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# European atmosphere in 2050, a regional air quality and climate perspective under CMIP5 scenarios

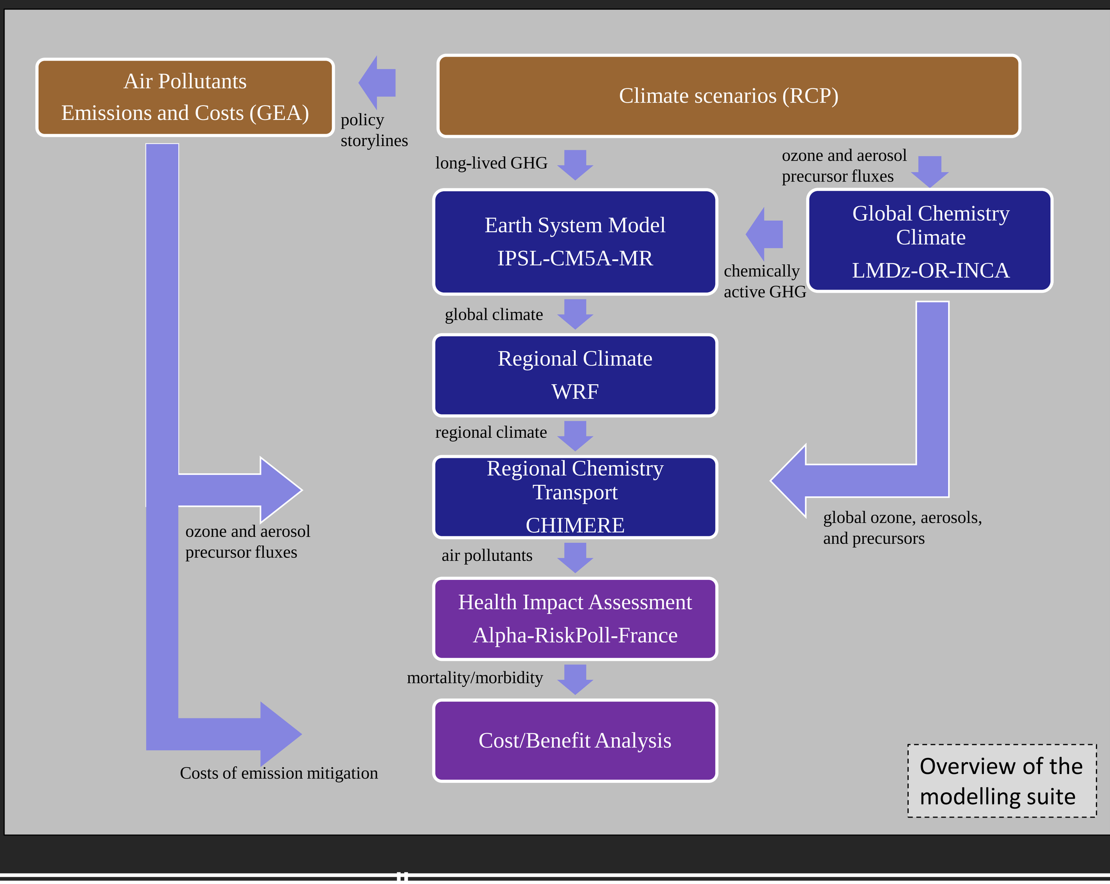
## Abstract :

We present a first assessment of future air quality under CMIP5 scenarios. This assessment relies on explicit representation of climate mitigation and air quality legislation, hence including a quantification of associated costs. It also relies on comprehensive atmospheric models (global and regional climate as well as chemistry and transport) hence offering a detailed representation of external factors. The modelled air pollutant concentrations are analysed in a monetised health assessment framework in order to put the costs in perspective with the sanitary benefits.

The main conclusion of this work are : (1) air pollutant emission reduction dominate the projected changes (compared to climate penalty and long range transport) and (2) mitigation costs are largely compensated by expected sanitary benefits.

## Modelling Framework

- We designed, developed and implemented a suite of climate and chemistry models designed to assess future air quality at the regional scale taking into account external factors such as climate change, or long range transport of pollution in addition to regional air pollutant emission changes.
- This suite of atmospheric models is embedded in a quantitative cost-benefit analysis framework in order to compare mitigation costs and expected sanitary benefits.



