

# Progress in modelling undertaken by CIAM for the GP Revision

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CIAM/IIASA

TFIAM meeting, Brussels, 22-23 April 2026

- Scenarios v6b
- Optimization for *joint* health and biodiversity targets
- Health *only* optimization, sensitivity to variable ambition level
- Sensitivity to assumptions for N mitigation costs
- Progress in revising ozone calculations in GAINS
- BC
- CA05, Next steps towards v7

# Emission scenarios for GP Revision: recent progress

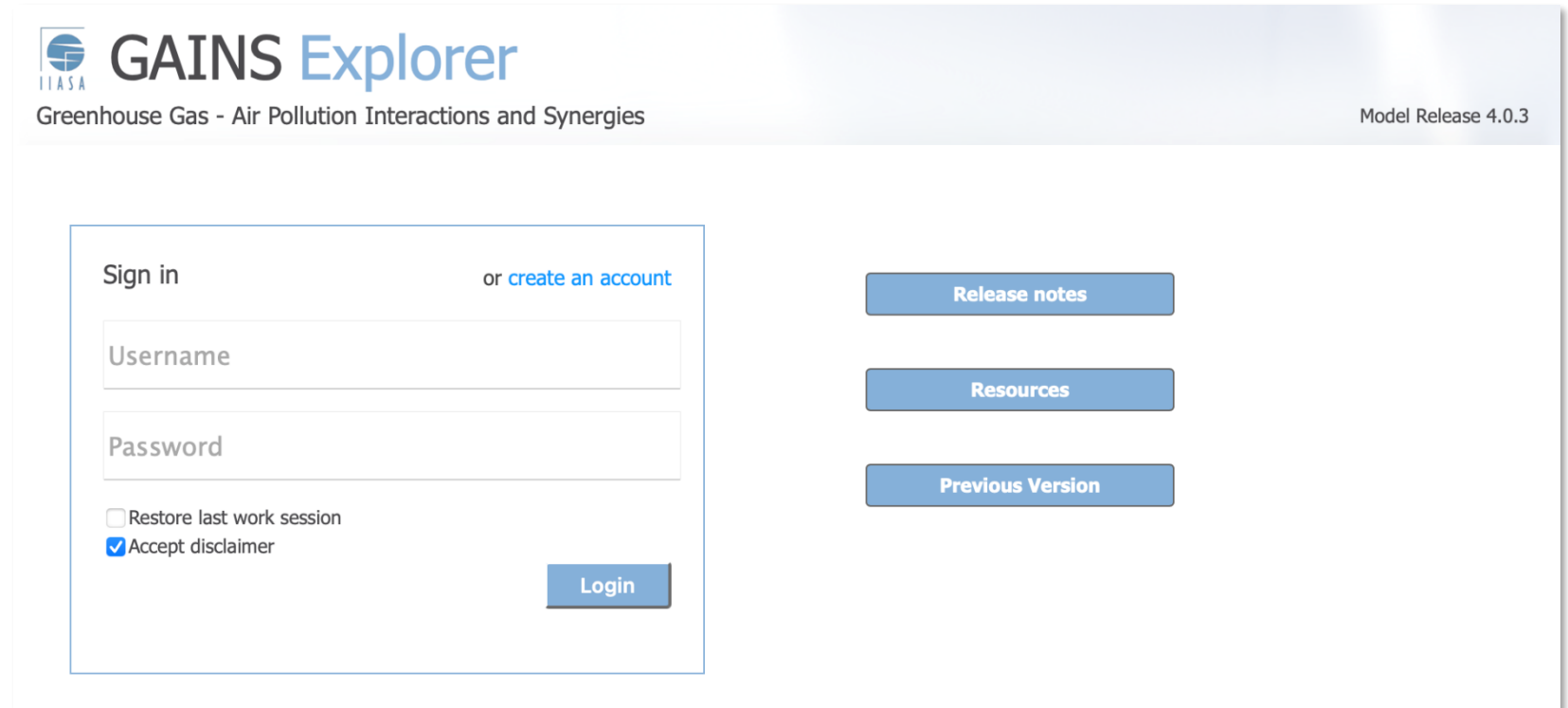
- **Baseline and MTR v5a:**
  - Inclusion of outcomes from the bilateral consultations with EU Member States for Clean Air Outlook 4 ([EC Report](#) and [support report led by IIASA](#) released March 2025)
  - Inclusion of results from the EU4Green project for West Balkan and other consultations
- **Baseline and MTR v6a:**
  - Revisions and updates following EU4Green-II consultations (West Balkan) and follow ups after TAIEX meeting (non-parties)
- **Baseline and MTR v6b:**
  - Includes updates following exchanges with UK, Switzerland
- **Cost-optimal scenarios**
  - PM<sub>2.5</sub> risk function updated to HRAPIE2 (RR=1.095 / 10µgm<sup>-3</sup> for natural-cause mortality)
  - Population projections were updated to UN WPP2024
  - Joint optimization for health and biodiversity risks
  - Variable ambition level for health targets (45-60%) with static and dynamic population
  - Sensitivity towards N mitigation costs
- **LOW** (not yet synchronized with latest updates)

# GAINS Explorer

<https://gains.iiasa.ac.at/gains/GPV/index.login>

## Online application to view for discussed policy scenarios:

- *Emissions,*
- *Concentrations,*
- *Exposure,*
- *Impacts,*
- *...and more coming*



The screenshot shows the GAINS Explorer login interface. At the top left is the IIASA logo and the text "GAINS Explorer". Below this is the subtitle "Greenhouse Gas - Air Pollution Interactions and Synergies". At the top right, it says "Model Release 4.0.3". The main content area features a login form on the left and three navigation buttons on the right. The login form includes a "Sign in" label, a link to "create an account", input fields for "Username" and "Password", a checkbox for "Restore last work session", a checked checkbox for "Accept disclaimer", and a "Login" button. The navigation buttons are labeled "Release notes", "Resources", and "Previous Version".

## Towards optimized scenarios considering joint **Health and Biodiversity** objectives/targets

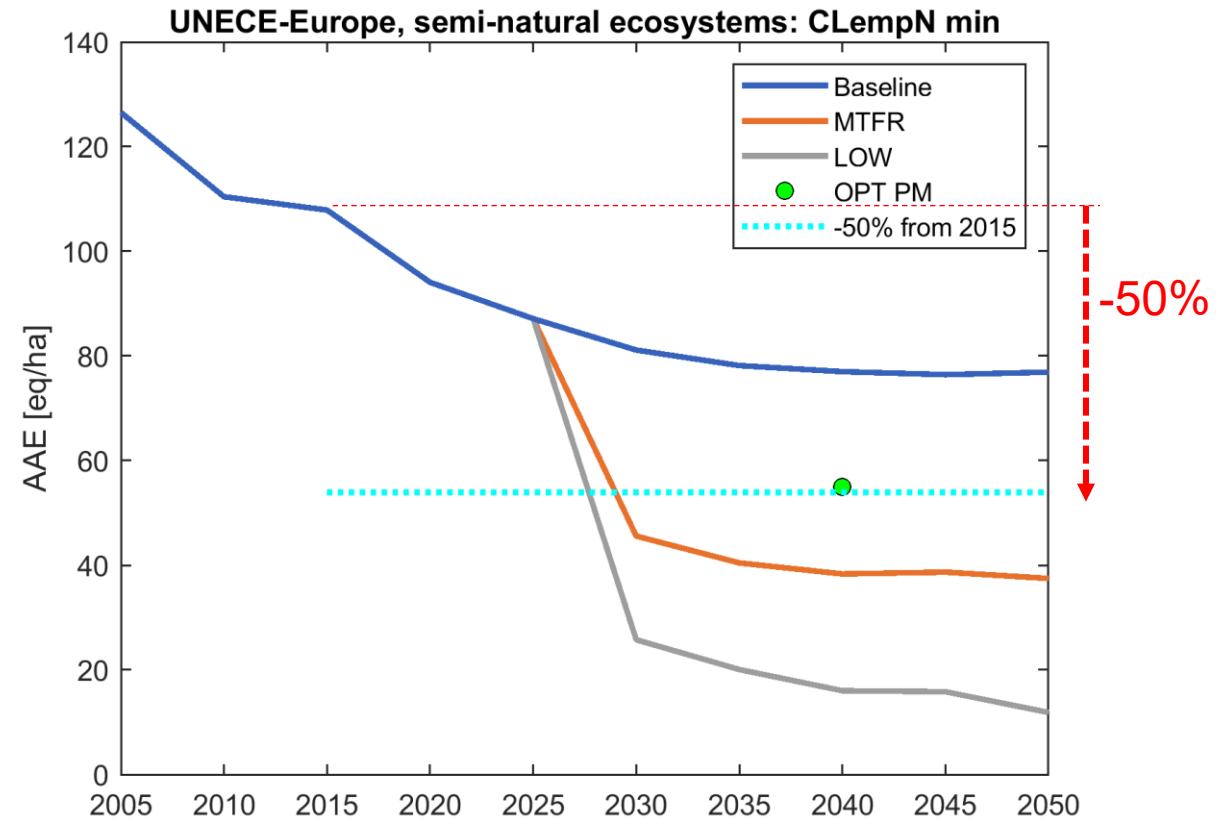
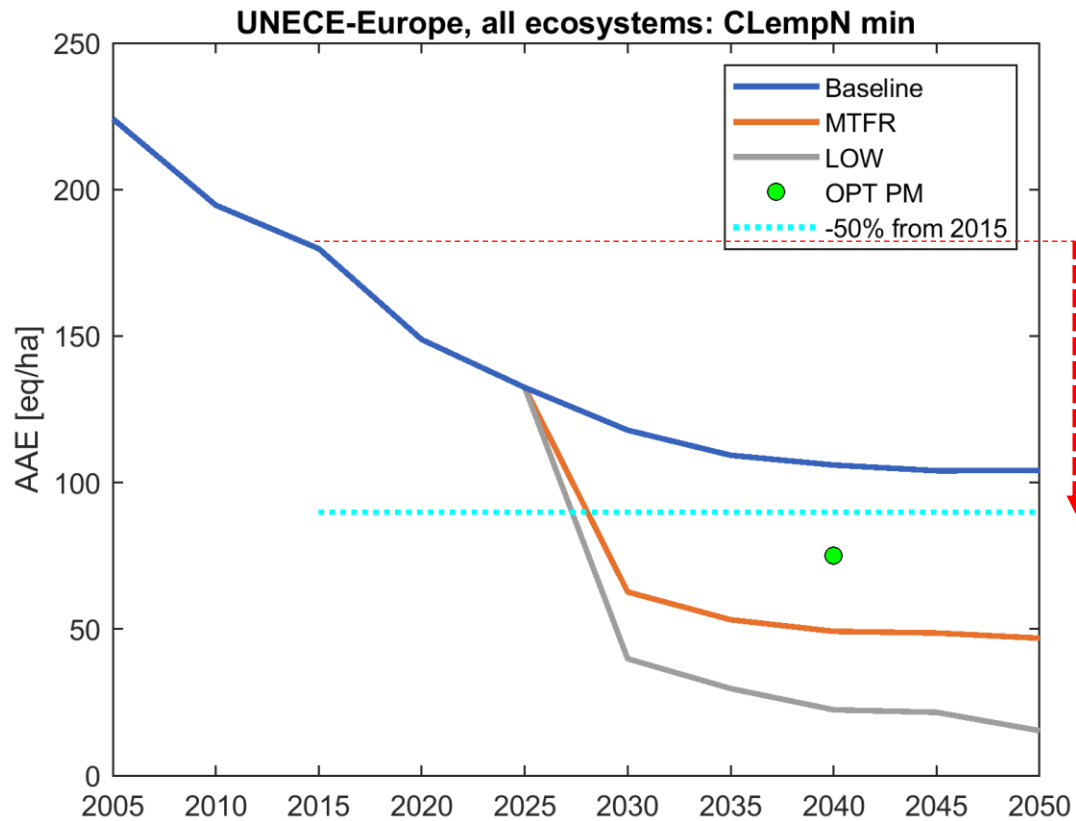
- *Using updated CL data (June 2025) and v6a scenario set*
- *Biodiversity goal set as 50% reduction of ecosystem specific AAE ( $CL_{empN_{min}}$ ) by 50%; rel. to 2015*
- *Feasible except for 4 ecosystem types*

# Empirical critical loads for nitrogen deposition

- CIAM received from CCE in April 2024, updated in June 2025:
  - Empirical critical loads for 50 ecosystem classes
  - Giving min and max CL [kgN/ha/yr]
  - And ecosystem maps for the whole domain (area of each class per grid cell)
- CIAM has processed and implemented them in GAINS
- Calculated indicators equivalent to the acidification/eutrophication calculations: area exceeding CL, average accumulated exceedance (AAE)
- Only land and freshwater ecosystems are considered, not marine
- *CCE provided in March 2025 CLs based on contribution from National Focal Centers. These have not been used in GAINS yet, but could be (if desired) in additional ex-post analysis, if provided in an equivalent format as the harmonized ones*

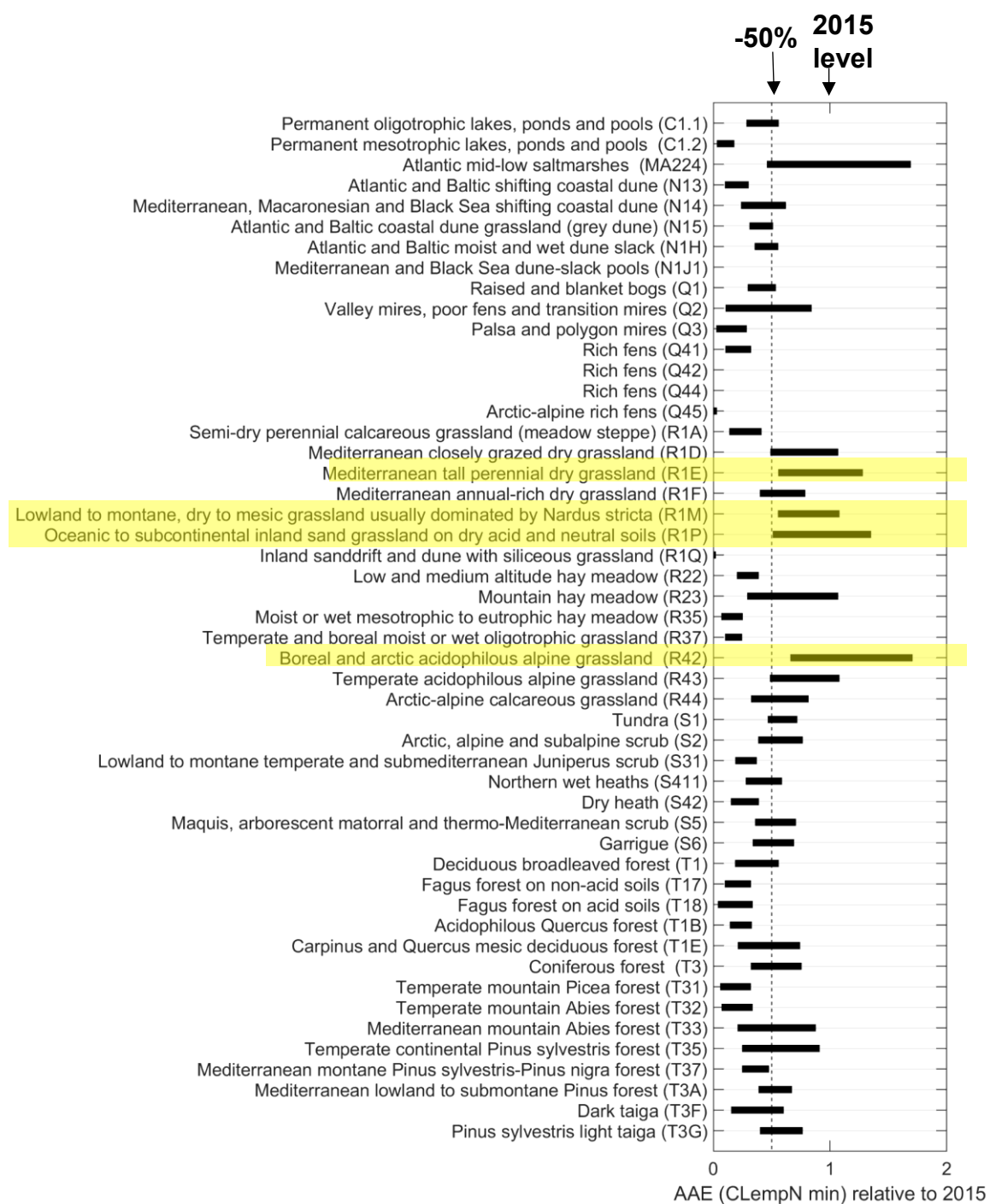
# Scope for further mitigation in the UNECE region

