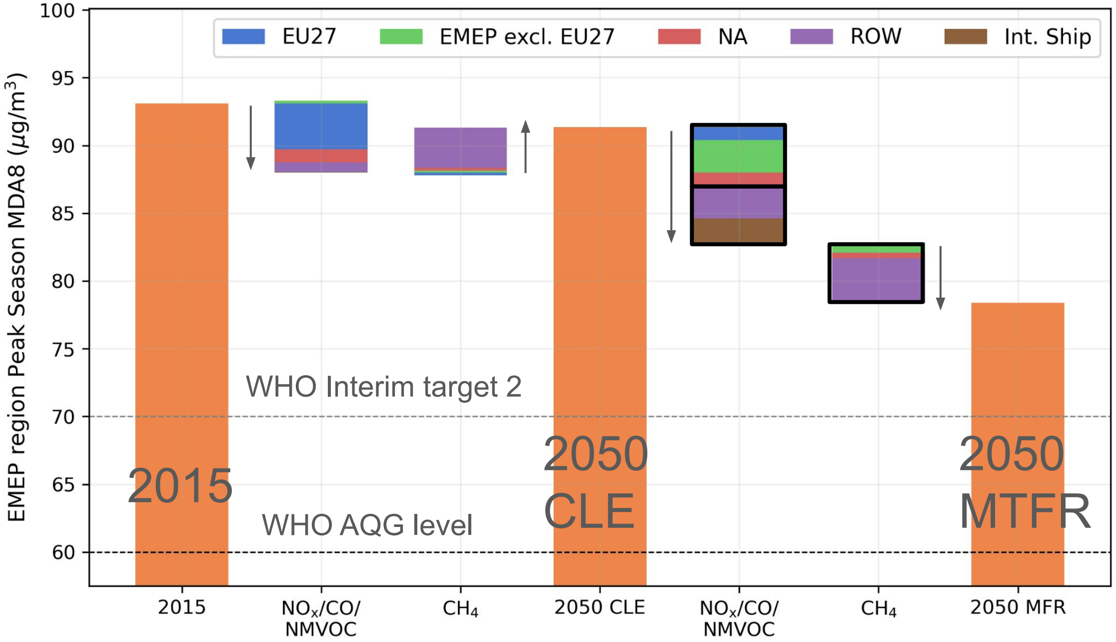


Figure 2. Modelled versus observed peak season MDA8 across Europe. Panel (a) shows five-year averaged values at each of the 56 stations, with panel (b) showing the annual values averaged over all stations. Panel (c) shows the yearly averages for Sweden, Germany, Spain, the United Kingdom, and Poland, with the number in brackets indicating the number of stations in each of the countries.

The EMEP MSC-W model is:

- reproducing MDA8 well for the 5-year average
- able to model and span the meteorological variability (compare well to observations for 'high' and 'low' MDA8 years)

The EMEP perspective



CLE:

- Peak season MDA8 (SOMO35) reduced by approx. 2% (4%) from 2015 to 2050
- CH_4 emission increase (outside UNECE) in the baseline scenario offsets the reductions expected from NOx/VOC declines

MFR:

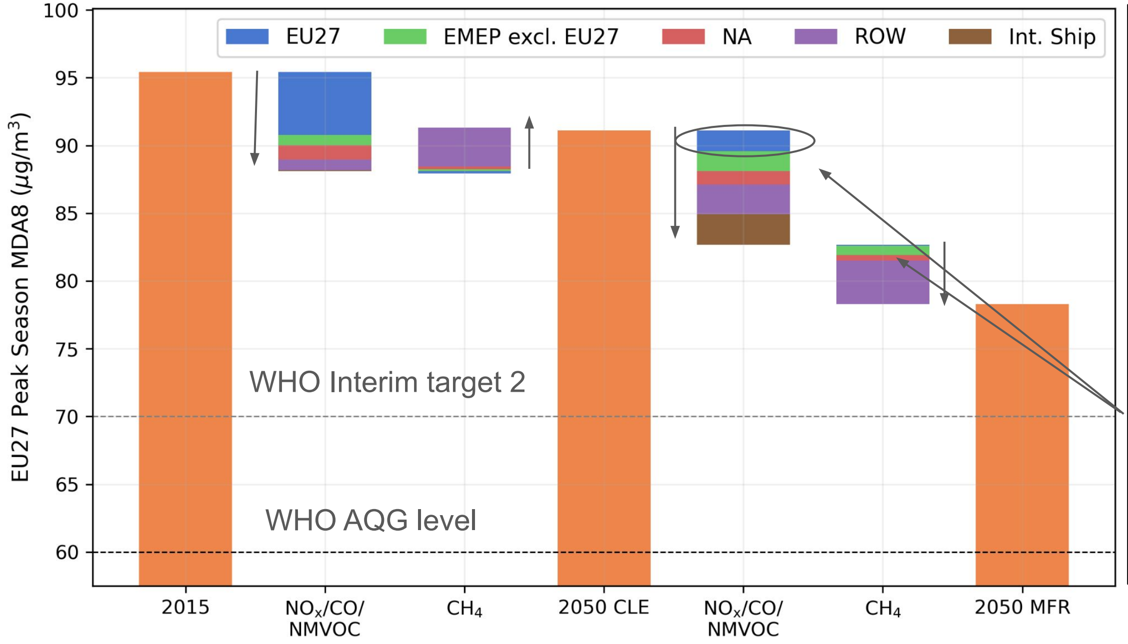
- Large reductions in surface ozone due to combined effects of methane, local NOx/NMVOC and remote NOx/NMVOC
- Global MFR gets you almost half way (40%) towards WHO AQG level