Overview of the modelling suite

## Emission Projections

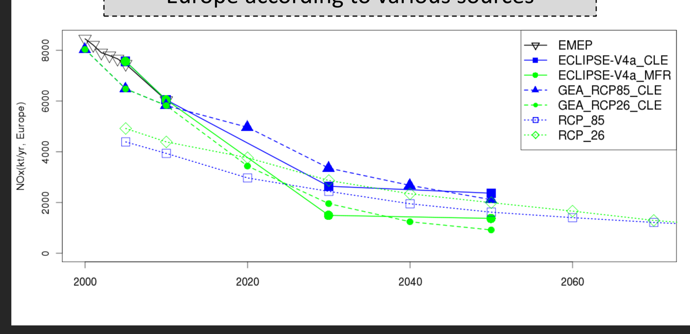
We use the prospective scenarios developed for the Global Energy Assessment (2012):

- Climate policy storylines matching the ambitions of $RCP_{2.6}$ and $RCP_{8.5}$
- Explicit representation of air quality policies up to 2030 (using GAINS emission factors)
- Possibility to derive associated cost of mitigation
- Available in gridded form, split accros activity sectors, hence relevant for CTM modelling.

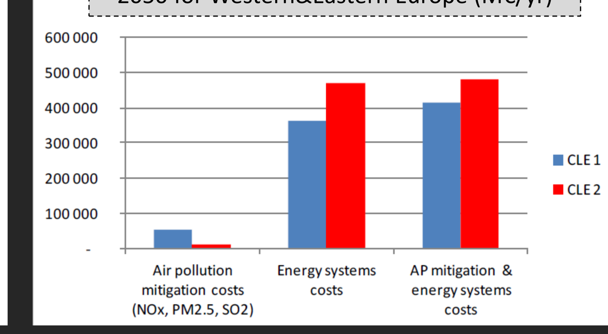
The range of future changes is narrow in the RCPs and important discrepancies are found for the present time (possible differences in sector accounted for).

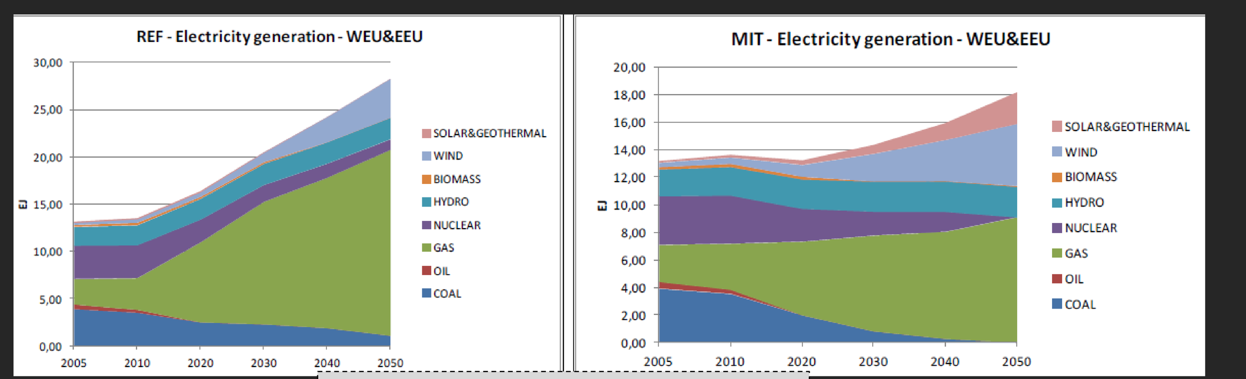
The switch towards a low carbon energy production system is accompanied by a collateral reduction of air pollutant emissions, hence a lower cost of AQ legislation.

