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Quantification of the action scales of emission reduction policies on PM and ozone concentrations in France and the EU with CHIMERE

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Introduction

<u>Air Quality Challenge:</u> Ozone (O_3) and Fine Particles ($PM_{2.5}$) remain major health and environmental issues despite current regulations.

<u>Key Question:</u> At what scale (National, European, or Global) must emission reductions be implemented to effectively improve French air quality in the future?

Center of TFMM mandate for the Gothenburg protocol

→ In 2021, the French ecological transition agency ADEME granted the R&D project: **ESCALAIR** (PI S. Mailler LMD/CNRS) involving the French teams working on the CHIMERE model.

ESCALAIR Project objectives:

- Improvement of large-scale processes in CHIMERE (LiNOX, Fires, Dusts, CH_4…)
- Development of a new version of CHIMERE working with unstructured domains

- First operational use of current CHIMERE version on hemispheric domain for policy support, to determine action scales to improve air quality in France.
  → overcome the uncertainties associated with using different models for global and regional scales regarding the effect of reductions at different action scales (national, European, global)
  → provide a more complex representation of the chemical aspects in an exercise generally carried out using global models

Strong connection with TF-HTAP work (HTAP3-OPNS exercise)

Emission scenarios

To match with HTAP3-OPNS exercise:

→ Use of the latest version of anthropogenic emissions produced by CIAM/IIASA with **GAINS** model for the 1990-2050 period (v2.1, *Klimont et al., 2025*)

→ Study focuses on **2040** and **3 emission areas**: GLO, EUR and FRA

→ Considering two emissions scenarios :

CLE scenario (current legislation)

MFR scenario (maximum technically feasible reduction)

→ 2015 with CLE emission is taken as Reference simulation for comparison and evaluation.

	2015CLE ($Tg.an^{-1}$)			2015CLE à 2040CLE			2015CLE à 2040MFR			2040CLE à 2040MFR		
	GLO	EUR	FRA	GLO	EUR	FRA	GLO	EUR	FRA	GLO	EUR	FRA
CH_4	336,1	18,5	2,4	+20,6 %	-33,3 %	-30 %	-28,9 %	-45,4 %	-37 %	-41,1 %	-18,1 %	-9,9 %
NO_X	144,2	8,4	1,1	-16,3 %	-71,8 %	-75,3 %	-68,1 %	-78,2 %	-78,2 %	-61,9 %	-22,8 %	-11,6 %
COV	125,4	7,4	1	-6,7 %	-32 %	-35,6 %	-45,4 %	-47,8 %	-45,1 %	-41,4 %	-23,1 %	-14,8 %
CO	496,9	22,7	2	-28,6 %	-59,5 %	-57,3 %	-72,1 %	-73,8 %	-73,5 %	-60,9 %	-35,3 %	-38 %
NH_3	54,3	3,8	0,6	+23,5 %	-10 %	-12,7 %	-22,2 %	-33,9 %	-35,8 %	-37 %	-26,5 %	-26,4 %
SO_2	67,8	2,5	0,15	-47,1 %	-76,7 %	-61,4 %	-77 %	-87,4 %	-74,2 %	-56,5 %	-45,8 %	-33,1 %
$PM_{2.5}$	39	1,6	0,21	-17,2 %	-61,2 %	-56,8 %	-80,8 %	-74,5 %	-68,8 %	-76,8 %	-34,3 %	-27,8 %
PM_{10}	52,4	2,2	0,3	-13,1 %	-46,2 %	-33,8 %	-74,5 %	-60,5 %	-45,1 %	-70,7 %	-26,6 %	-17,1 %