Difference between the 2050 CLE and 2050 MFR:

- ⅓ from CH4 (of which ca 27% from UNECE)
- ⅓ from UNECE NOx/VOC
- ⅓ from ROW - where international shipping is ⅓ of that

EMEP modelling domain as receptor

The EU perspective (EU as a receptor)



CLE:

- Peak season MDA8 (SOMO35) reduced by approx. 5% (10%) from 2015 to 2050 in EU (more than in EMEP domain)
- CH_4 emission increase (outside UNECE) in the baseline scenario offsets the reductions expected from NOx/VOC declines

MFR:

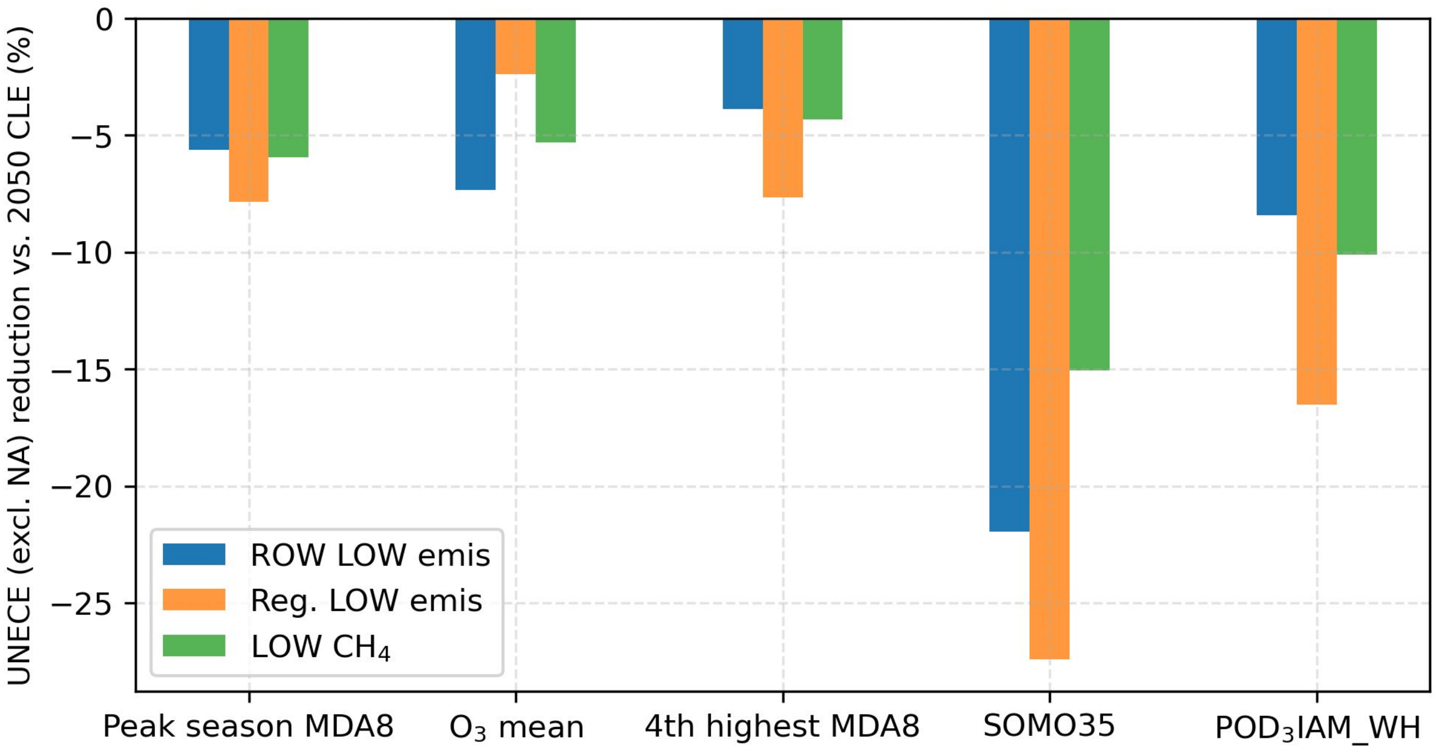
- Large reductions in surface ozone due to combined effects of methane, local NOx/NMVOC and remote NOx/NMVOC, but EU alone can only account for 13 (13)% of the total ozone mitigation potential
- Global MFR gets you almost half the way (40%) towards WHO AQG level