*Exploring attainability of 50% ecosystem (biodiversity) protection goal*

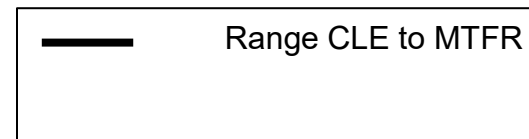


● Biodiversity risk when the health target of reducing premature mortality by 50% is achieved (dynamic population)

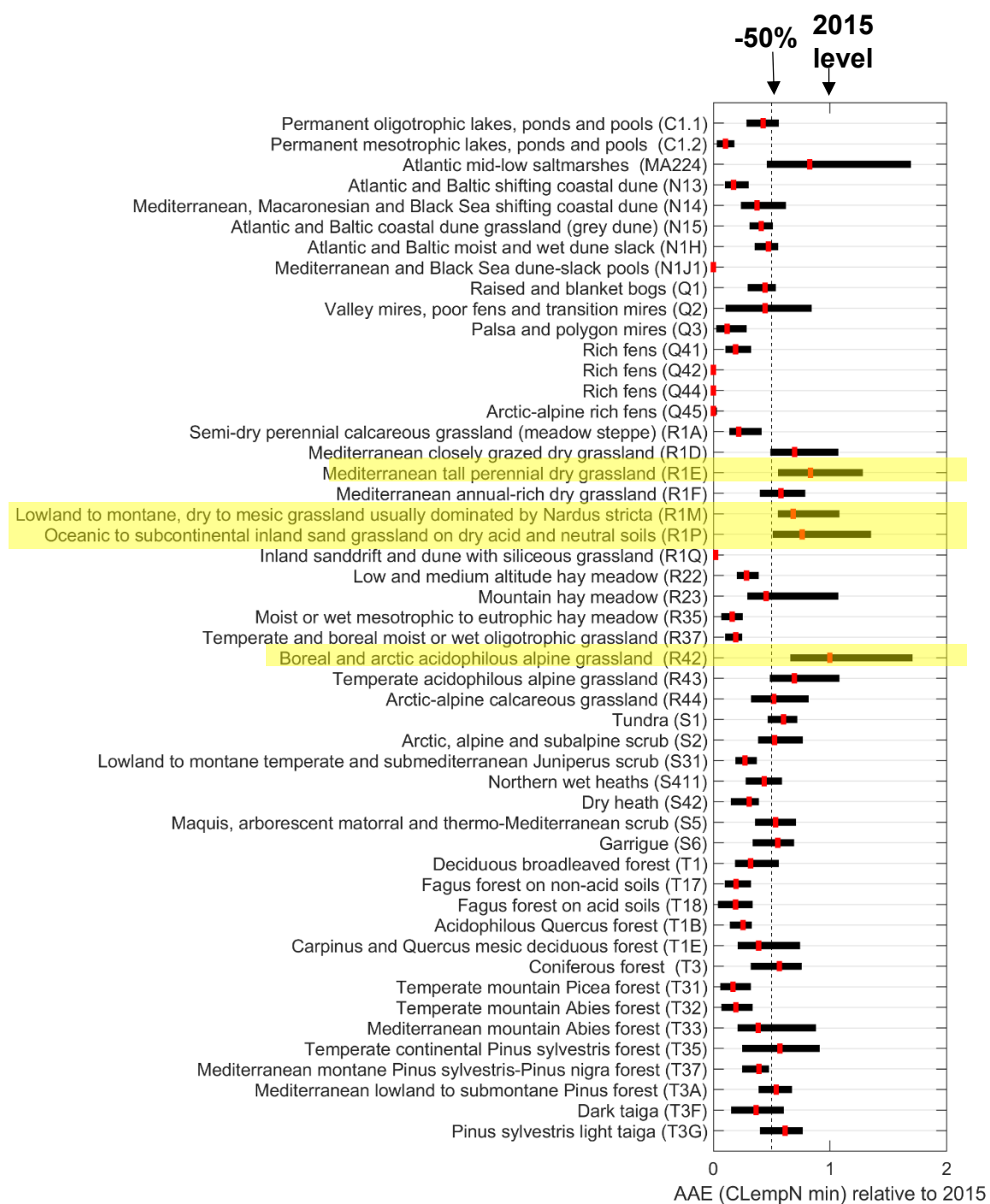
# AAE for individual EUNIS habitat types (2040)



Reduction of AAE by 50% vs 2015 is not feasible for several grassland habitat types.

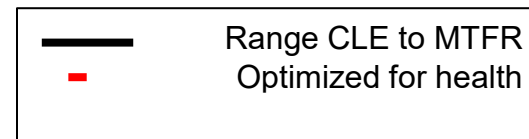


# AAE for individual EUNIS habitat types (2040)

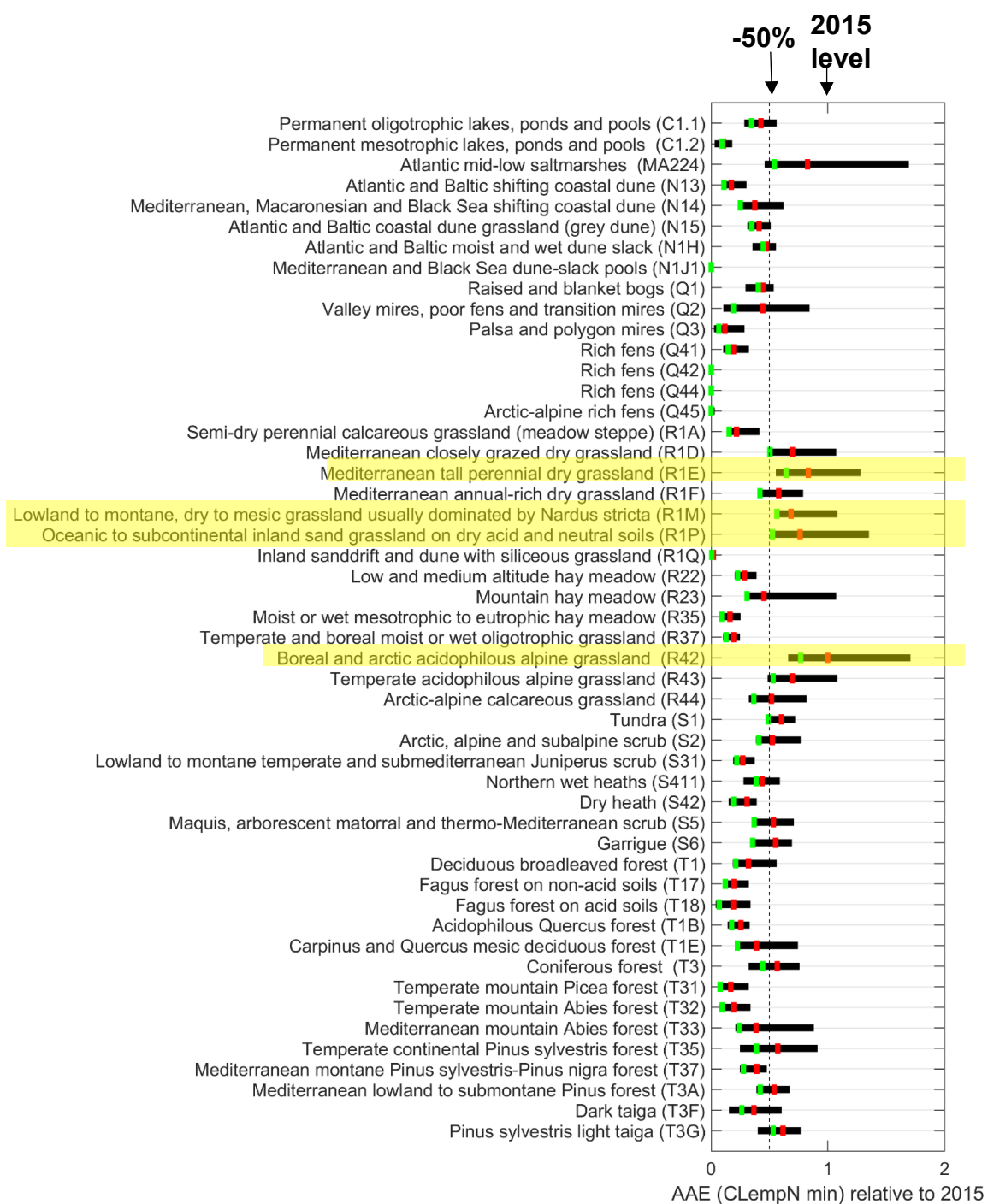


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Already the PM-health target alone brings considerable reductions in AAE and for many habitat class delivers 40% reduction of risk.



# AAE for individual EUNIS habitat types (2040)



Reduction of AAE by 50% vs 2015 is not feasible for several grassland habitat types.

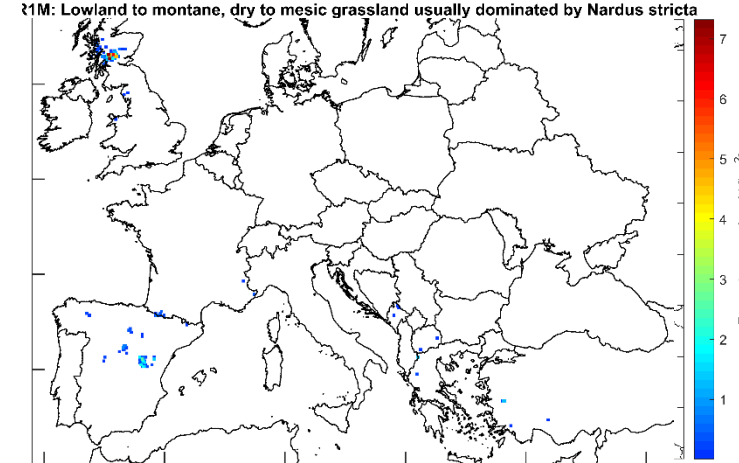
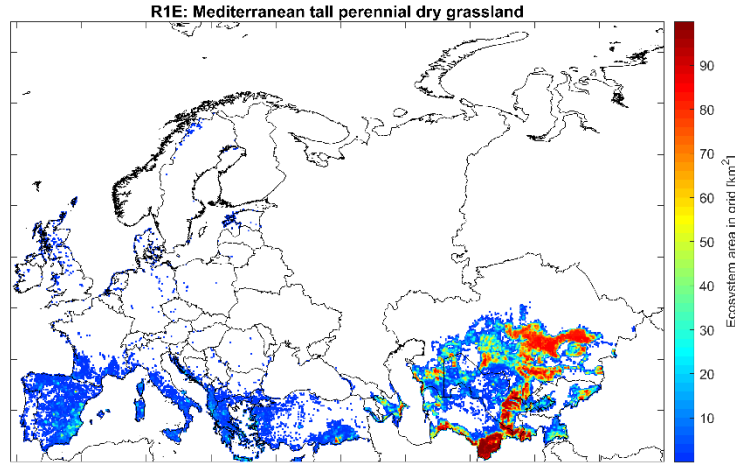
Already the PM-health target alone brings considerable reductions in AAE and for many habitat class delivers 40% reduction of risk.

Additional reductions in the health+AAE optimized case through further NO<sub>x</sub> and NH<sub>3</sub> reductions.

# Habitat types unable to reach -50% AAE (CLempN<sub>min</sub>)

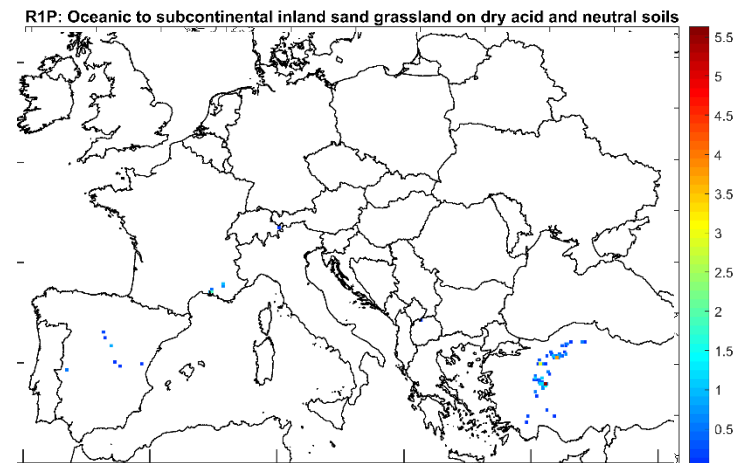
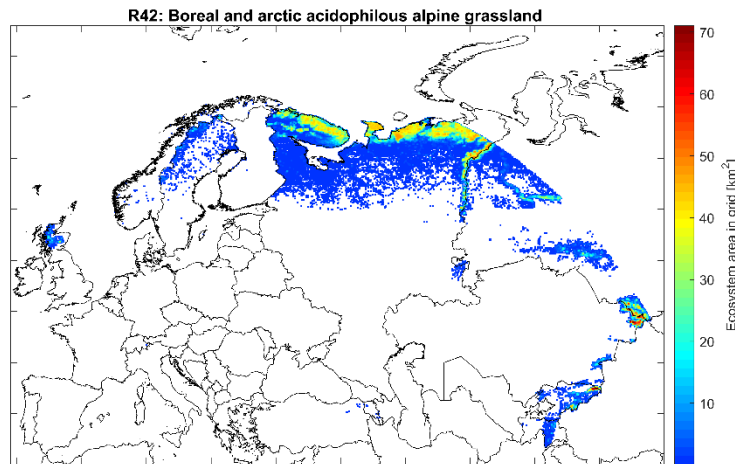
using harmonized receptor map and CLempN from CCE June 2025

Total ecosystem  
area: 899693 km<sup>2</sup>  
Exceeded in 2040  
CLE: 289252 km<sup>2</sup>



Total ecosystem  
area: 400km<sup>2</sup>  
Exceeded in 2040  
CLE: 9km<sup>2</sup>

Total ecosystem  
area: 285367 km<sup>2</sup>  
Exceeded in 2040  
CLE: 1585 km<sup>2</sup>

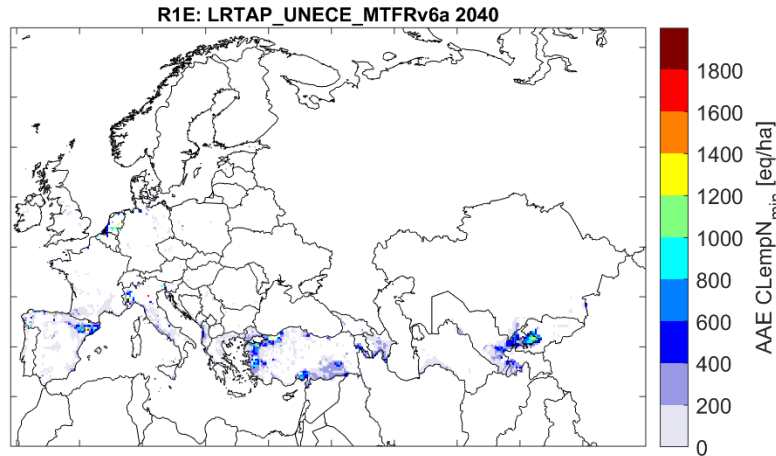


Total ecosystem  
area: 80km<sup>2</sup>  
Exceeded in 2040  
CLE: 73km<sup>2</sup>