NOx emission projections over Western Europe according to various sources




Energy expenditures and mitigation cost in 2050 for Western&Eastern Europe (M€/yr)



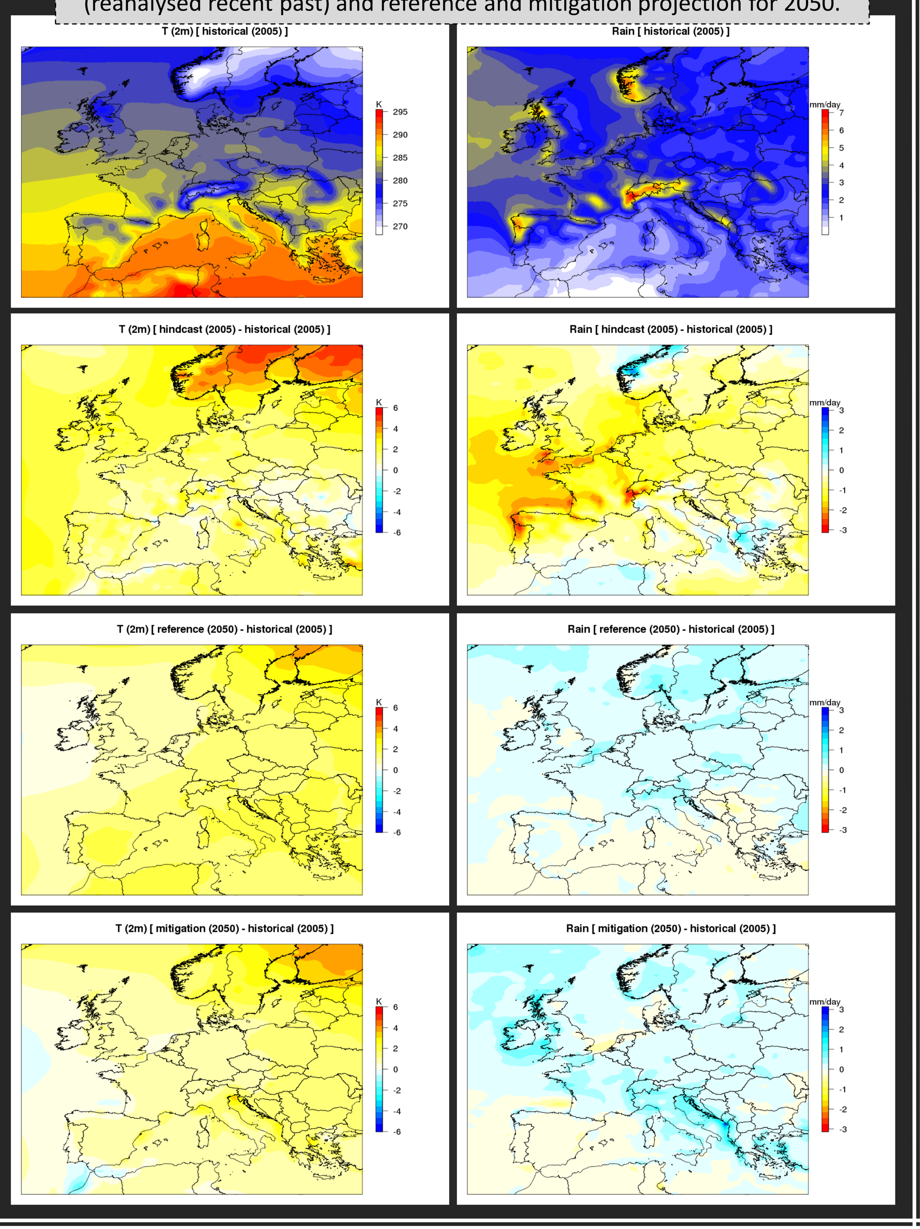
Evolution of electricity production according to the reference and mitigation scenarios

## Regional Climate Projections

The global climate projection (IPSLcm5-MR member of CMIP5) is downscalled with WRF at 50km resolution (similar setup as the low resolution IPSL-INERIS member of Euro-Cordex).

The regional climate model is colder and wetter than the reanalysis (ERA-Interim) over the past 10yr. The magnitude of the bias is of the same order as the changes between present and future.

Temperature (95th quant. daily mean in JJA) and rain (daily mean) in - top - the historical climate simulation and - lower panels - change for the hindcast (reanalysed recent past) and reference and mitigation projection for 2050.