Difference between the 2050 CLE and 2050 MFR:

- ⅓ from CH4 (of which ca 27% from UNECE)
- ⅓ from UNECE NOx/VOC
- ⅓ from ROW - where **international shipping** is ½ of that

EU27 as receptor

2050 LOW versus 2050 CLE - different indicators



LOW is somewhat lower than MTFR

- Results are qualitatively similar (except ozone mean for which European actions are less important and 4th highest where they are dominating).
- The % effect of LOW versus CLE for 2050 is much larger for SOMO35 and POD3 (because of the cut off)

Some internal details, just for MET to keep track for later

Emissions:

- CAO4 emission scenarios for Europe, meaning that spatial gridding also comes from IIASA (not MET gridding based on EMEP as in CAO3)
- Global scenarios are still the same as used for CAO3
- Ship emissions CLE and MFR are a couple of years old, but still kind of valid according to ZIg

Model runs:

- Extra runs are done in order to separate out UNECE:
    - NA (=US+CANADA) reduced separately in the global runs for NOx/VOC
    - Russia outside of EMEP domain reduced separately in global runs for NOx/VOC
- Calculations only done for 1 meteo year (not 5 as usual), but WIllem has checked that another year gives consistent results [for receptor domain averages]
- EMEP domain in regional scale resolution (0.1x0.1), global scale in 0.5x0.5

Emission numbers etc here:

https://docs.google.com/spreadsheets/d/1-F3qC08yVjdpB6XEaB7rarj3p-bEBB7Vw-JE-JWoKW4/edit?gid=686194391#gid=686194391

Scenarios assessment with uEMEP for the Gothenburg Protocol review

- Similar work as described here are planned for the uEMEP ex-post analysis

Can the WHO air quality guidelines be attained under a revised Gothenburg protocol (**how far can we get**)?
Focus on Europe: Future scenarios for the EU, West Balkans and EECCA - **differences between regions?**

- CIAM (IIASA) provided emissions for Baseline, Maximum technical feasible reduction (MFR) and an additional scenario with diet changes and other climate related reductions (LOW)
  - 2015, 2030, 2050 (Baseline/CLE, MFR, LOW)
- **Boundary conditions were kept constant**
- Focus on $PM_{2.5}$ and NO_2 (O_3)

Future scenarios for air quality in Europe, the Western Balkans and EECCA countries: An assessment for the Gothenburg protocol review. Denby et al., 2024 https://doi.org/10.1016/j.atmosenv.2024.120602

How?

WHO guidelines for annual mean $PM_{2.5}$ = 5 $\mu g/m^3$ and NO_2 = 10 $\mu g/m^3$

Proposed EU AAQD in 2030 for $PM_{2.5}$ = 10 $\mu g/m^3$ and NO_2 = 20 $\mu g/m^3$

EMEP/uEMEP

- Regional scale EMEP (0.1x0.1 degree) + uEMEP (downscaling to ca 250 m) modelling of PM, NO_2, ozone
- Comparison at AirBase stations for 2015 (check of methodology etc for present day)

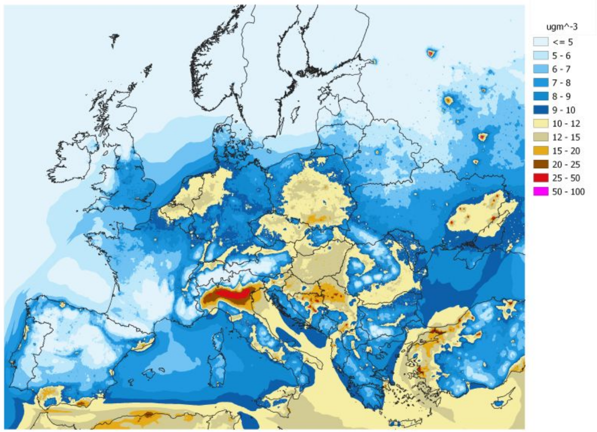


Figure 4.12: uEMEP Western calculation domain showing annual mean $PM_{2.5}$ concentrations for the 2015 Baseline scenario.