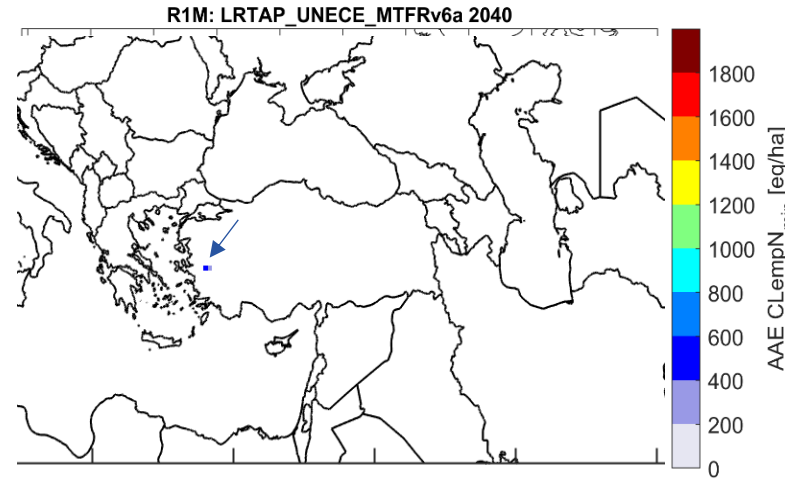
# AAE of $CLempN_{min}$ in MTRF 2040

using harmonized receptor map and  $CLempN$  from CCE June 2025

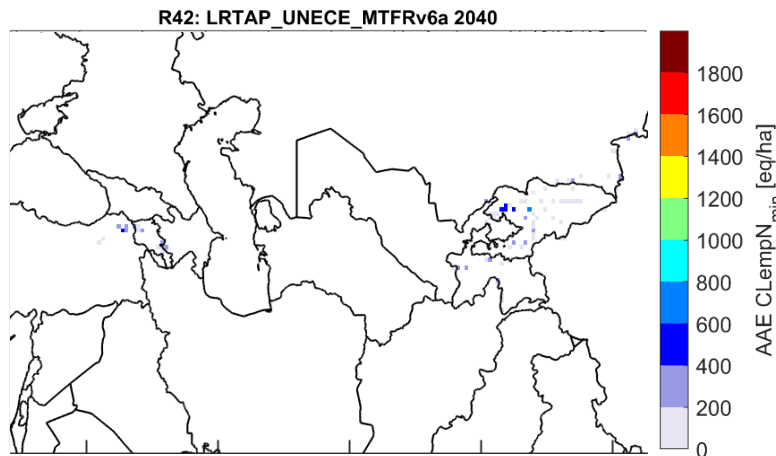
Total ecosystem area: 899693 km<sup>2</sup>  
Exceeded in 2040 MTRF: 188039 km<sup>2</sup>



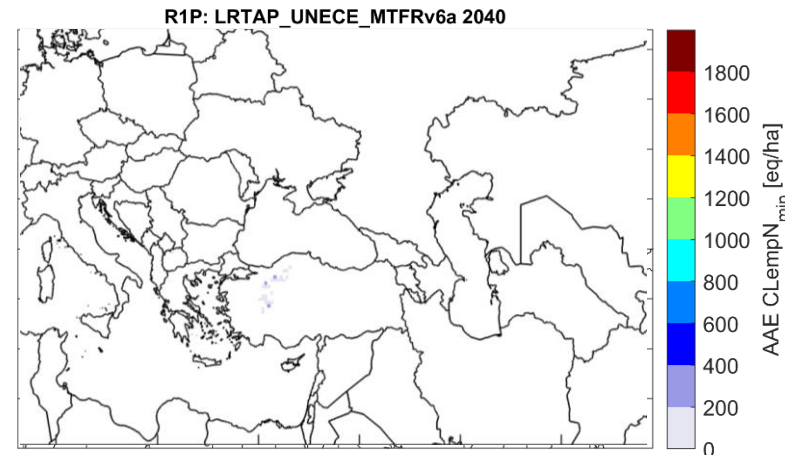
Total ecosystem area: 400km<sup>2</sup>  
Exceeded in 2040 MTRF: 6km<sup>2</sup>



Total ecosystem area: 285367 km<sup>2</sup>  
Exceeded in 2040 MTRF: 750 km<sup>2</sup>



Total ecosystem area: 80km<sup>2</sup>  
Exceeded in 2040 MTRF: 71km<sup>2</sup>

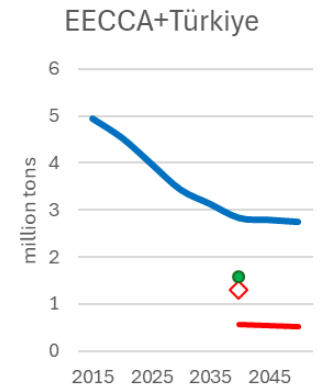
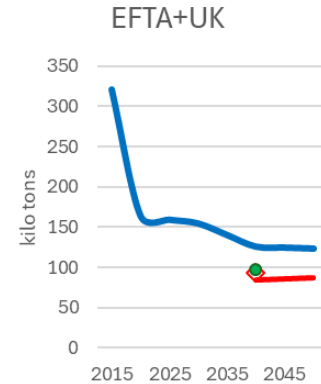
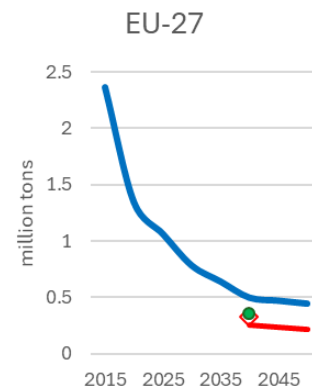
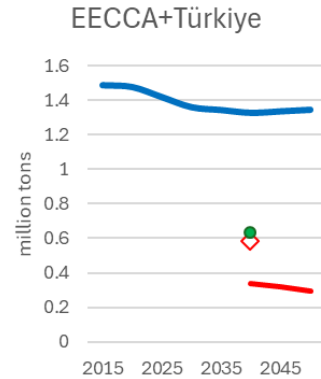
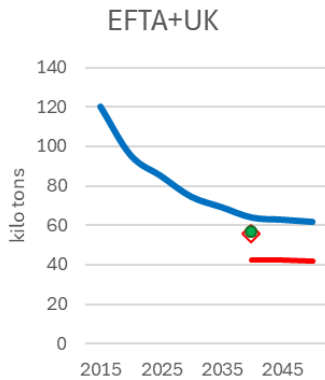
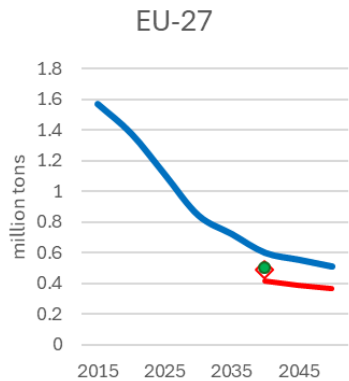
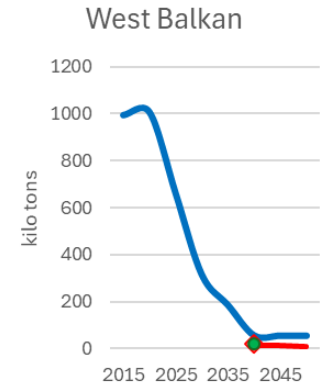
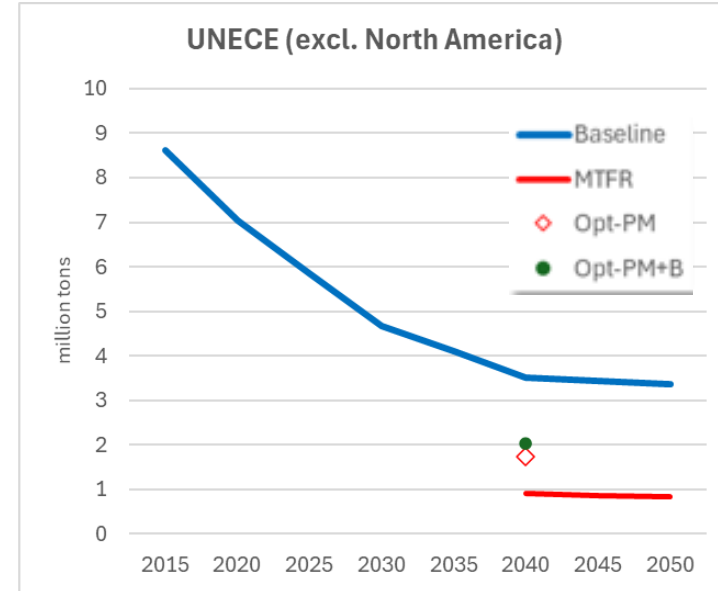
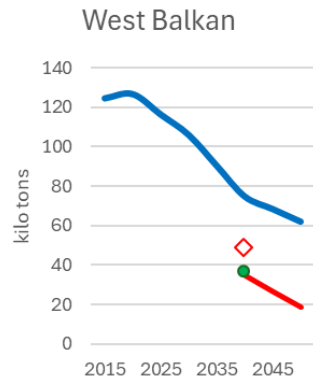
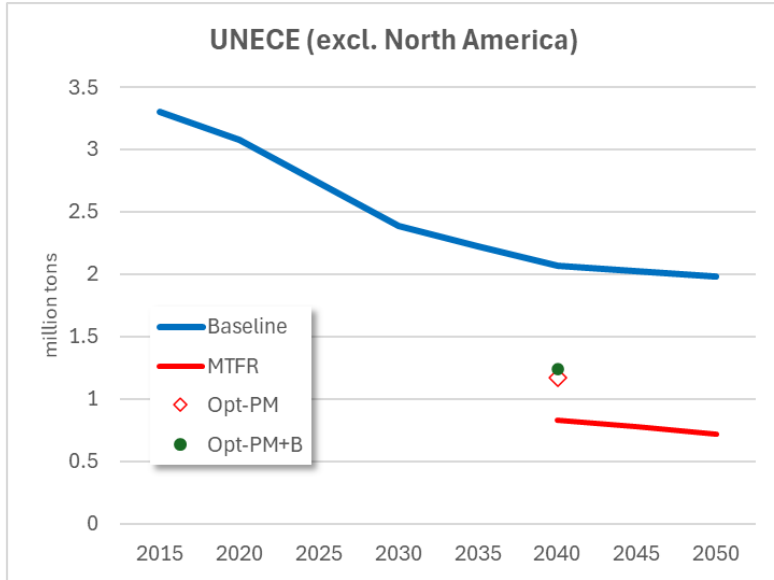


# Sulfur and nitrogen emissions in the current scenarios (v6a)

Opt-PM - 50% reduction of premature mortality (PM) for UNECE, dynamic population,  
 Opt-PM+B refers to PM and biodiversity (B) targets,

## Particulate Matter (PM<sub>2.5</sub>)

## Sulfur Dioxide (SO<sub>2</sub>)

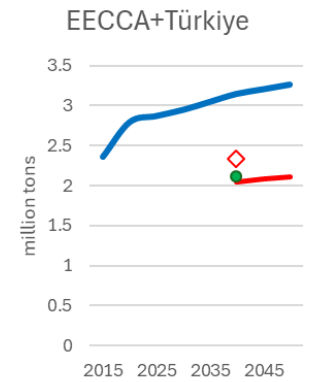
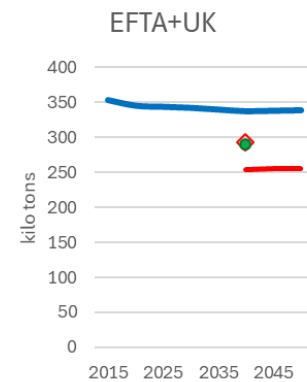
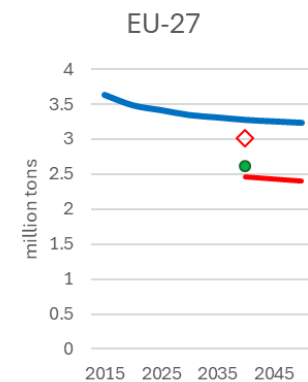
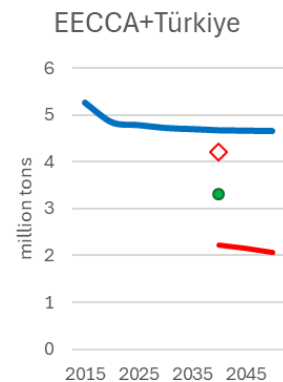
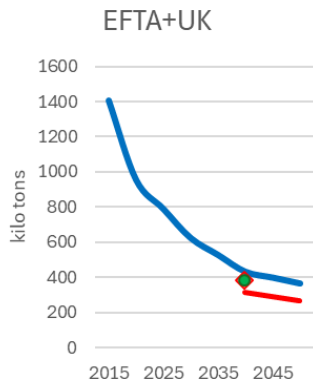
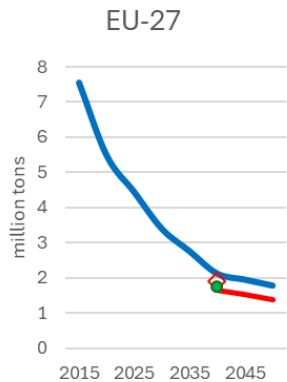
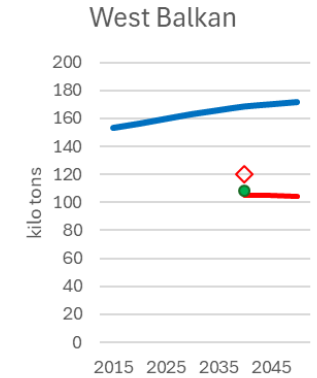
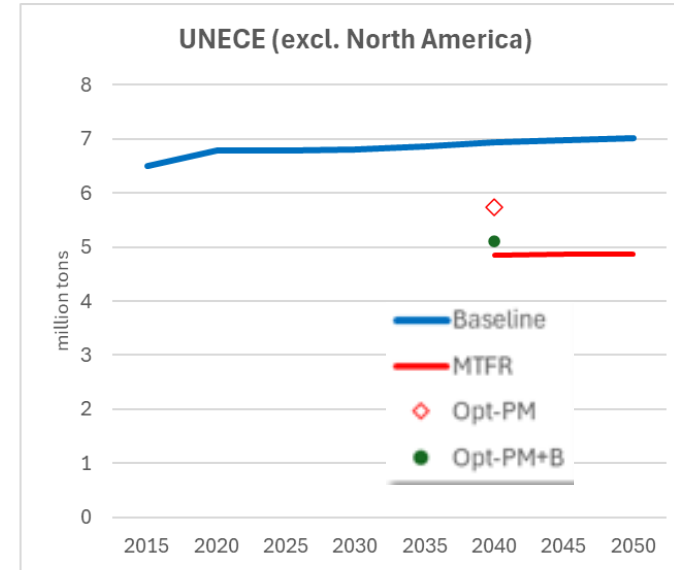
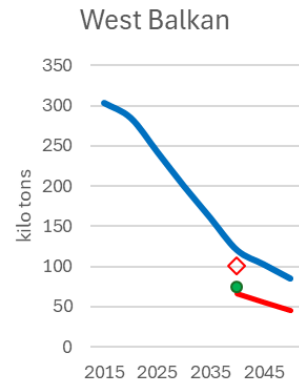
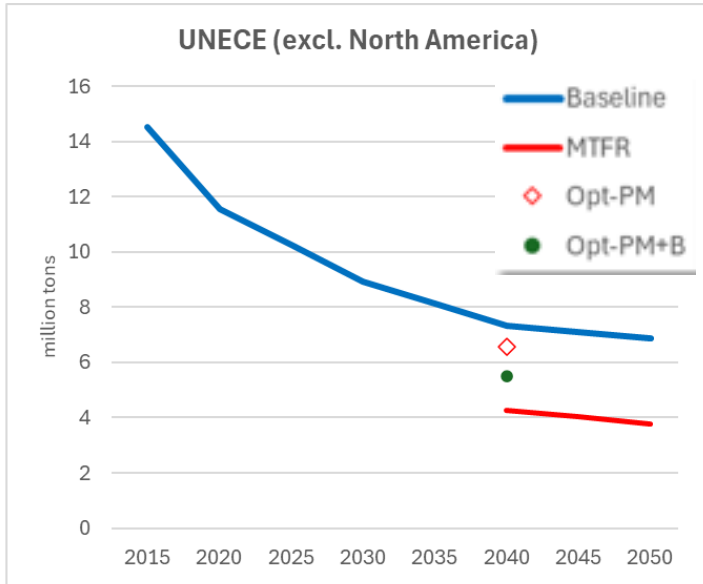


# Sulfur and nitrogen emissions in the current scenarios (v6a)

Opt-PM - 50% reduction of premature mortality (PM) for UNECE, dynamic population,  
 Opt-PM+B refers to PM and biodiversity (B) targets,

## Nitrogen Oxides (NO<sub>x</sub>)

## Ammonia (NH<sub>3</sub>)



# Summary – including biodiversity goals

**Feasibility:** Achieving 50% reduction of 2015 AAE for CLempN by 2040 appears feasible at the UNECE-Europe level and within all sub-domains for total ecosystems, but not for each habitat type individually. Exploiting transformational measures such as in LOW scenario can offer further potential and reduce costs.