GLO: Entire World

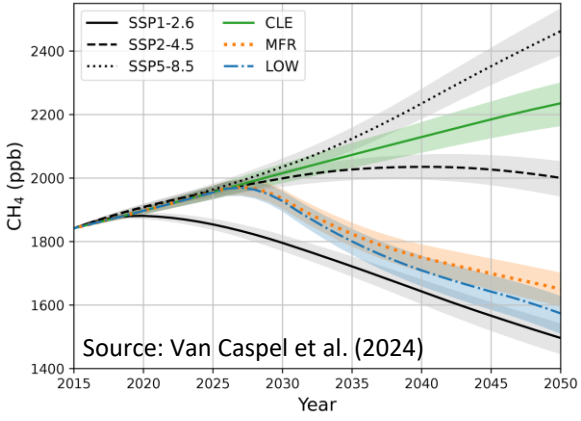
EUR: European zone (EU, UK, Norway, Iceland and Switzerland)

FRA: France

Set of simulations

To quantify the role of the different compounds and emissions area on the evolution of ozone and $PM_{2.5}$ concentrations. Multiple simulation were driven applying successively MFR reductions to groups of emitted compound and/or world regions

For CH_4: mean annual concentrations for 2040 calculated in framework of HTAP with MAGICC7 v7.5.3 model, here weighted for EUR and FRA scenarios.



	Emissions sur le monde (hors Europe)	Emissions sur l'Europe (hors France)	Emissions sur la France	CH_4 (ppb)
scen0	**2015CLE**	**2015CLE**	**2015CLE**	**1834**
scen1	NO_X/COV 2040CLE / Autres 2015CLE	NO_X/COV 2040CLE / Autres 2015CLE	NO_X/COV 2040CLE / Autres 2015CLE	1834
scen2	NO_X/COV/CH_4 2040CLE / Autres 2015CLE	NO_X/COV/CH_4 2040CLE / Autres 2015CLE	NO_X/COV/CH_4 2040CLE / Autres 2015CLE	2119
scen3	**2040CLE**	**2040CLE**	**2040CLE**	**2119**
scen4	NO_X/COV 2040MFR / Autres 2040CLE	2040CLE	2040CLE	2119
scen5	NO_X/COV 2040MFR / Autres 2040CLE	NO_X/COV 2040MFR / Autres 2040CLE	2040CLE	2119
scen6	NO_X/COV 2040MFR / Autres 2040CLE	NO_X/COV 2040MFR / Autres 2040CLE	NO_X/COV 2040MFR / Autres 2040CLE	2119
scen7	NO_X/COV/CH_4 2040MFR / Autres 2040CLE	NO_X/COV 2040MFR / Autres 2040CLE	NO_X/COV 2040MFR / Autres 2040CLE	1761
scen8	NO_X/COV/CH_4 2040MFR/ Autres 2040CLE	NO_X/COV/CH_4 2040MFR / Autres 2040CLE	NO_X/COV 2040MFR / Autres 2040CLE	1752
scen9	NO_X/COV/CH_4 2040MFR/ Autres 2040CLE	NO_X/COV/CH_4 2040MFR / Autres 2040CLE	NO_X/COV/CH_4 2040MFR / Autres 2040CLE	1750
scen10	**2040MFR**	**2040MFR**	**2040MFR**	**1750**
scen11	2040MFR	NO_X/COV/CH_4 2040MFR / Autres 2040CLE	NO_X/COV/CH_4 2040MFR / Autres 2040CLE	1750
scen12	2040MFR	2040MFR	NO_X/COV/CH_4 2040MFR / Autres 2040CLE	1750

Model Configuration

Model Version:

- CHIMERE v2023r2 (*Menut et al., 2024*)

Domain:

- ESCA100 domain (~100km×100km resolution North hemispheric domain with polar stereographic projection (260x260cells)
- 20 vertical levels (up to 200hPa)

Meteo:

- Meteorological data from IFS reanalysis ERA5 (*Hersbach et al., 2020*).
- 2015 as REF. year without climatological modifications for 2040

Other emissions:

- DUST, LiNOx, DMS, SeaSalt emissions considered
- Biogenic emissions from MEGAN (*Guenther et al., 2006*).
- No wildfire emission, no aviation emission

Boundary conditions:

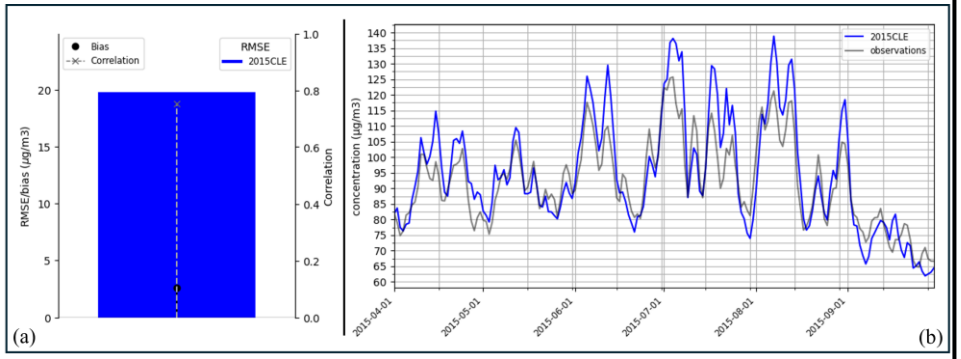
- Climatological boundary conditions from LMDZ-INCA Global Model (*Hauglustaine et al., 2004 ; Folberth et al., 2006*).

Other:

- Fixed homogeneous CH4

Simulation evaluation (European stations)

2015CLE peak season Ozone PS-MDA8

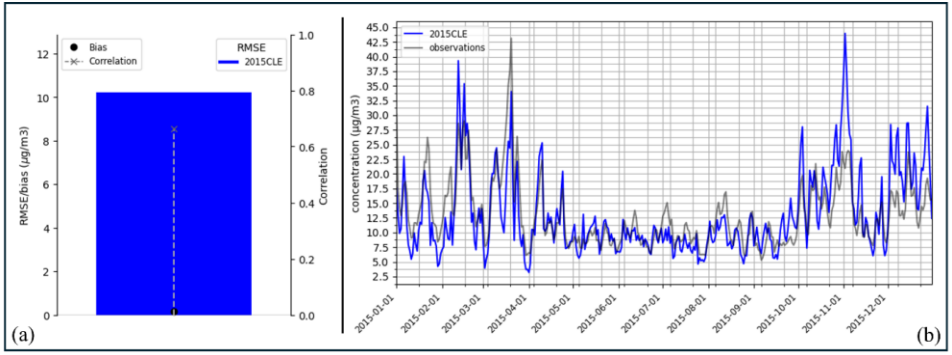


Mean Bias : +2.5 µg m^{-3}

RMSE : 20 µg m^{-3} (overestimation of high concentrations)

Correlation : 0.78

2015CLE annual and daily mean $PM_{2.5}$ conc.