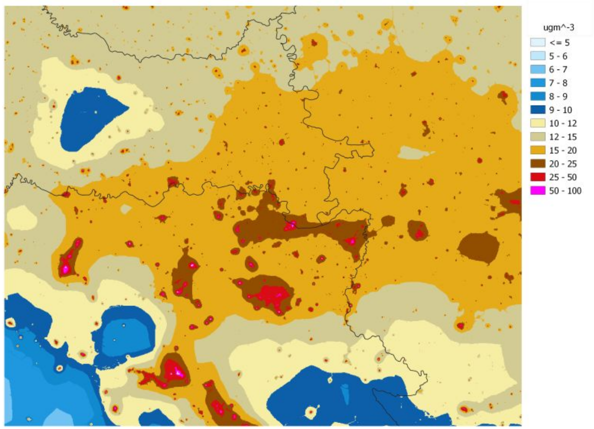
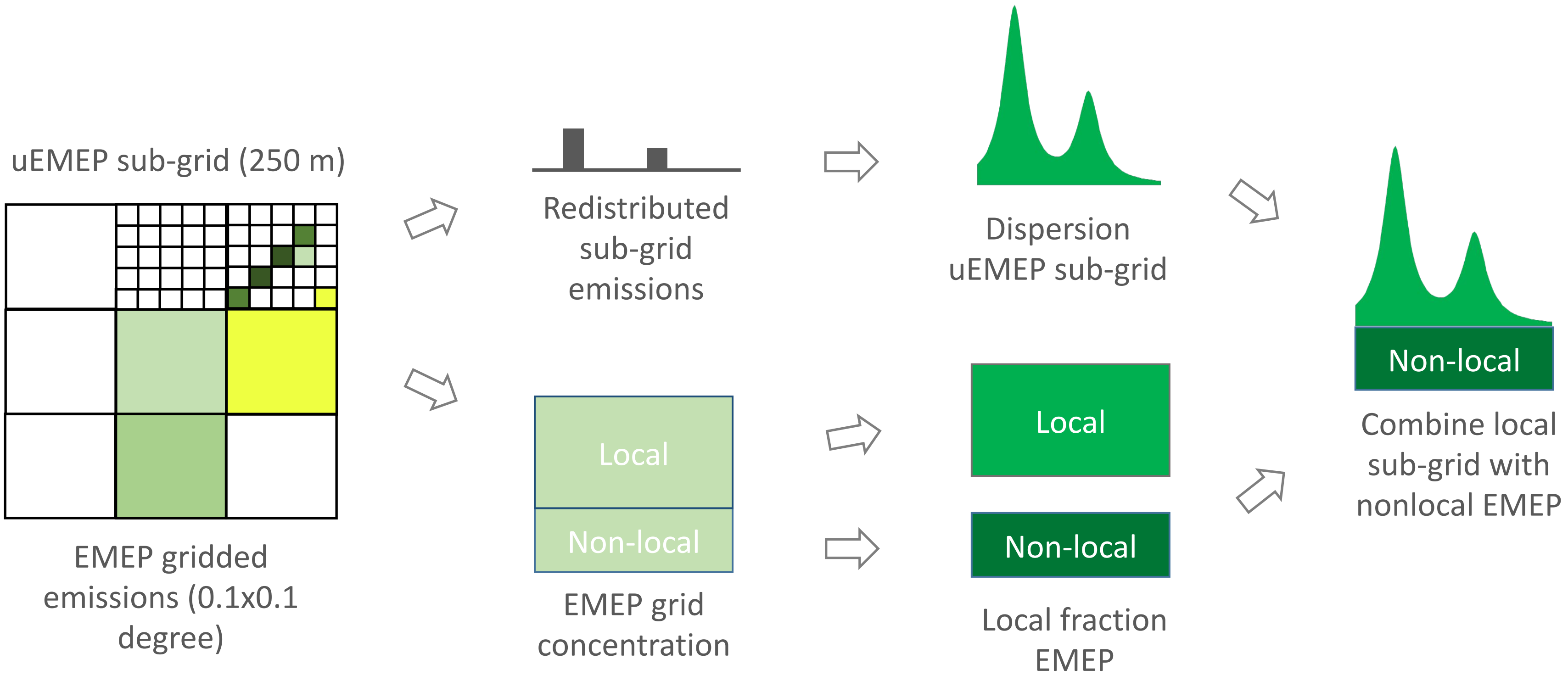


Figure 4.13: uEMEP zoom to the Western Balkan region including Croatia, Hungary, Serbia and Bosnia-Herzegovina showing annual mean $PM_{2.5}$ concentrations for the 2015 Baseline scenario.