**Importance of CLE enforcement:** Full enforcement of Baseline policies (CLE) achieves by 2040 about 41% to 54% reduction in AAE in UNECE-Europe compared to 2015, for CLempN-MIN and CLempN-AVG, respectively.

**Achieving 50% health (PM mortality) target brings large benefits:** Over 58% and nearly 72% of biodiversity risk (CLempN-min, CLempN-avg) could be reduced when PM health target of 50% reducing premature mortality is met by 2040

**Cost optimization:** Reduction targets for different ecosystem types rather than for different countries. Selected target: -50% AAE for each habitat, except 4 where this is not attainable.

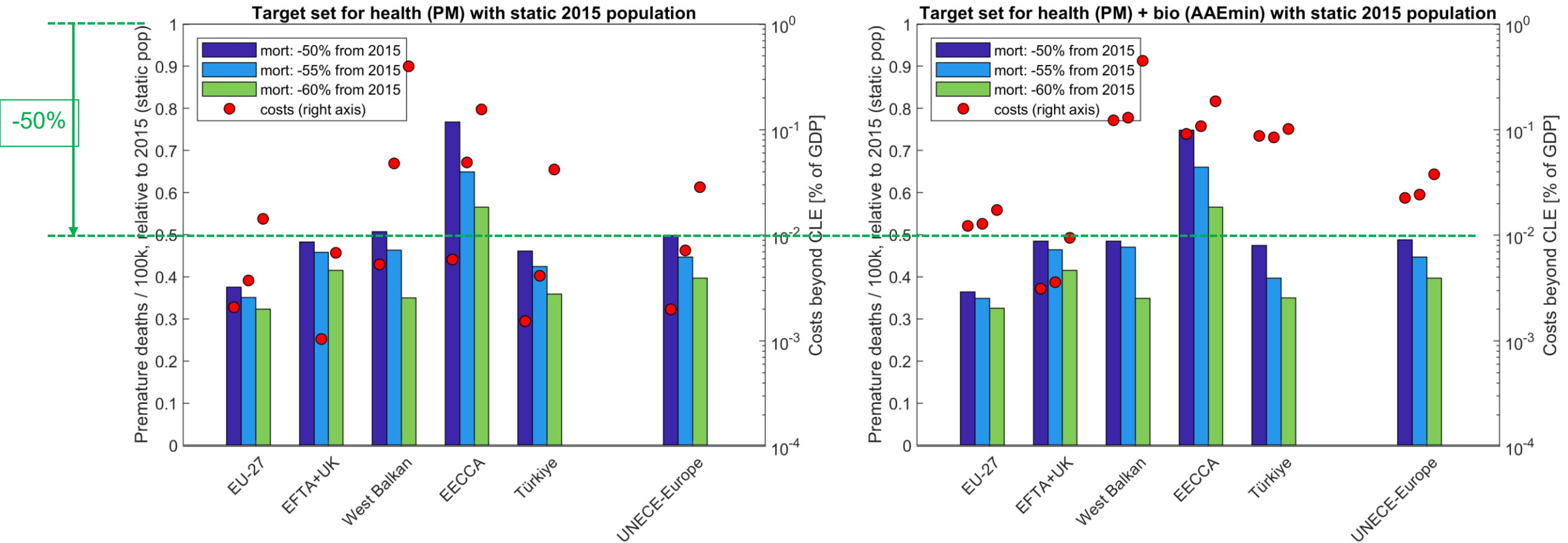
**Health vs Health+Biodiversity:** More pressure on NH<sub>3</sub>, NO<sub>x</sub> reductions; slight decline for SO<sub>2</sub> and PM<sub>2.5</sub> reduction needs.

## Sensitivity analysis on cost-optimal scenarios

- Different ambition levels for the mortality target
- Reduced N mitigation costs

# Sensitivity analysis *(using v6b scenario set)*

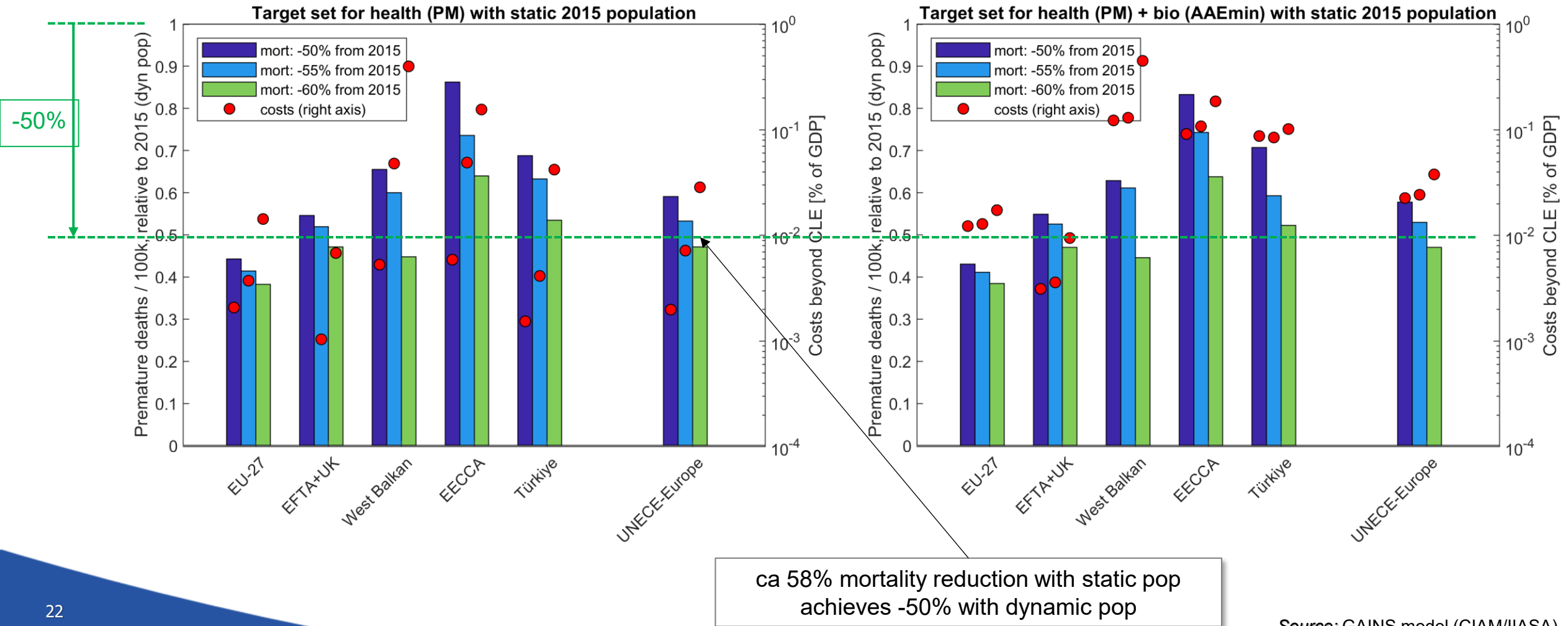
*Optimization outcomes for varying ambition levels for mortality reduction (static 2015 pop)*



# Sensitivity analysis *(using v6b scenario set)*

Optimization outcomes for varying ambition levels for mortality reduction (static 2015 pop)

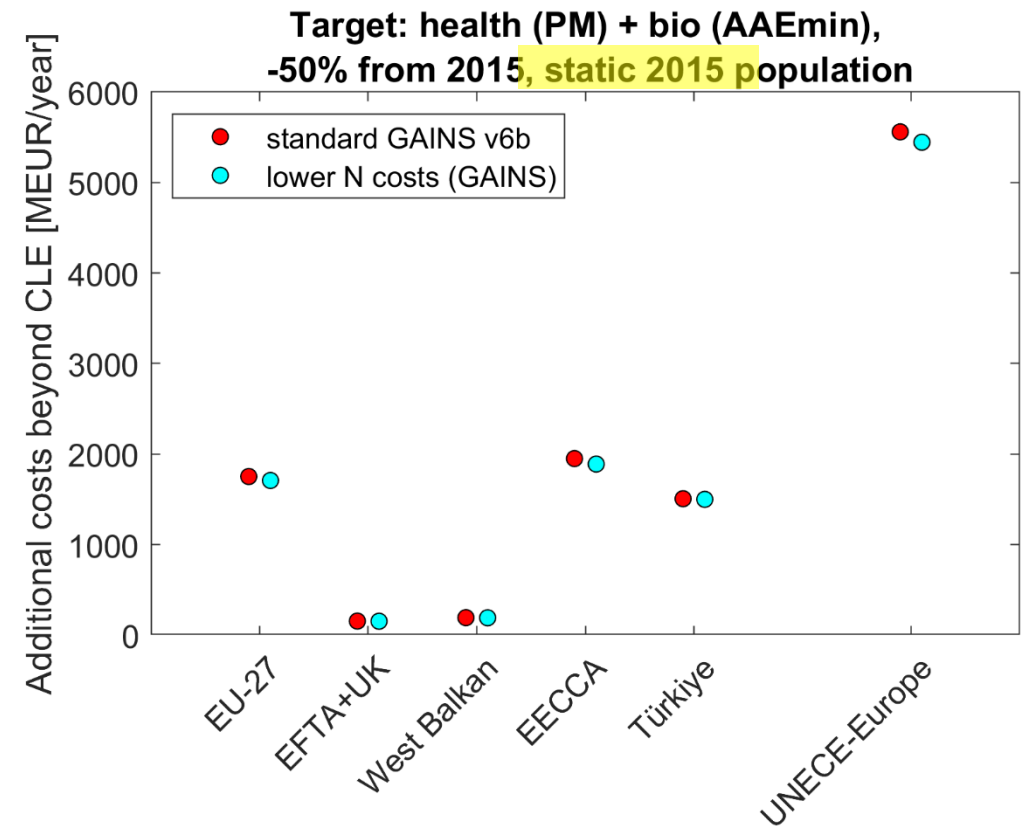
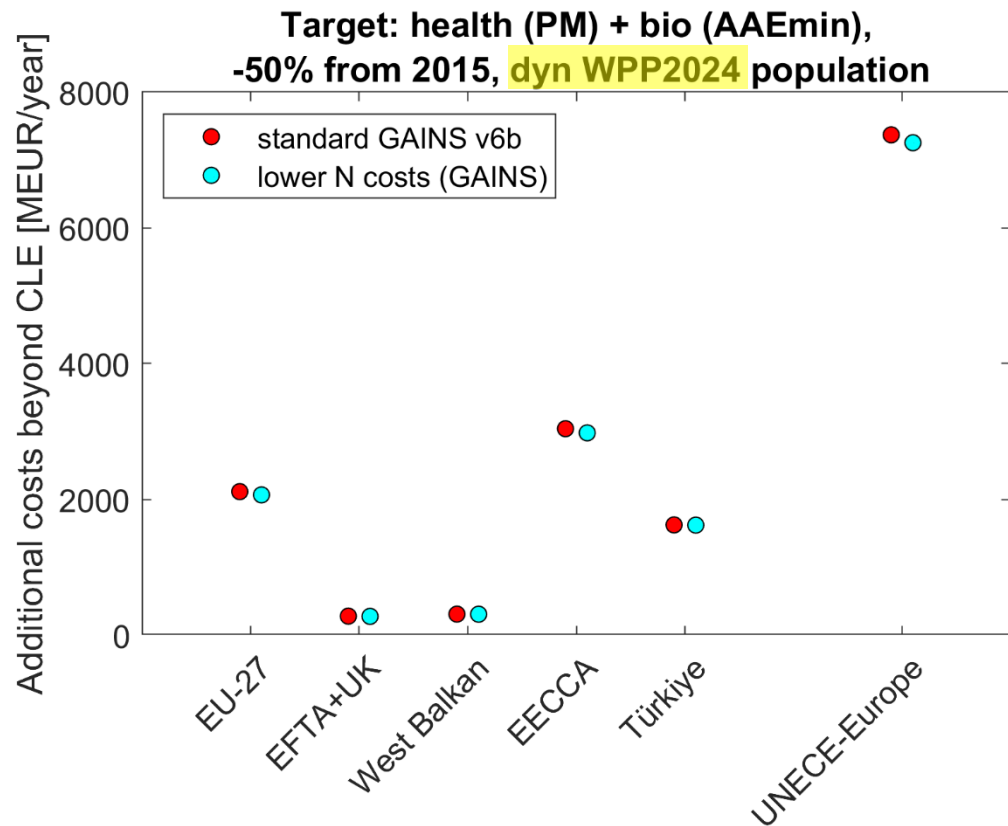
Expressing mortality with dynamic population for the same scenarios



# Sensitivity analysis *(using v6b scenario set)*

*Impact of updated costs for NH<sub>3</sub> mitigation from manure management*

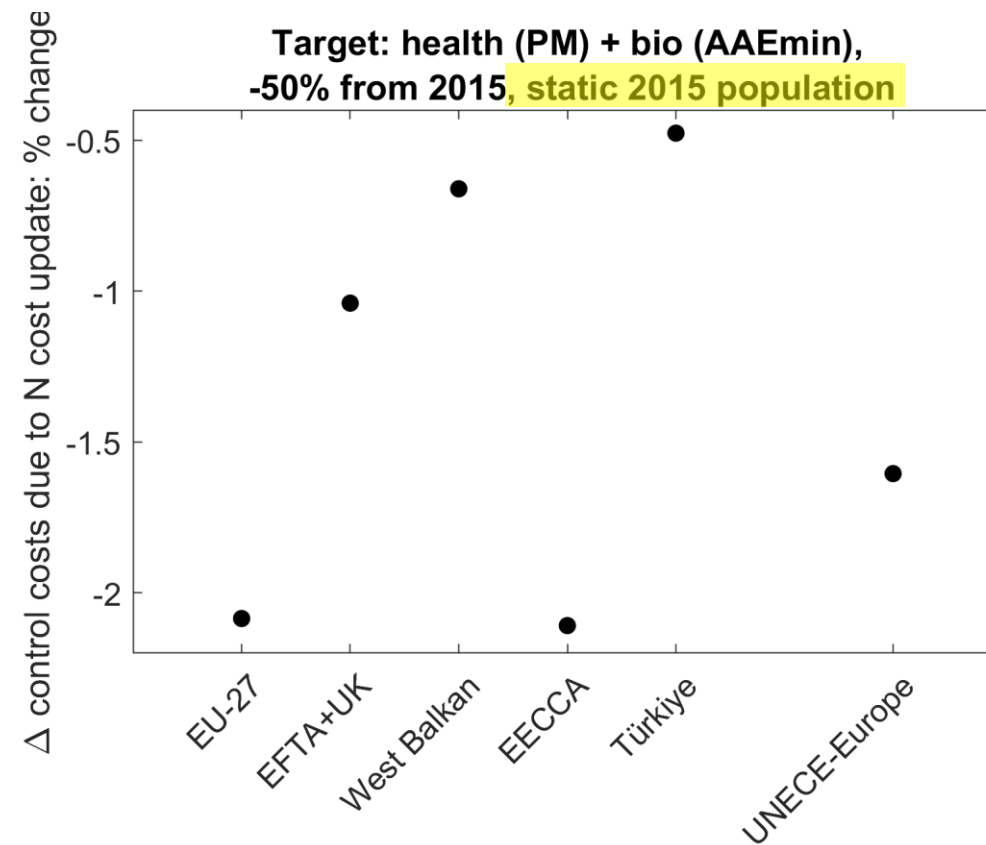
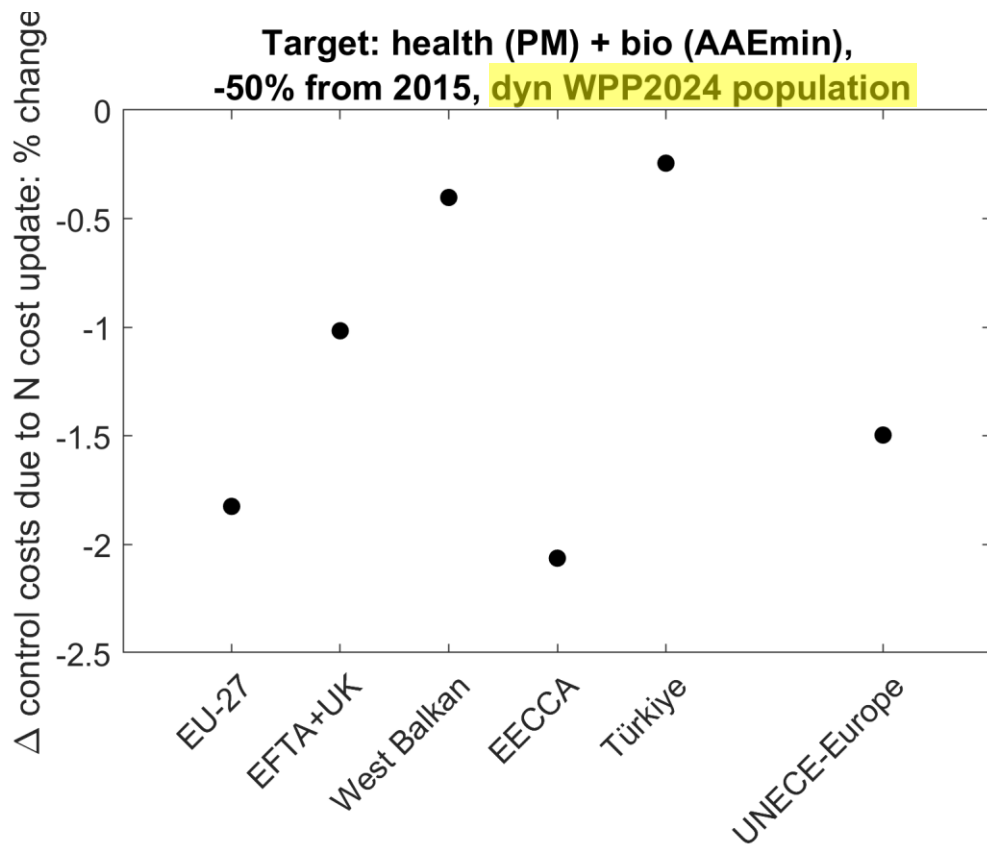
**Work in progress:** Update to NH<sub>3</sub> mitigation costs in agriculture based on input from TFRN. Details see presentation by W. Winiwarter later today.