Mean Bias : +0.1 µg m^{-3}

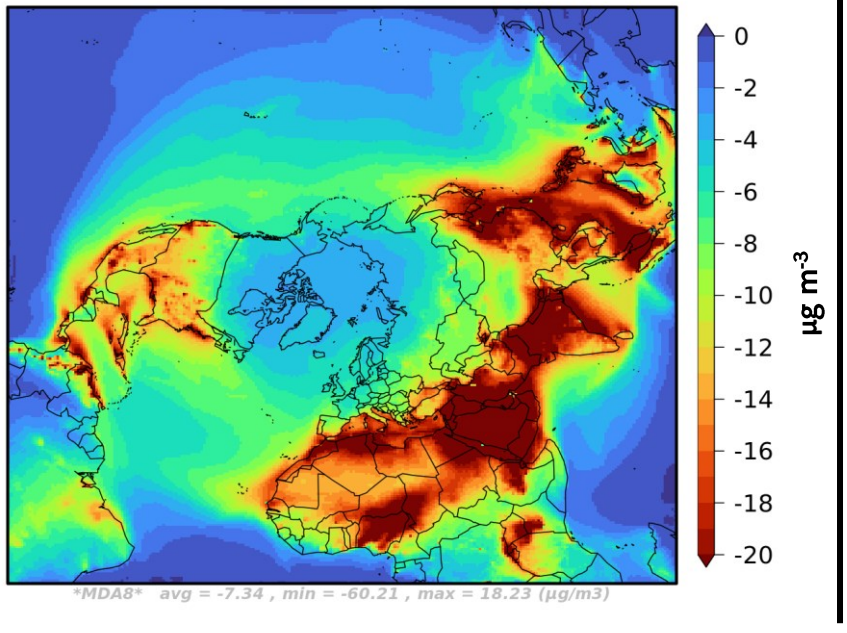
RMSE : 10 µg m^{-3}

Correlation : 0.65

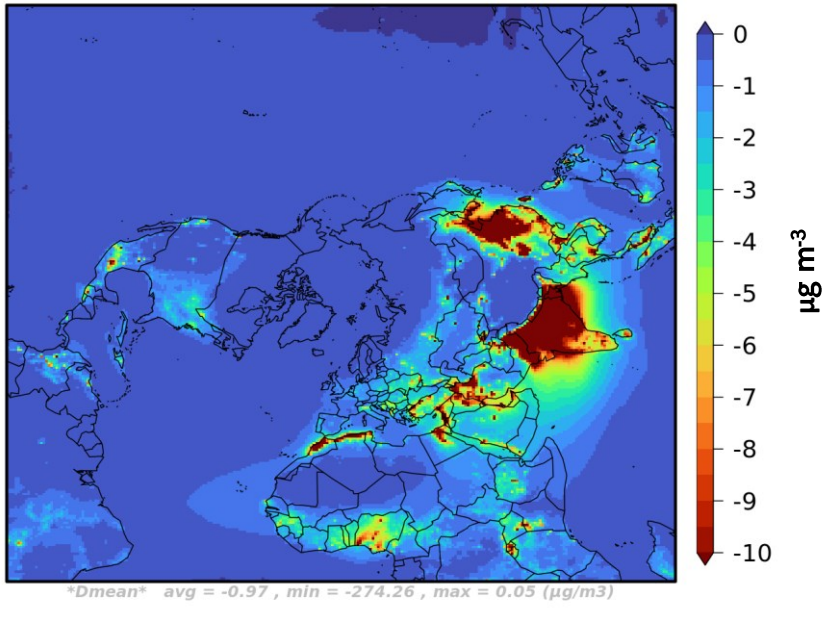
→ Consistent results with higher resolution simulations on Europe domain.

Mapping of changes between CLE and MFR for 2040 (global)