How does uEMEP downscaling work ?



E.g. Open Street Map used as proxy for traffic

Conclusions on $PM_{2.5}$ from GP review

- uEMEP calculations show that in 2015 most of the population in EU, Western Balkan and EECCA live in areas that have $PM_{2.5}$ values above current WHO annual mean guideline values of 5 $\mu g m^{-3}$
- By 2030, the Baseline scenario indicates that 75% of the EU population will still be exposed to $PM_{2.5}$ levels above 5 $\mu g\ m^{-3}$ (40% in the 2050 Baseline, 15% in 2050 MFR)
- For the **Western Balkan** and **EECCA** countries, the baseline scenario shows **much less improvement** in the $PM_{2.5}$ levels. For the EECCA countries, the 2050 baseline scenario gives **similar levels to 2015**. Implementation of more stringent air quality policies, and especially the MFR scenario, would result in significant reduction of $PM_{2.5}$ concentrations in these countries. However, some EECCA countries are limited in achieving very low PM concentrations by high levels of wind-blown dust.

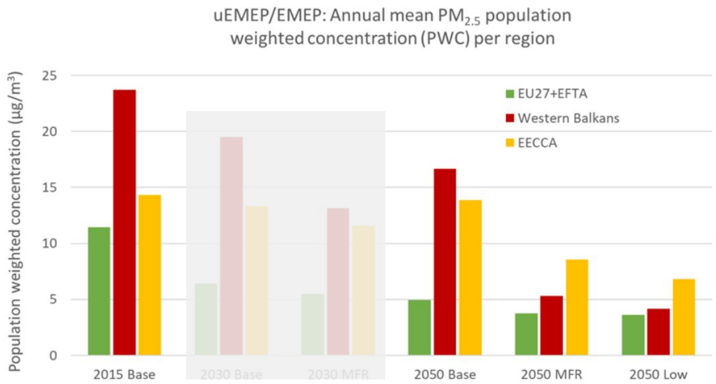


Figure 4.44: Calculated population weighted concentrations (PWC) for the 3 regions and for all scenarios using uEMEP for $PM_{2.5}$.

$PM_{2.5}$

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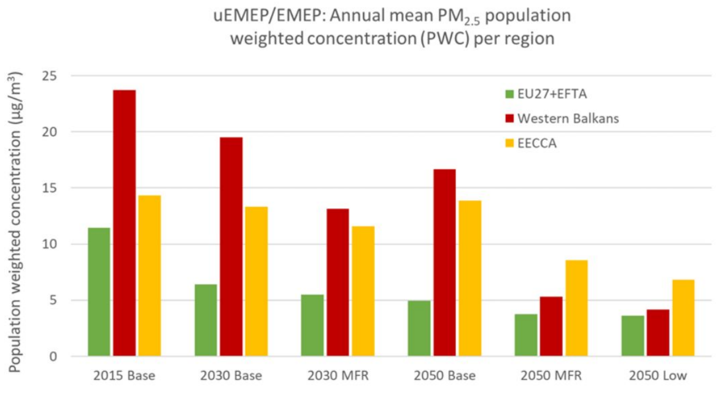


Figure 4.44: Calculated population weighted concentrations (PWC) for the 3 regions and for all scenarios using uEMEP for $PM_{2.5}$.

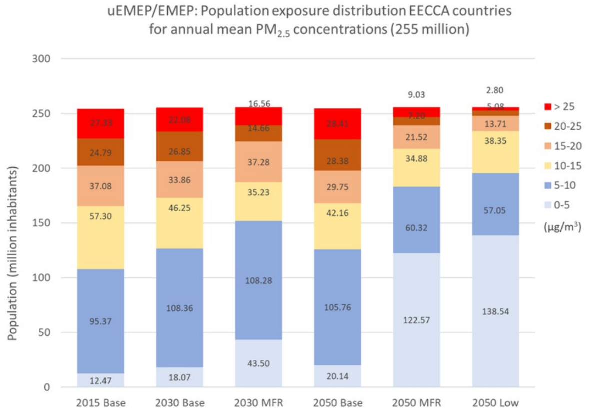


Figure 4.32: EECCA country population exposed to annual mean $PM_{2.5}$ concentrations within defined concentration ranges for all scenarios.