**Preliminary analysis** seems to indicate only very limited total cost reductions of the cost-optimal combined health+biodiversity solution.

# Sensitivity analysis *(using v6b scenario set)*

*Impact of updated costs for NH<sub>3</sub> mitigation from manure management*

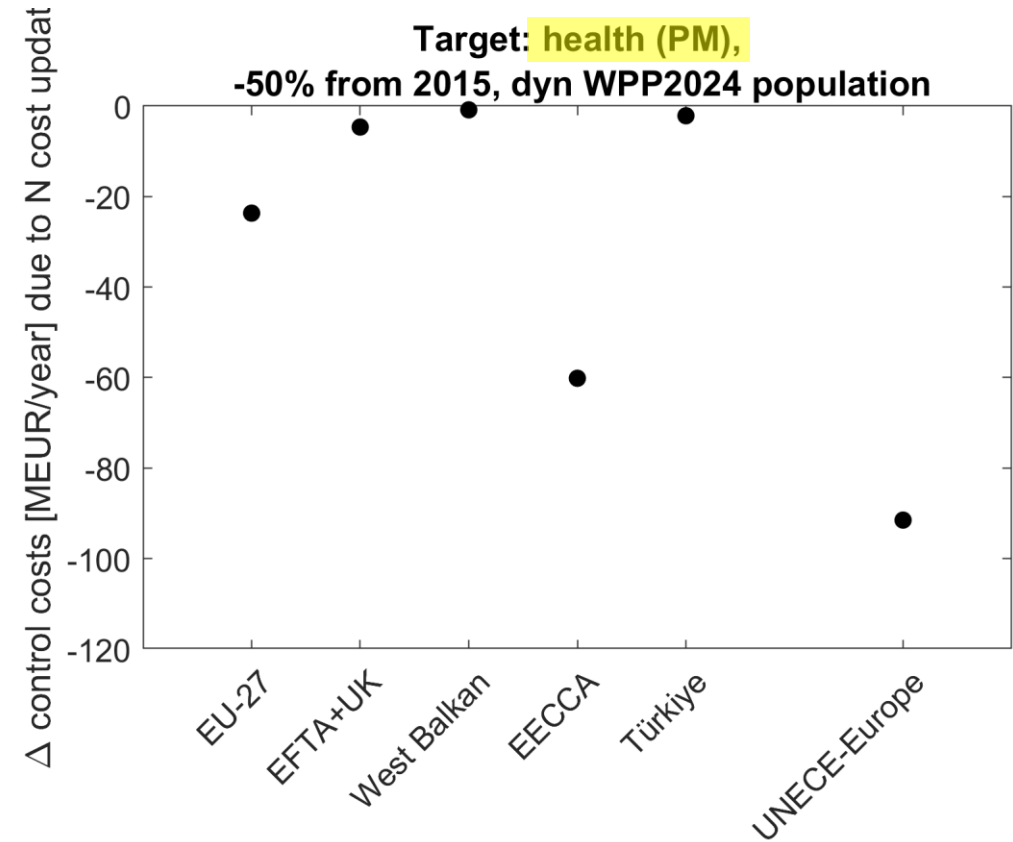
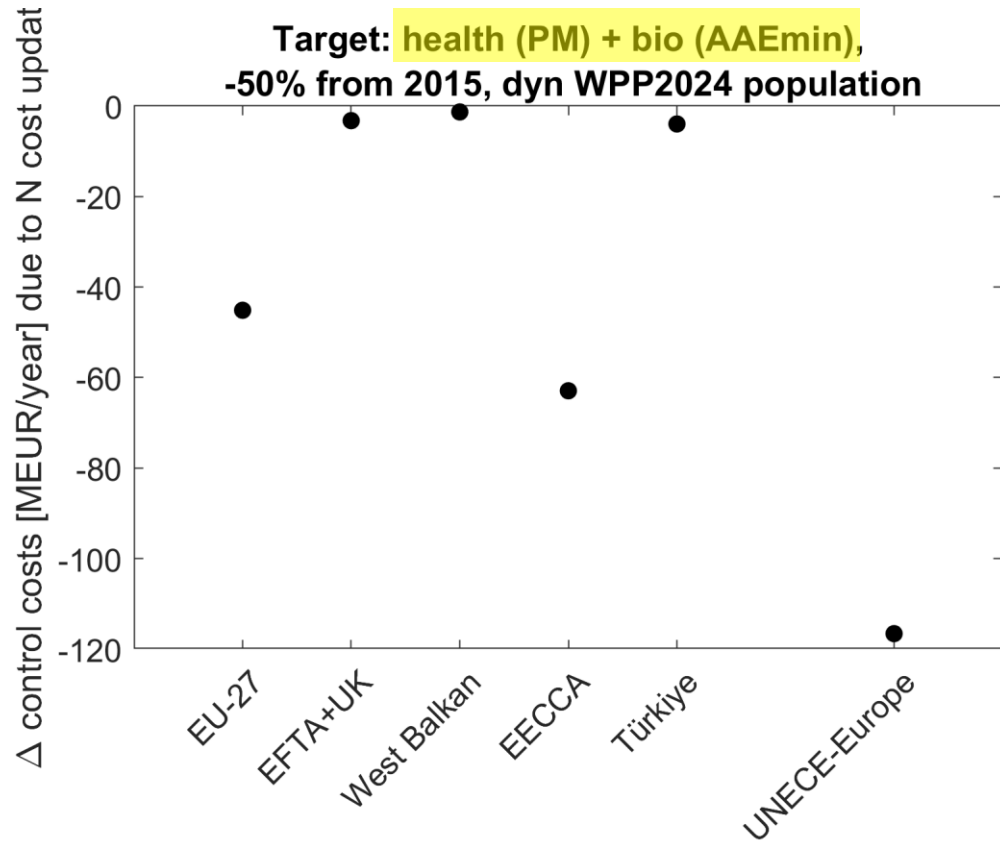


Lower NH<sub>3</sub> mitigation costs in agriculture lead to ~1.5% lower total costs beyond CLE for the combined health+biodiversity target (independent of static or dynamic population).

# Sensitivity analysis *(using v6b scenario set)*

*Impact of updated costs for NH<sub>3</sub> mitigation from manure management*

Do the lower N costs influence the additional costs of biodiversity protection beyond the health-only solution?



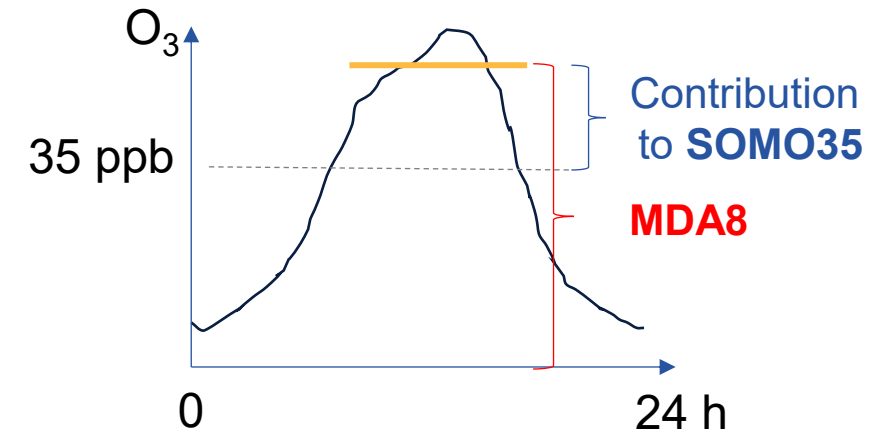
Most of the measures with lower costs are already taken in the health-only solution.

## Feasibility of health target considering *both* PM<sub>2.5</sub> and ozone (ex-post analysis)

- *ozone health metrics*
- *Initial assessment of feasibility to achieve 50% mortality reduction (using v6a)*
- *Sensitivity to mitigation of global methane and its precursors*
- *Progress in implementation of updates for ozone in GAINS*

# 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).

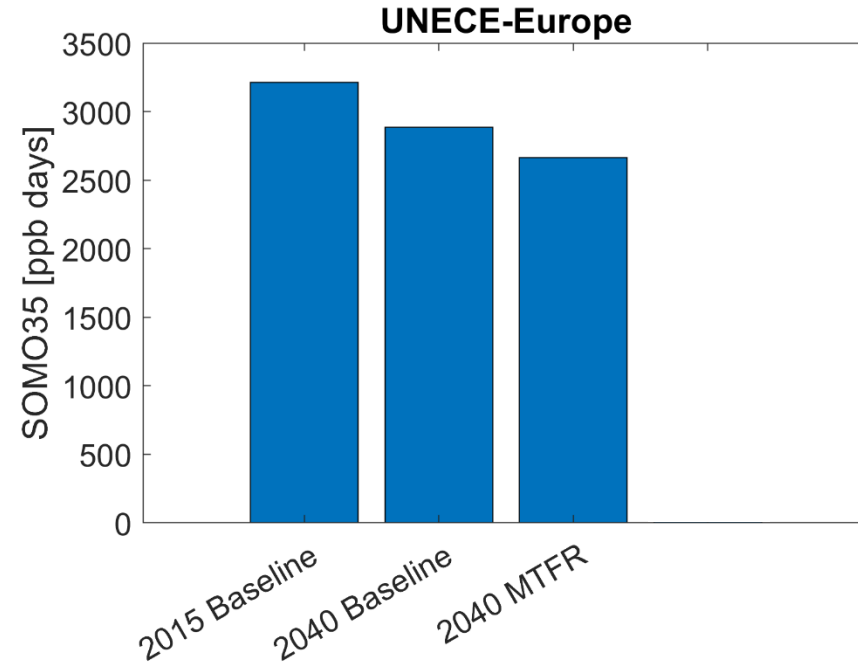
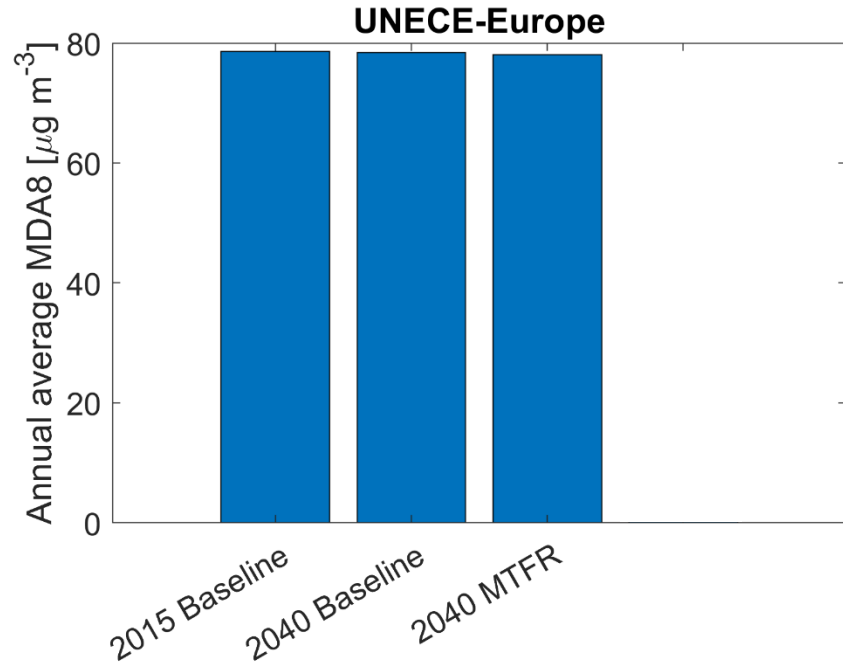


Recent epidemiological evidence:

- Short-term exposure:
  - Vicedo-Cabrera et al (2020): significant for all-cause mortality,  $RR=1.0018/10\mu\text{g}\text{m}^{-3}$ . Endorsed by HRAPIE2 (A). Recommended range: from 30ppb => **SOMO30** metric!
- Long-term exposure:
  - Annual average **MDA8**: found significant for respiratory mortality by Kasdagli et al (2024), but not for all-cause mortality. Endorsed by HRAPIE2 (B+).
  - Peak-season average **MDA8**: Not endorsed by HRAPIE2.