Ozone PS-MDA8 variations

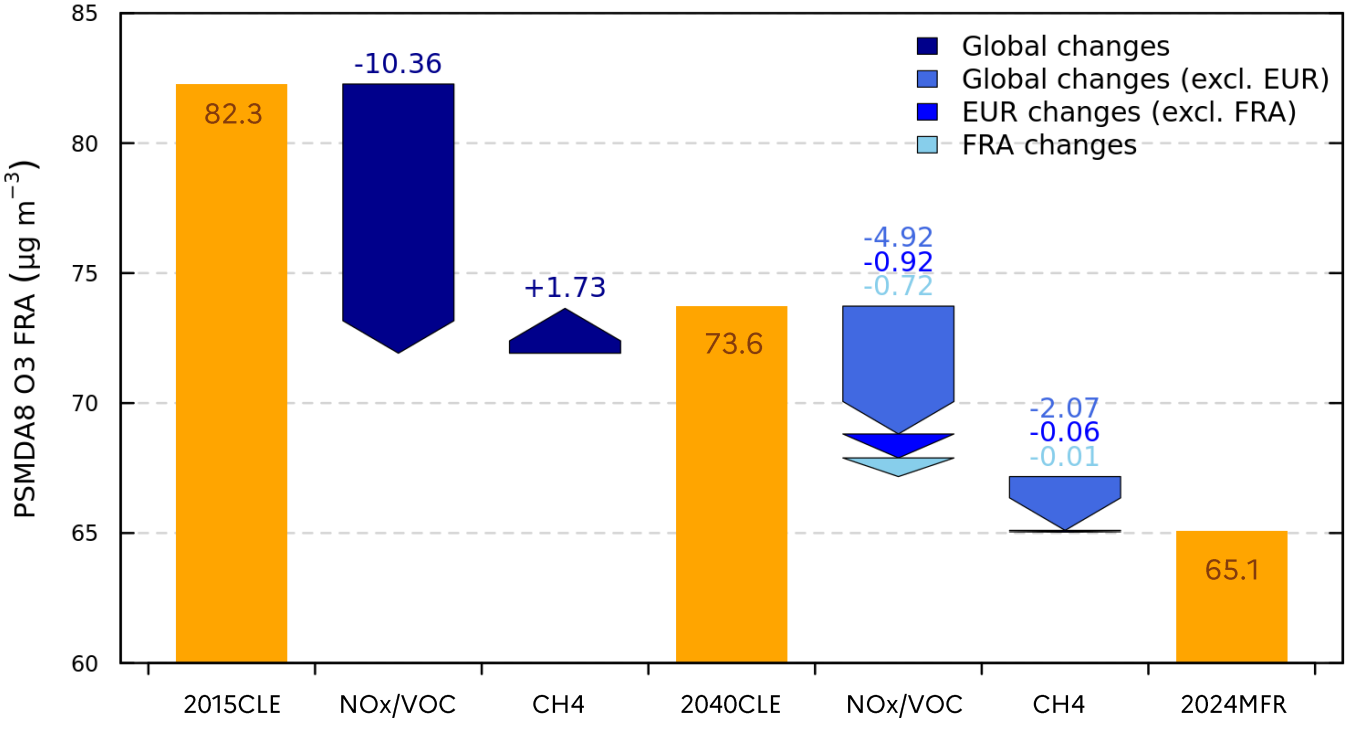


Mean $PM_{2.5}$ conc. variations



Major additional emission reductions with MFR outside of Europe
→ Major reduction in concentrations outside of Europe

Results on ozone concentrations in France



2040CLE vs 2015CLE:
-8,63 µg m^{-3}

2040MFR vs 2040CLE:
additional -8,7 µg m^{-3}

→ Still higher than WHO guideline (60 µg m^{-3})

2040MFR vs 2040CLE:

- Reduc. by species:

75 % NO_x/VOC
25 % CH_4

- Reduc. by region:

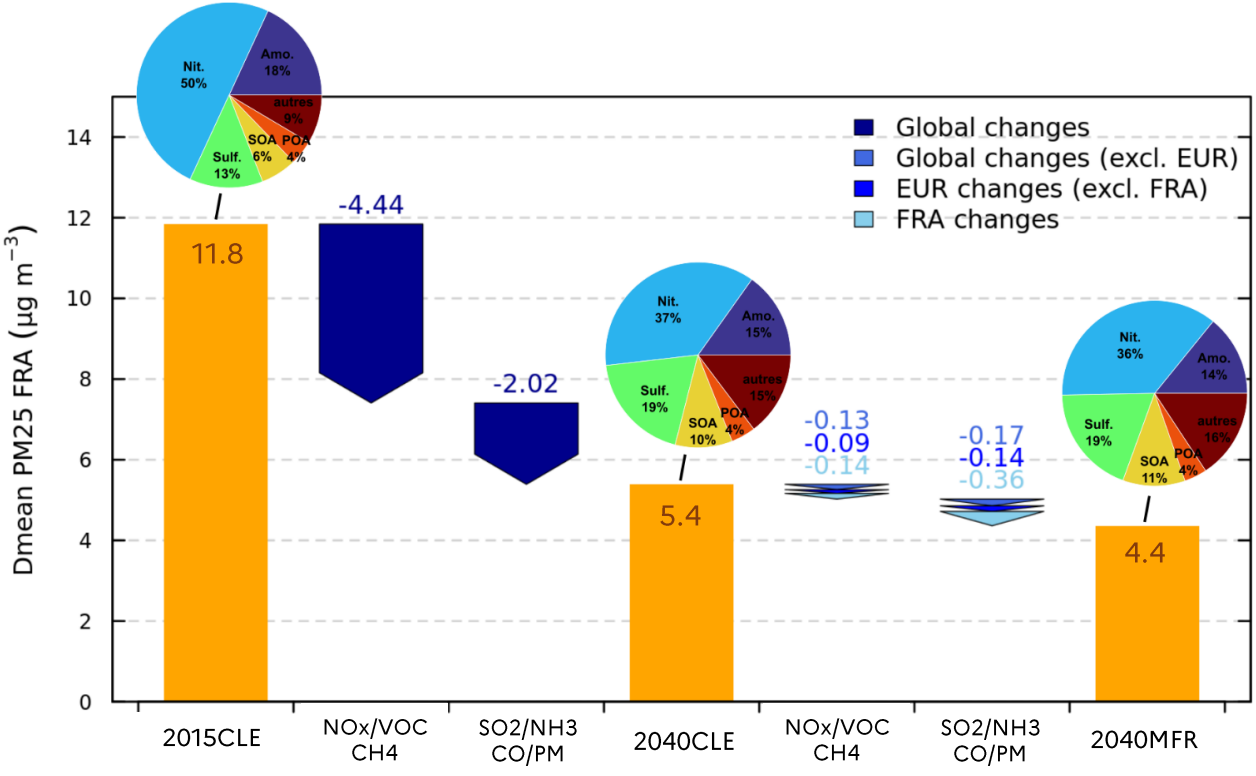
~8 % France NO_x/VOC
~11 % R. of Europe NO_x/COV
55 % R. of the world NO_x/COV
25 % R. of the world CH_4