NO_2

- uEMEP calculations show that in 2015 around 65% of the population in the EU, 40% of Western Balkan and 50% of EECCA countries lived in areas above the WHO NO_2 guideline value of 10 $\mu g m^{-3}$
- All the scenarios show that in 2050 less than 2% of the EU population are still exposed to levels above the recommended WHO exposure level of 10 $\mu g\ m^{-3}$. For the Western Balkan, 21% of the population is exposed to NO_2 above 10 $\mu g\ m^{-3}$.
- For the 2050 baseline, EECCA countries show an increase in NO_2 concentrations, compared to 2015, with about 50% of the population exposed to levels above 10 $\mu g\ m^{-3}$ and still with 13% of the population (33 million inhabitants) above the 40 $\mu g\ m^{-3}$ level. It is only with the implementation of MFR that NO_2 concentrations approach, but do not achieve, the WHO guidance level.

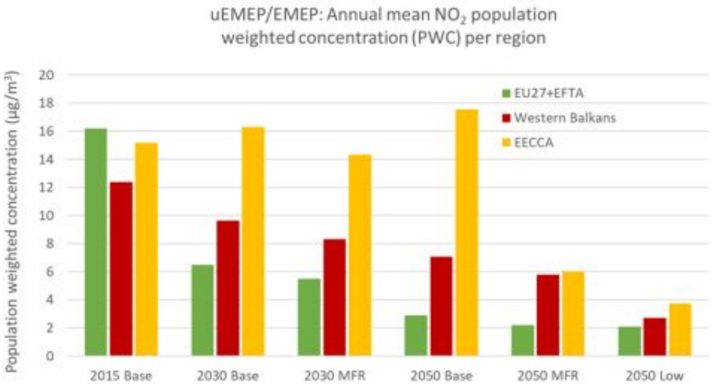
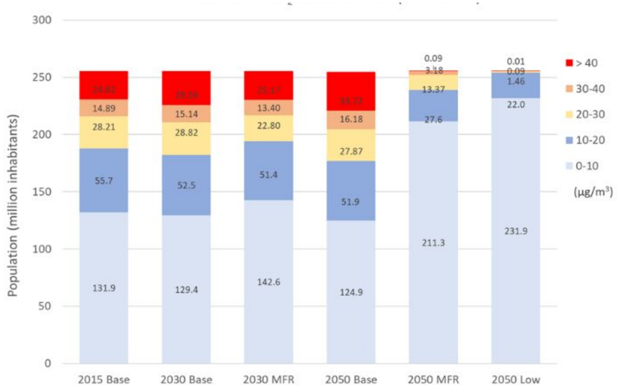


Figure 4.45: Calculated population weighted concentrations (PWC) for the 3 regions and for all scenarios using uEMEP for NO_2.



4.35: EECCA country population exposed to annual mean NO_2 concentrations within defined ntration ranges for all scenarios.

uEMEP analysis for GP revision - upcoming

- A similar analysis with uEMEP will be performed for the ex-post model runs (= TFHTAP runs), for 2 different purposes:
    - Assessment of scenarios
    - Comparison of the results to corresponding results from GAINS (for consistency & validity checks)
- Mostly focused on PM and NO_2

Summary and discussion points

- To ensure robustness of the policy relevant results, the multi model exercise of TFHTAP is (&TFMM) is very valuable - both wrt regional and global modelling

- Should some of the regional runs in the TFHTAP exercise be aligned with model runs as done for the ex-post analysis? ('ensemble ex-post analysis')
- Domain of the regional models (EMEP or CAMS?)
- Boundary conditions? Temporal, species

The End

What MSC-W has done and what we are planning to do - and how you can contribute to the support of the GP revision

-mixture of results using previous versions of the scenarios

-some forward-looking material on the planned analysis using the new scenarios and how the ensemble of regional models we are hoping to recruit could contribute to this.

Part of the reason for the session is to motivate groups to participate in the exercise. It will also be important to show how this all contributes to the revision of the Gothenburg Protocol. The draft TFMM agenda I have seen so far focuses on other aspects of the work plan, so your talk might be one of the few in the whole TFMM meeting where modelling of the GAINS scenarios is discussed.