# O<sub>3</sub> exposure trends (total UNECE-Europe)

In EMEP model simulations for WGE (Jan 2025)



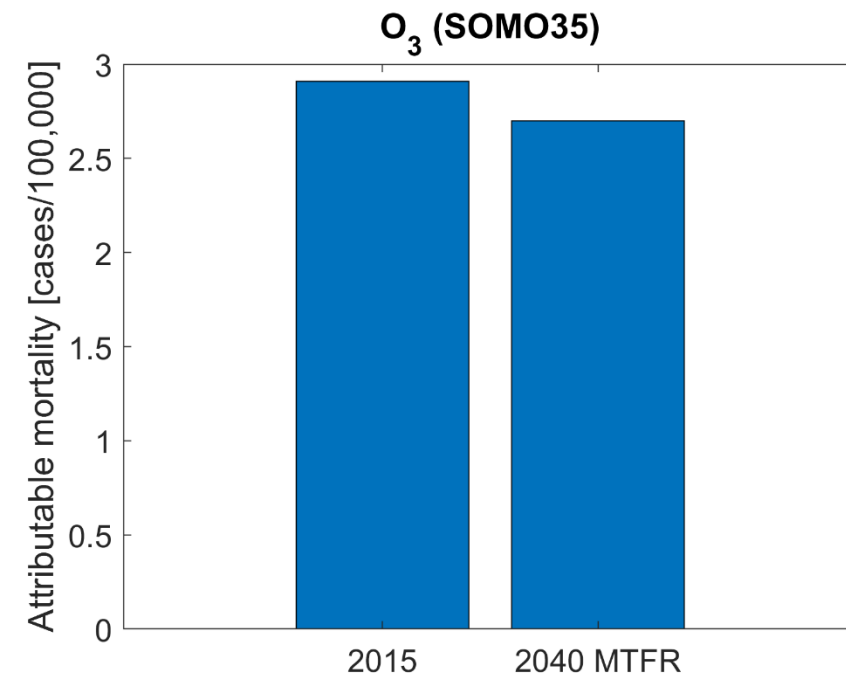
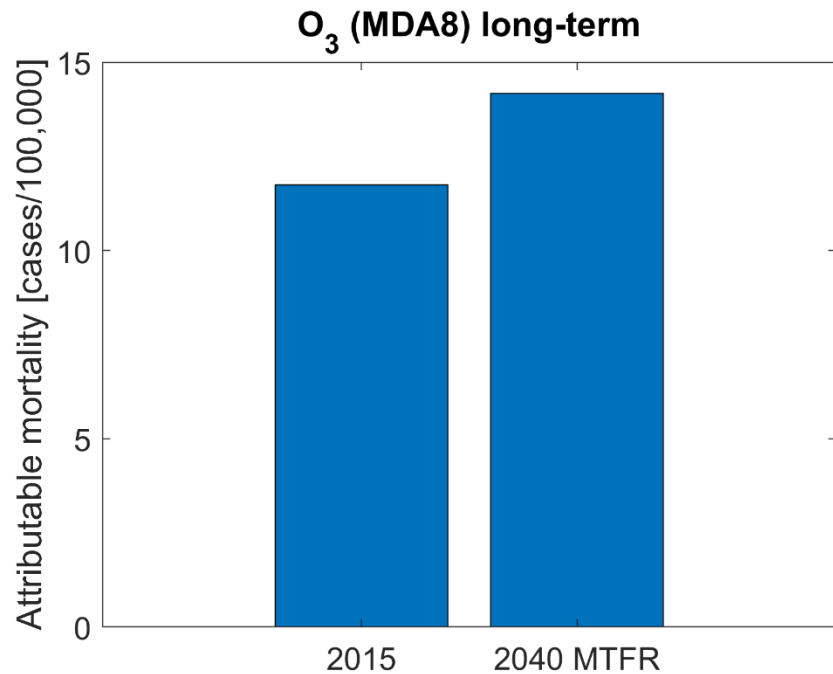
Annual mean MDA8 is very insensitive to emission changes within the UNECE domain

SOMO35 shows more sensitivity

*Global MTR includes CH<sub>4</sub>, NO<sub>x</sub>, VOC mitigation outside of UNECE-Europe and is from v5 scenario set*

# O<sub>3</sub> mortality trends (total UNECE-Europe)

- Based on EMEP model simulations for WGE (Jan 2025)
- Including population aging

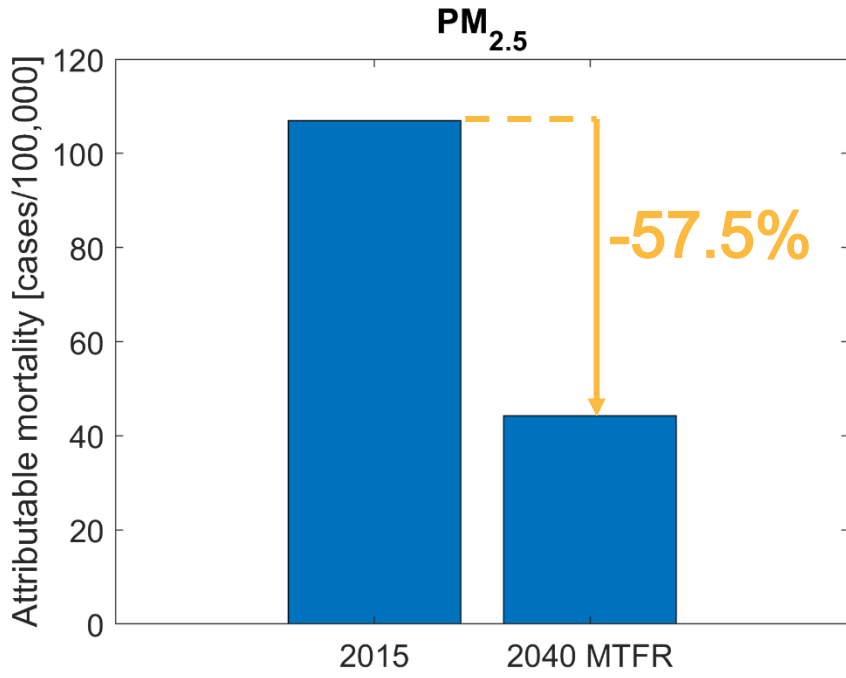


Respiratory mortality from long-term exposure  
Annual mean daily 8-hour max O<sub>3</sub>  
RR from HRAPIE2

All-cause mortality from short-term exposure  
SOMO35  
RR from HRAPIE2

# Combined mortality $PM_{2.5} + O_3$ : total UNECE-Europe

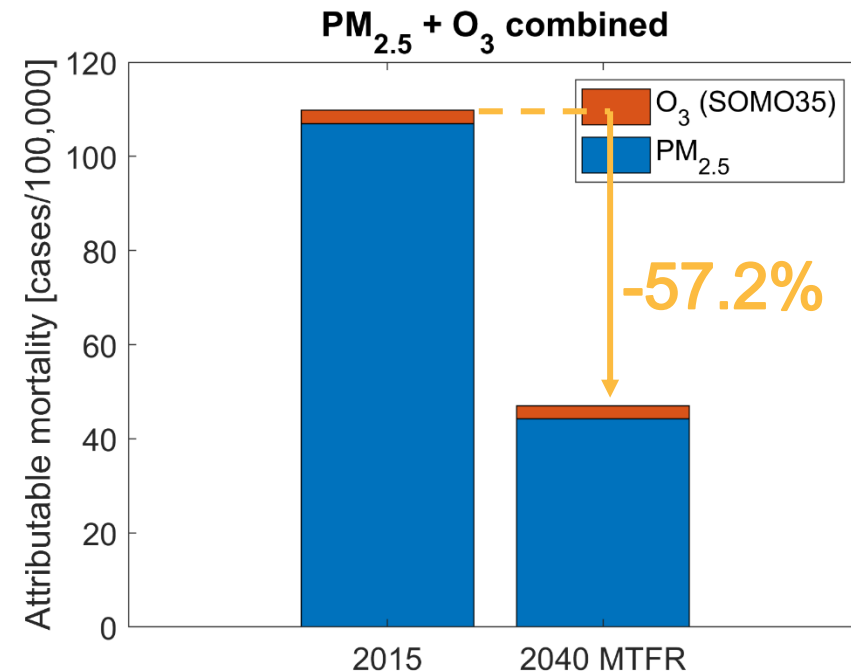
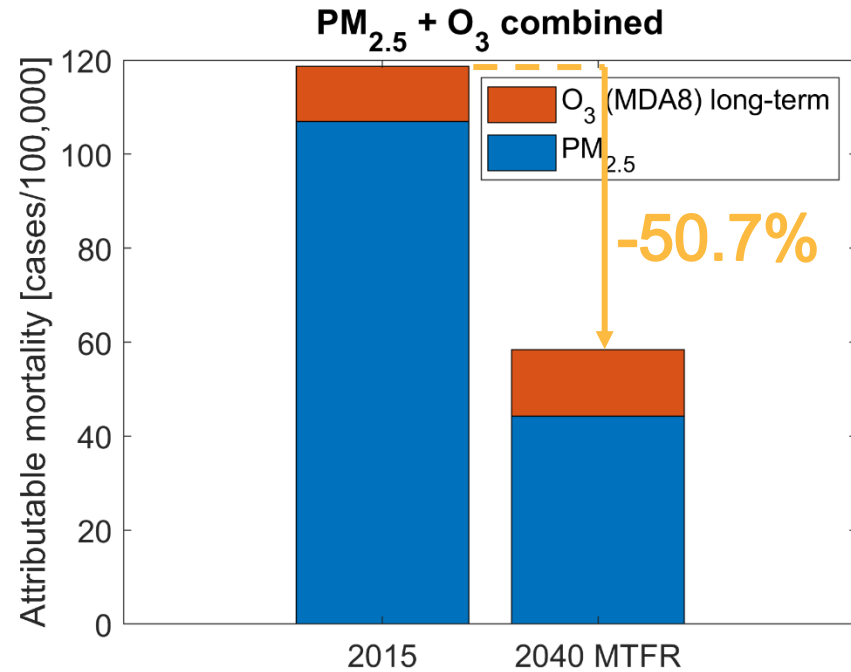
Based on EMEP model simulations for WGE (Jan 2025)  
Including population aging



anthrop.  $PM_{2.5}$ : RR from HRAPIE2

# Combined mortality: $PM_{2.5} + O_3$

Based on EMEP model simulations for WGE (Jan 2025) for  $O_3$ , GAINS for  $PM_{2.5}$   
Including population aging



anthrop.  $PM_{2.5}$ : RR from Orellano et al (2024)  
 $O_3$ : Respiratory mortality from long-term exp  
 MDA8, RR from Kasdagli et al (2024)

anthrop.  $PM_{2.5}$ : RR from Orellano et al (2024)  
 $O_3$ : SOMO35, RR from Vicedo-C. et al (2020)

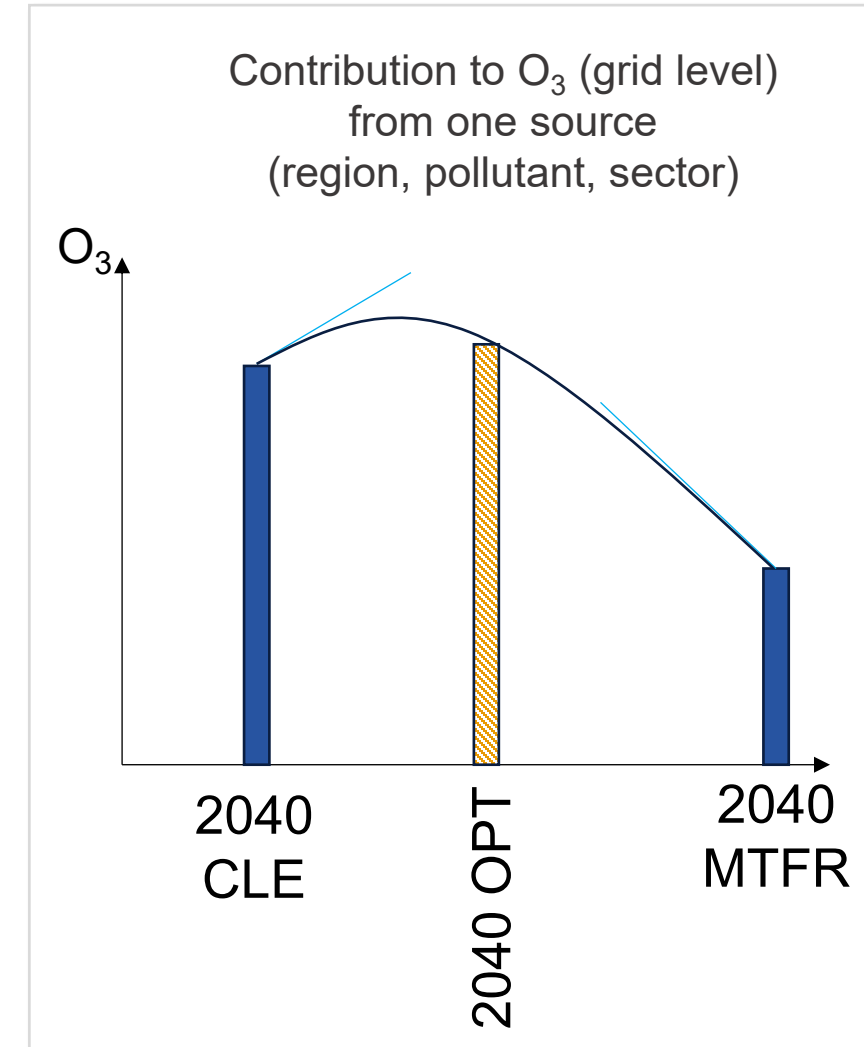
**Feasibility of a combined  $PM_{2.5} + O_3$  target depends on methodological choices!**

# Implementing O<sub>3</sub> in GAINS

- The EMEP model allows to quantify the sensitivity of ambient O<sub>3</sub> to a large set of emission sources simultaneously.
- Approach chosen: calculate sensitivities of all relevant O<sub>3</sub> metrics
  - to emissions of NO<sub>x</sub> and VOC
  - from all UNECE-Europe source countries + 10 sea regions
  - for 3 aggregate sectors (power & industry, low-level, agriculture) separately
  - for a high (CLE2040) and a low (MTFR2040 in UNECE) case
- use a quadratic or linear fit to determine the derivative at a given emission level, country-to-country

## Progress:

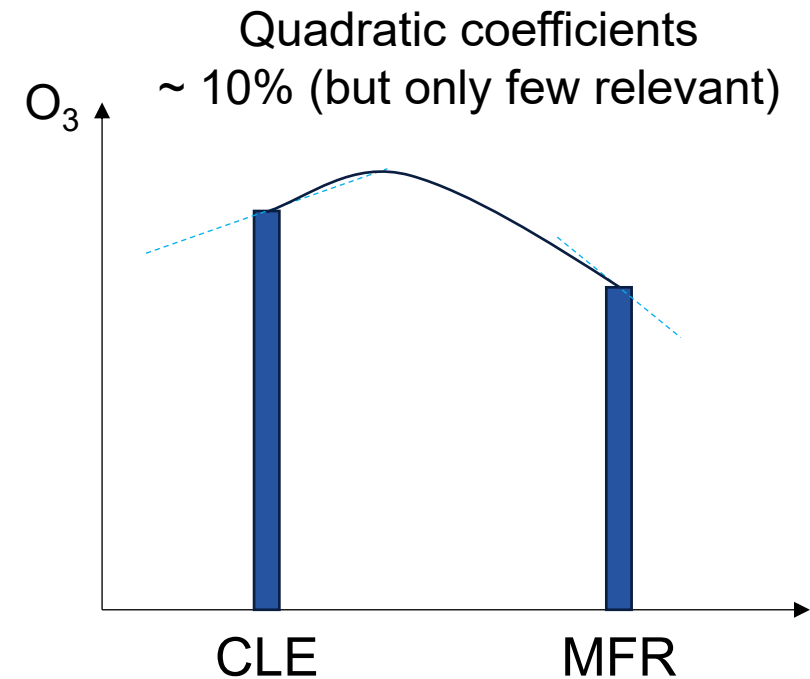
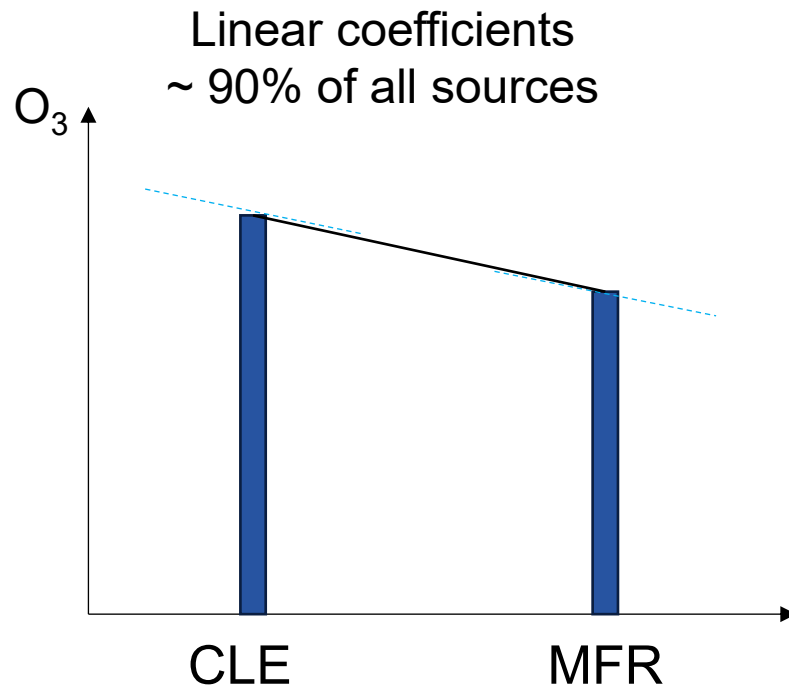
- Simulations by MSC-W for met. year 2017 done
- Tested different EMEP model parameters, e.g., boundary conditions, advection scheme
- Transfer coefficients developed, testing ongoing - reproduce difference between CLE2040 to MTFR2040



# Implementation in GAINS – Simulation mode

- We use a mixed approach between linear and quadratic coefficients to represent titration where needed