MFR additional reduction distribution 55%/20%/25% ([NOx/VOC GLO] / [NOX/VOC EUR] / [CH4 GLO])

→ Different than *van Caspel et al. (2024)* (33%/33%/33%) but consistent with!

- Differences in areas EMEP≠EUR≠FRA (less reductions and impact in EUR and FRA)
- Different horizons 2040 or 2050 (increase of NOx/VOC/CH4 GLO emissions between 2040–2050, a decade of further reduction)

Results on PM2.5 concentrations in France



2040CLE vs 2015CLE:

-6,46 µg m^{-3}

2040MFR vs 2040CLE:

additional -1,0 µg m^{-3}

→ Lower than WHO guideline (5 µg m^{-3})

2040MFR vs 2040CLE:

- Reduc. by species:

35 % *NO_X/VOC/CH_4*

65 % *SO_2/NH_3/CO/PM*

- Reduc. by region:

49 % France *(mainly NH3/PM)*

22 % R. of Europe

29 % R. of the world *(all)*

MFR additional reduction is limited compared to CLE (+15%) but allows to meet the WHO recommendations

→ Orders of magnitude coherent with previous EMEP work (*Denby et al.,2024*)

→ Strong decrease with CLE between 2015-2040 due to reduction of NOx emissions in Europe -> HNO3 conc.

Conclusions and perspectives

First operational use of current CHIMERE version on hemispheric domain for policy support with good evaluation and results consistent with previous EMEP studies.

→ Ozone in France 2040:

- **MFR double the reduction**
- **Strong effectiveness of NOx/VOC emission reductions** (national, European and global scale)
- CH_4 emission reductions becomes substantial **only implemented globally**.
- Ozone level remain **higher than WHO guidelines**.

→ $PM_{2.5}$ in France 2040:

- **Strong effectiveness of NOx emissions reductions** (nitrates)
- MFR add 15% reduction
- **MFR Reach WHO guideline**
- National emissions play a major role, making **local action particularly effective**.

⚠ *Study at a coarse resolution and would need to be geographically refined to consolidate the results.*

→ To go further:

- Send different European simulations for HTAP3-OPNS Reg. exercise using BC from global model or CHIMERE Hemispheric
- Adding simulations to better quantify :
  - The role of each emitted compound on pollutant evolutions
  - The role of the different emission sectors on pollutant evolutions (especially in EUR and FRA)