I think your suggestions sound good. The CH4/O3 work is important because this will be a focus of the ensemble exercise. Since you are also planning to do downscaling with uEMEP, then this would also be worth mentioning. It would also be great if you could say something about the boundary conditions you could provide to other regional models from your EMEP simulations.

We currently plan on a 30 minute time slot including questions and discussion.

HTAP3-OPNS

Overarching questions of HTAP3-OPNS:

- What are the relative contributions of intra-regional and extra-regional sources to air pollution and its impacts in different world regions?
- How suitable are current models for quantifying these contributions? Can we explain the inter-model differences?
- How will these contributions change under different possible future emission scenarios and under future climate change?

New aspects:

- A stronger focus on the **impacts** of ground-level ozone, especially damage to vegetation.
- A stronger focus on the effects of **methane** on ground-level ozone.
- A stronger focus on the effects of **wildfires** on long-range air pollution.
- A stronger focus on **total atmospheric deposition**, in support of the World Meteorological Organization (WMO) MMF-GTAD
- The use of **free-running future simulations** with atmospheric chemistry-climate models in addition to an ensemble emulator based on source-receptor relationships.
- Calculation of source/receptor relationships for air pollution based on a **future emissions scenario** rather than historical emissions.
- Comparison of **different methods for calculating source-receptor relationships**, such as tagging and adjoint techniques.

What MSC-W has done and what we are planning to do - and how *you* can contribute to the support of the GP revision

- Multi-scale modelling (down to 100/250m) of NO2, PM25, PM10, O3
    - Present and Future => What is possible to gain for NO2, PM with CLE/MFR
    - Done 2 years ago and published: XX
    - Will be redone with new scenarios for ex-post analysis
- LF calculations + exposure corrections (fine scale) analysed and implemented in GAINS (so that GAINS can take into account fine scale+pop). Published XX
- Ozone analysis and Conc response to emis change analysis (Monday talk)
- Assessment of EC (Monday?)
- CH4 & Ozone - published XX, plus Policy brief
- Focus on EECCA & Western Balkans
- New scenarios for ex-post analysis - to feed WGE (plus uEMEP)

How can you contribute?

- Assessment of the GAINS LRTAP scenarios using high resolution regional models for Europe (and North America)
- The policy brief

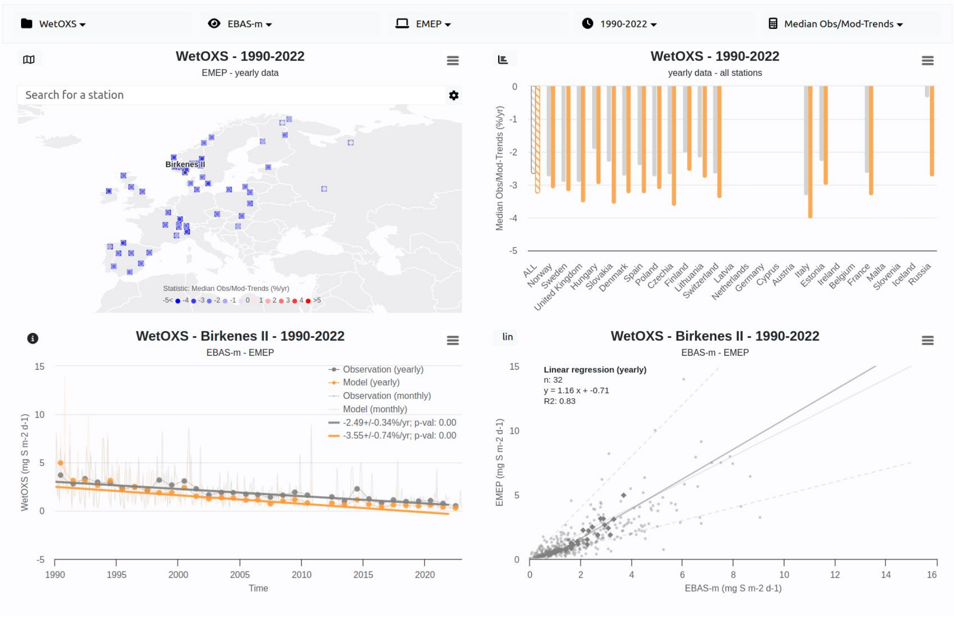
Trend interface & 1990-2023 model results

EMEP MSC-W model runs for 1990-2023 available (34 years!) with updated emissions (by CEIP) and a consistent model version. Available from *https://emep.int/mscw/mscw_moddata.html*