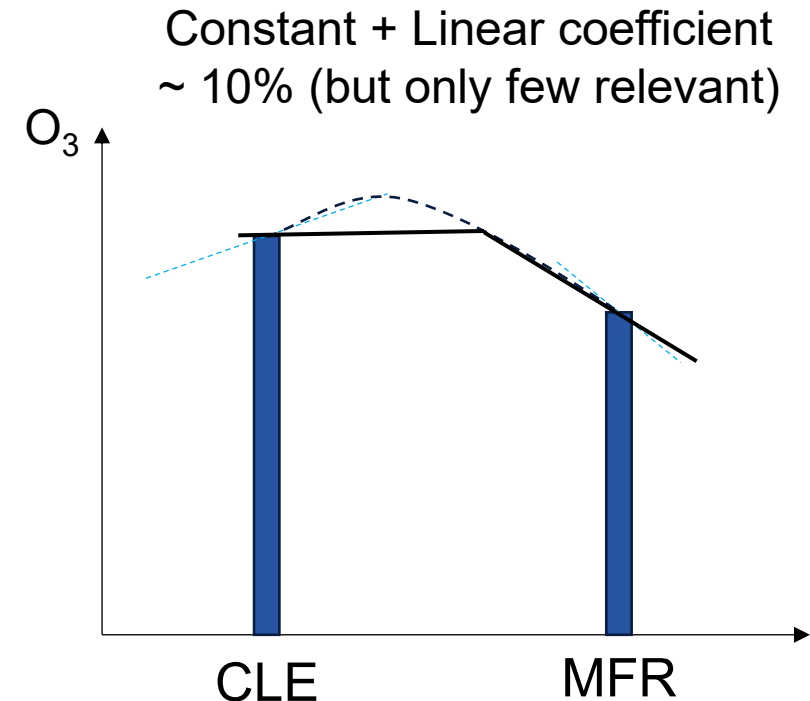
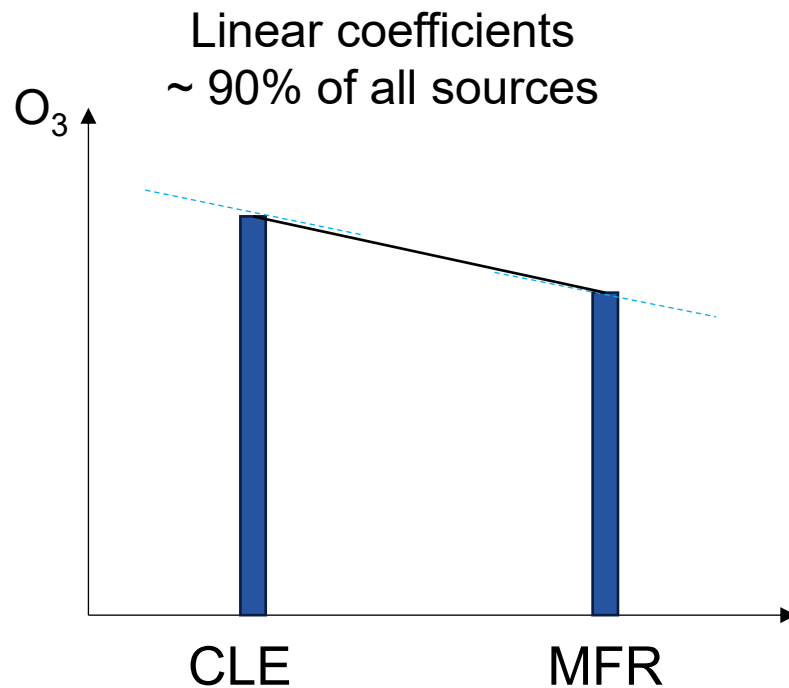
Contribution to  $O_3$  (country level) from one source (region, pollutant, sector):



# Implementation in GAINS – Optimization mode

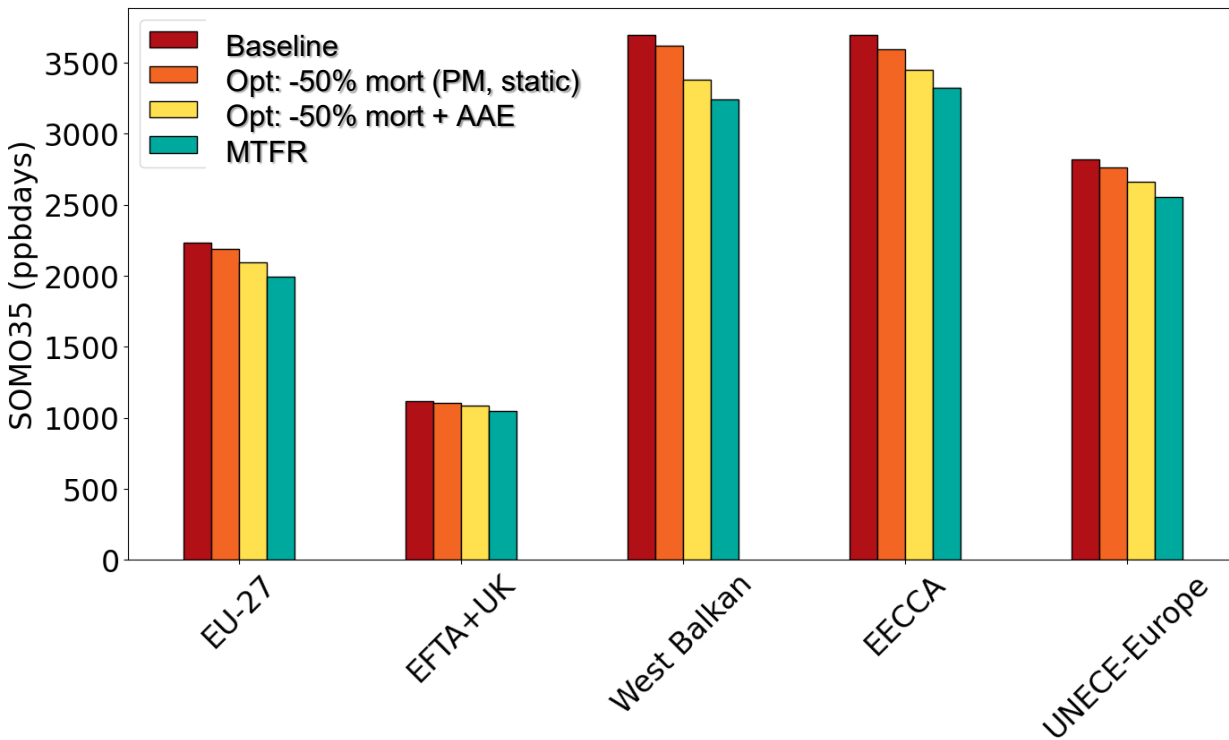
- For the non-linear cases, the curve is approximated by a constant (O<sub>3</sub> contribution in CLE2040) and a linear function

Contribution to O<sub>3</sub> (country level) from one source (region, pollutant, sector)

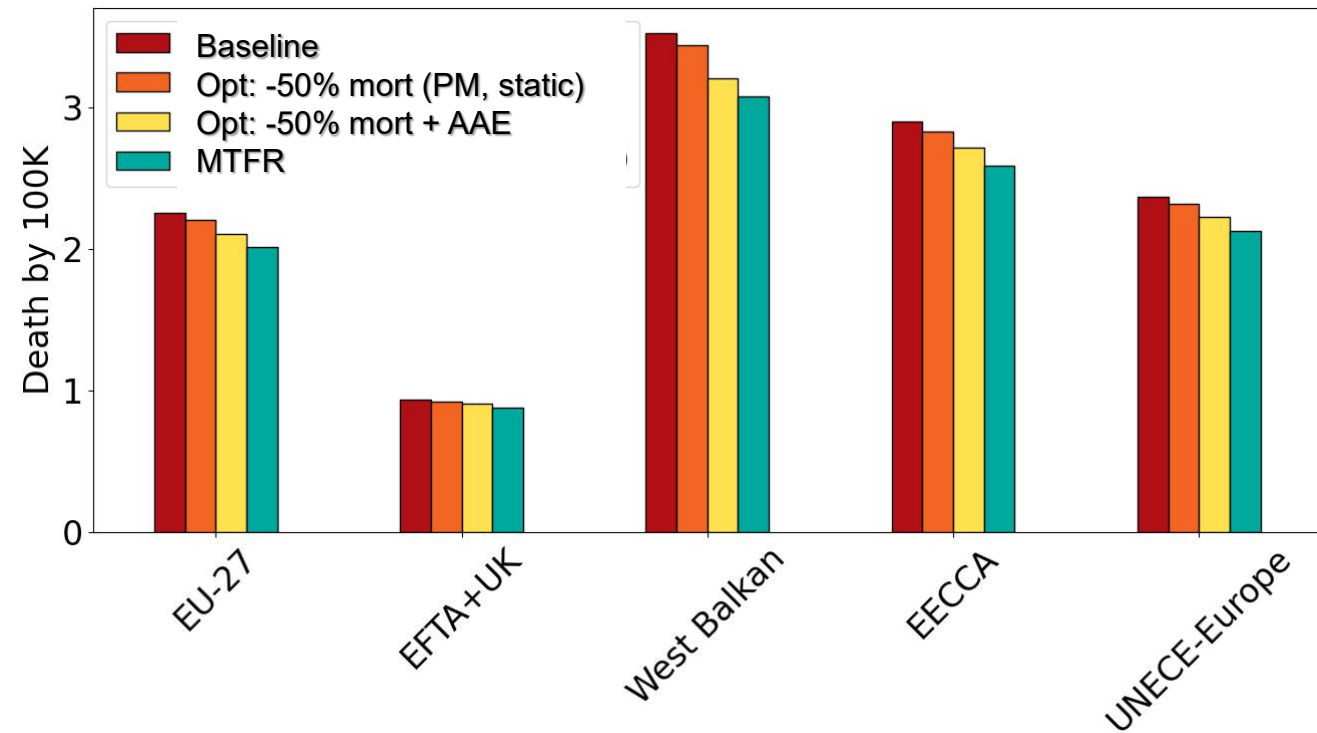


# O<sub>3</sub> mortality in the optimized scenarios

## SOMO35

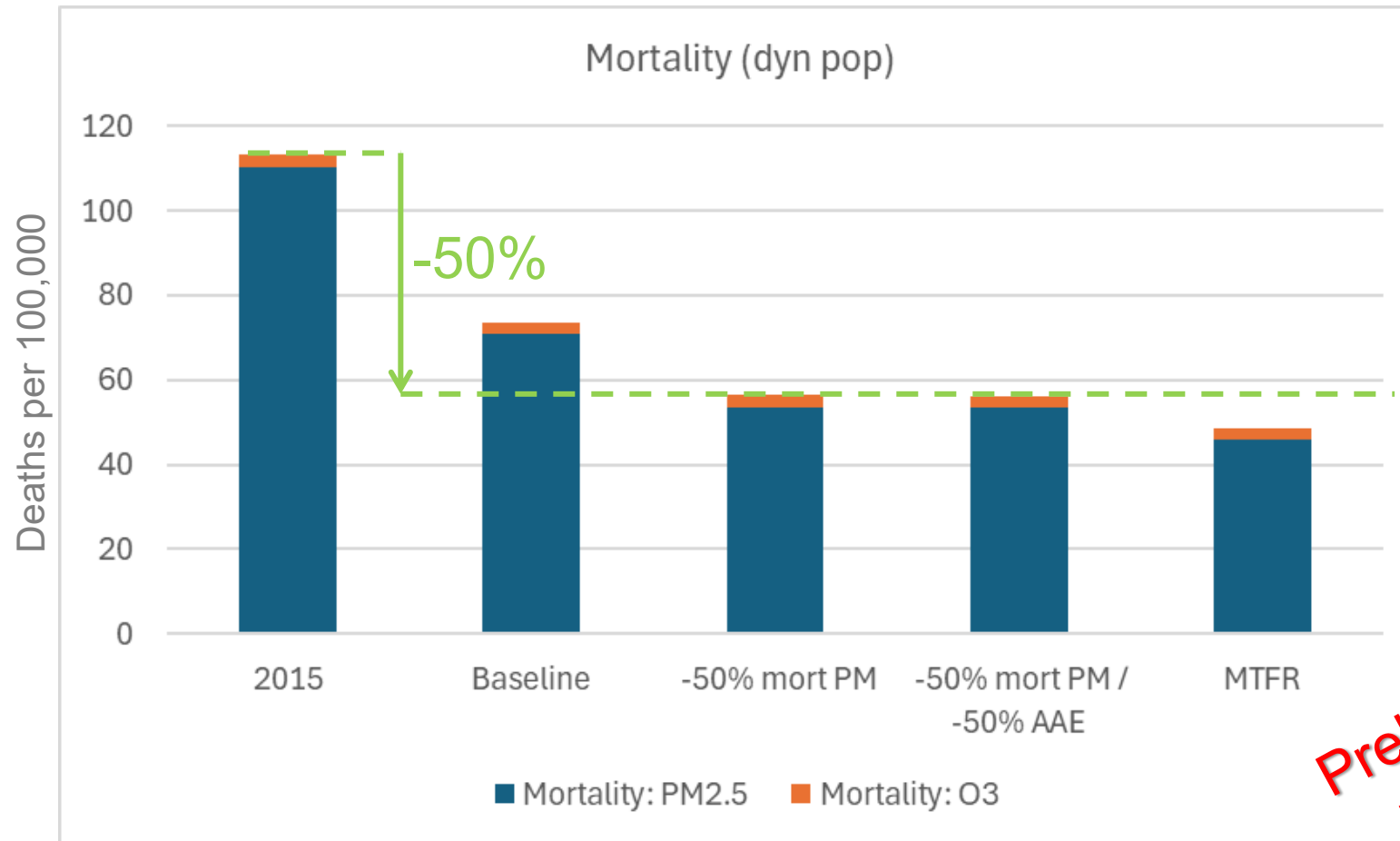


## Mortality rate



# PM+O<sub>3</sub> mortality in the optimized scenarios

- The PM-health optimized solution almost achieves -50% combined mortality
- Additional optimization runs are possible, target needs to be discussed



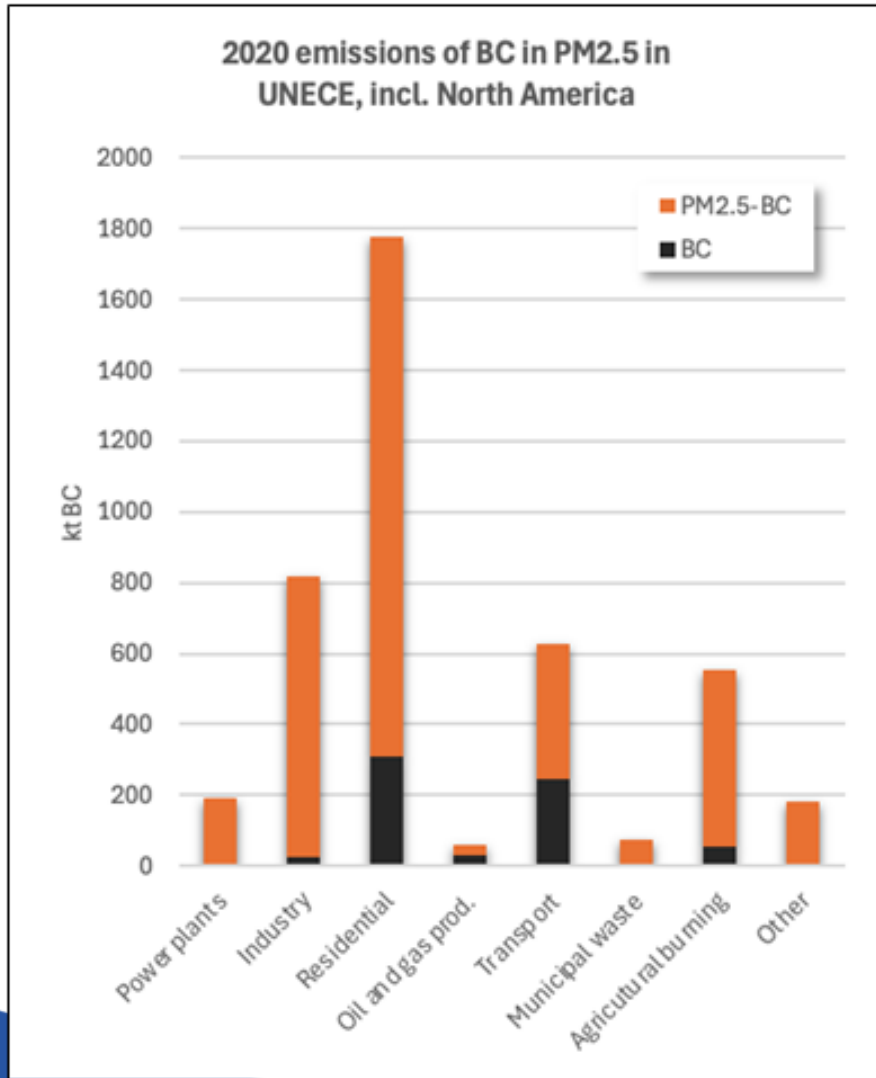
**Preliminary results!**

# Summary of ozone progress

- Feasibility check of a combined -50% target for  $PM_{2.5} + O_3$  mortality:
  - Achievable if short-term exposure (SOMO35) is used for quantification
  - Barely feasible if long-term exposure (annual MDA8)
  - Global emission reductions from outside UNECE would open more potential
  
- Implementation in GAINS is in testing phase
  - Methodology: local fractions (propagation of 1<sup>st</sup> derivative through chemistry module)
  - Mostly linear. Quadratic formulation for cases with titration
  - Implemented in simulation mode and in optimization (simplified version) for SOMO35
  - *On a first glance*, the implications are small: The cost-optimal solution for -50%  $PM_{2.5}$  mortality essentially also achieves -50%  $PM+O_3$ <sub>shortterm</sub> mortality.

# Spotlight on BC in the scenarios

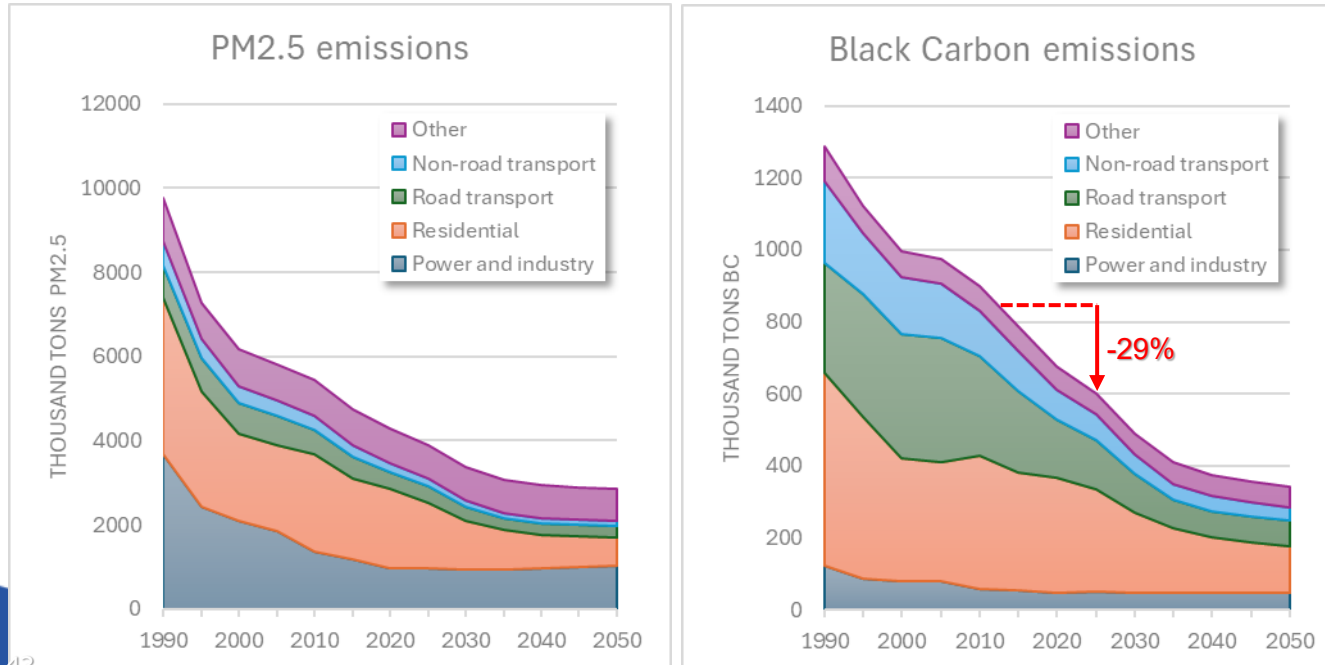
# Anthropogenic PM<sub>2.5</sub> and BC emissions in the UNECE (incl. North America) in 2020



- Overall share of BC in PM<sub>2.5</sub> is about 16%
- Key sectors are residential combustion and transport, representing about 13% of PM<sub>2.5</sub>
- These two sectors are responsible for nearly 85% of total BC in PM<sub>2.5</sub>
- The share of BC in PM is expected to decline further due to transformation and regulation of transport sector and reduction of residential sector emissions

# Emissions of PM<sub>2.5</sub> and BC in the current LRTAP Baseline scenario (*UNECE, incl. NA*)

- Stronger decline of PM<sub>2.5</sub> than BC since 1990 due to reductions in industry
- In the last decade 2010-2020 strong decline in transport BC, largest source in 2010, playing key role in overall BC reduction
- In the future a stronger reduction of BC (than total PM<sub>2.5</sub>) is expected



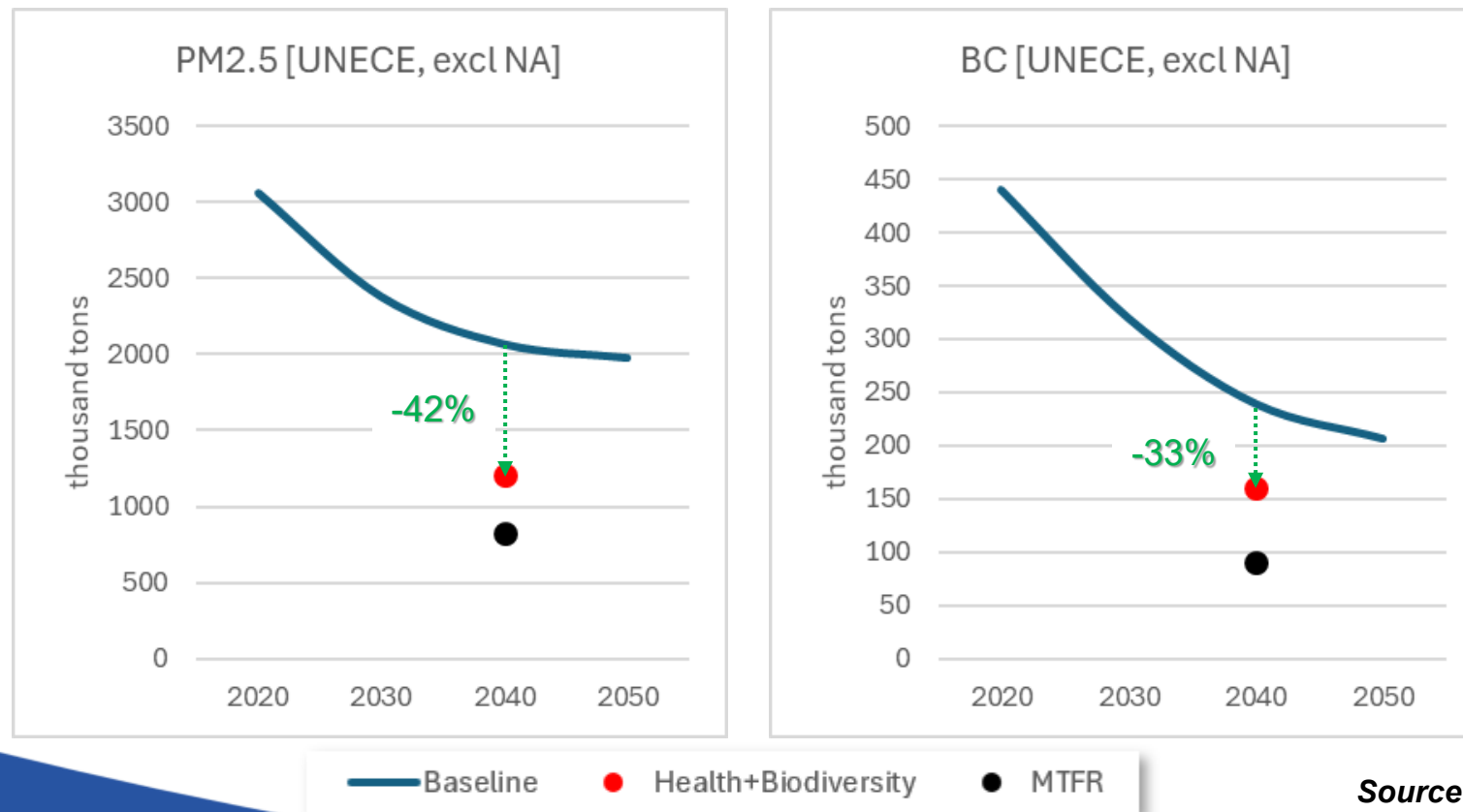
***Comment on the Arctic Council BC goal: 25-33% reduction between 2013 and 2025***

**We estimate that in the UNECE, BC emissions will be reduced in this period by nearly 29%**

# BC vs PM<sub>2.5</sub> in further mitigation scenarios (1)

At the **UNECE level** (excl. North America):

- Further mitigation potential (MTFR) for BC similar to PM<sub>2.5</sub> (about 60%)
- In the cost-effective scenario to achieve 50% reduction of health and loss of biodiversity risks, impact on BC lower than PM<sub>2.5</sub>, i.e., 33% vs 42%



# Next steps (1)

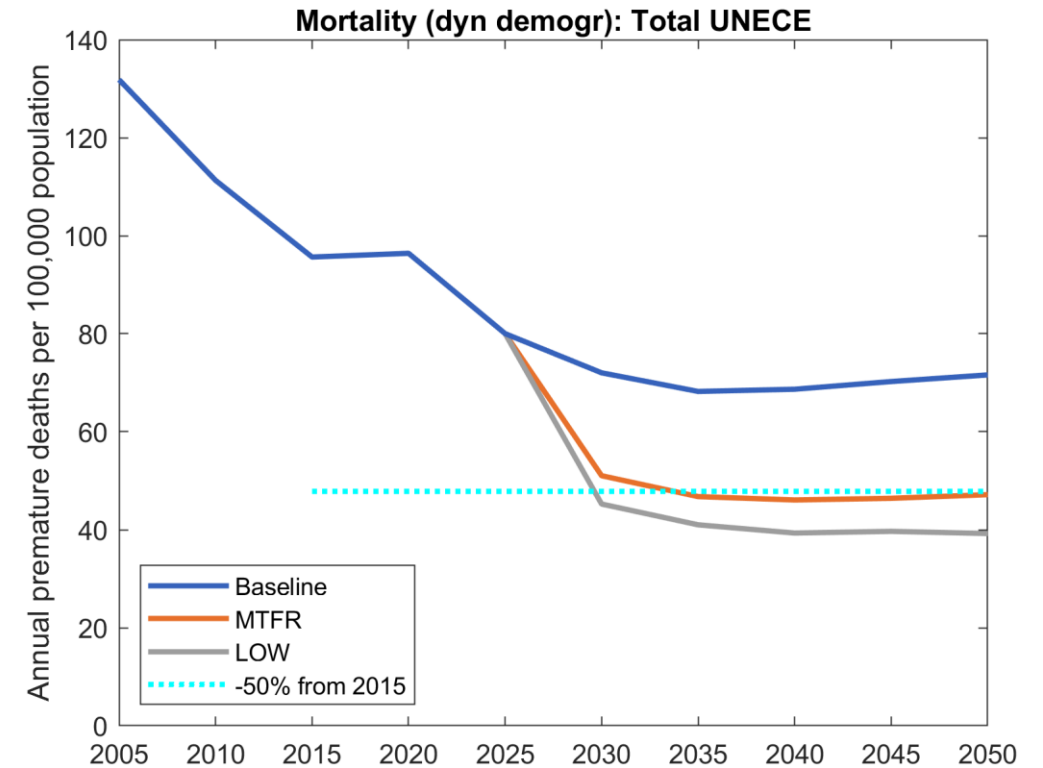
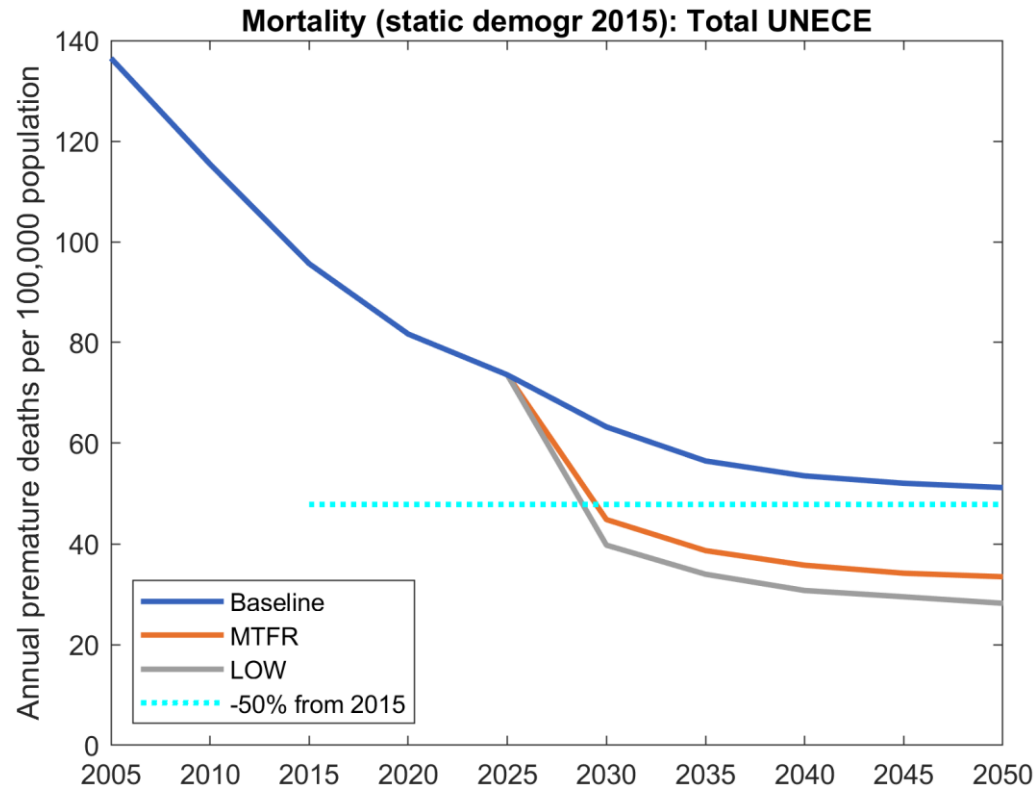
- Ongoing work supporting EU **Clean Air Outlook 5**, incl new baseline projections from PRIMES/CAPRI and bilateral consultations with EU Member States
- Once the CAO5 Baseline is completed (May 2026), it will be incorporated into a **Baseline v7**, and key optimization scenarios will be recreated for EMEP-WGE SB Sep 2026.
- In parallel, feedback from non-EU parties on the v6 Baseline can be incorporated if received in time (April/May 2026)
- Further update of **mitigation cost data** (2026)
- Finalizing the implementation of **ozone** in GAINS, analysis (2026)
  - Further testing of updated ozone calculations in GAINS, confirmation of preliminary results
  - Additional simulations considering variable methane and NO<sub>x</sub>/VOC mitigation scenarios outside of the UNECE (jointly with MSC-W) – in 2026

## Next steps (2)

- Complete update of the **LOW scenario** – potentially high relevance for attainability and affordability of biodiversity targets. Explore scenarios with alternative fuels (NH<sub>3</sub>, hydrogen, ...)
- If desired, scenarios exploring **variable timeline for goal setting** across different regions?
- Further work on **flexibility options** and **more equitable solutions?** (on hold)
- Implementation of updated **CLnutN, CLaci for the whole domain** once available from CCE for the ex-post calculation of acidification and eutrophication in GAINS
- If desired, inclusion in GAINS of **NFC CLs** for biodiversity in ex-post analysis (supported by CCE)
- Towards quantification of **BC concentrations** and health impacts in GAINS (with MSC-W, TFH)
- Discussion and potential ex-post analysis of health impacts considering WHO AQG as a cutoff
- Other **model updates**, e.g., further improvement and validation of sectoral source apportionment, urban/rural contributions (MSC-W)

# Backup slides

# Trends in PM<sub>2.5</sub> mortality: static vs dynamic pop



# Trends in PM<sub>2.5</sub> mortality: static vs dynamic pop