NB: ‘Condensables’ consistent from 2005

Trend interface extended back to 1990 (with ‘raw observations’) https://aeroval.met.no/pages/evaluation/?project=emep_trends&experiment=2024-trends_1990-2022
Online model evaluation (and observation assessment) for a range of years on AeroVal:

https://aeroval.met.no/evaluation.php?project=emep&exp_name=2024-reporting&station=ALL



Everything can be accessed from emep.int/mscw

CEIP provided updated emission data and CCC provided an extract of observational EBAS data base

GP revision runs for ex-post analysis

Future reduction scenarios apply only to the EMEP countries, with the **rest-of-world (global) following Current Legislation (CLE) emissions** (e.g. 2040 CLE in 2040)

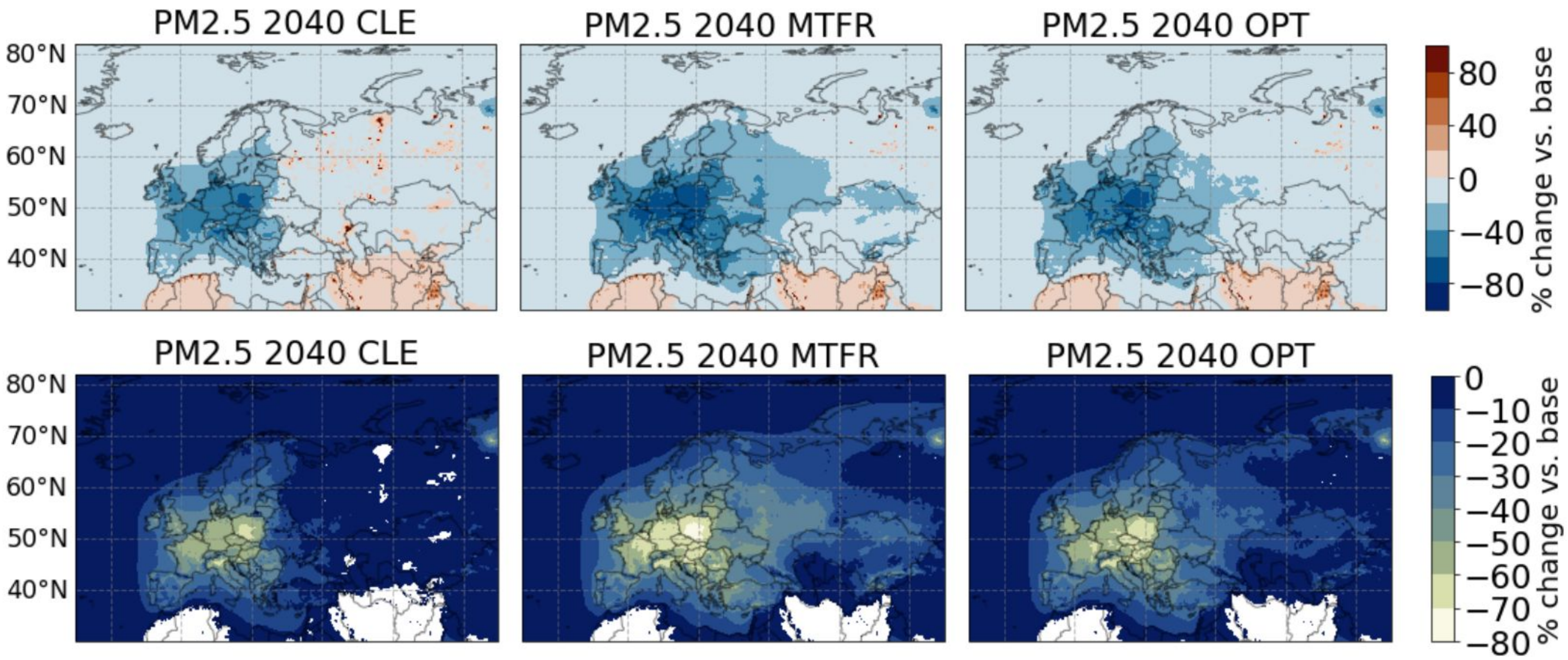
- All EMEP MSC-W model calculations with 5 meteorological years

Emissions:

- ➢ **2015** baseline emission year
- ➢ **2040 CLE** represents ‘business as usual’ for the target year
- ➢ **2040 MTFR** applies Maximum Feasible Technical Reductions with CLE activity data
- ➢ **The optimized 2040 OPT** scenario achieves a reduction of premature mortality (attributable to ambient PM2.5) in 2040 by 50% compared to 2015

International shipping follows CLE in all scenarios. Emissions from soil-NOx follow climatological conditions.

Changes in PM2.5 relative to 2015



Examples of total deposition