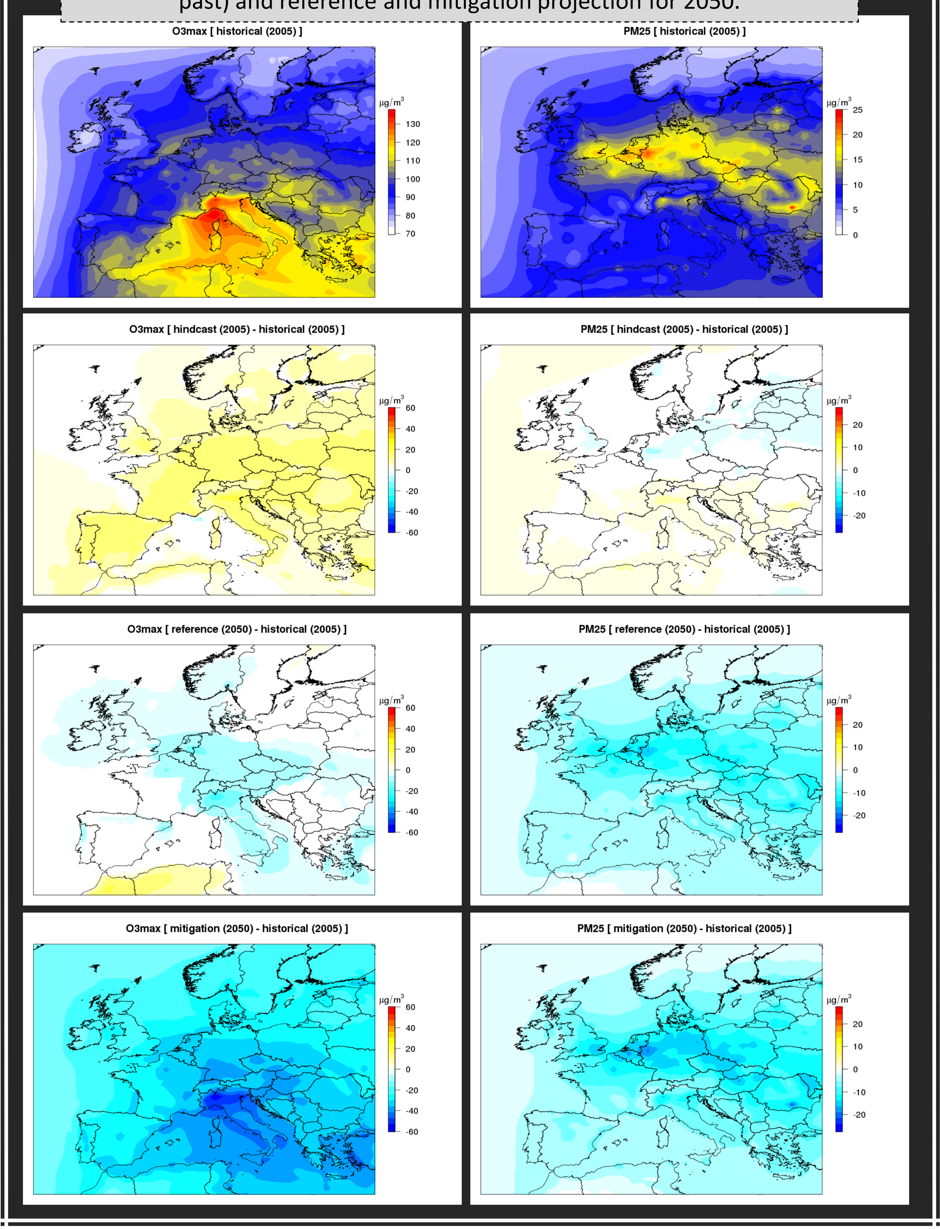
## Air Pollution Projections

Ozone is underestimated when using a climate model instead of reanalyses to drive the CTM. This difference is largely due to the impact of reduced incoming SW radiation (due to altered cloud cover) on biogenic emissions.

$PM_{2.5}$ concentrations are not largely impacted by the overestimated precipitations.

Large reductions of ozone and $PM_{2.5}$ are projected, except under the reference scenario (no climate policy).

Ozone (daily max in JJA) and $PM_{2.5}$ (annual) in - top - the historical climate simulation and - lower panels - change for the hindcast (reanalysed recent past) and reference and mitigation projection for 2050.



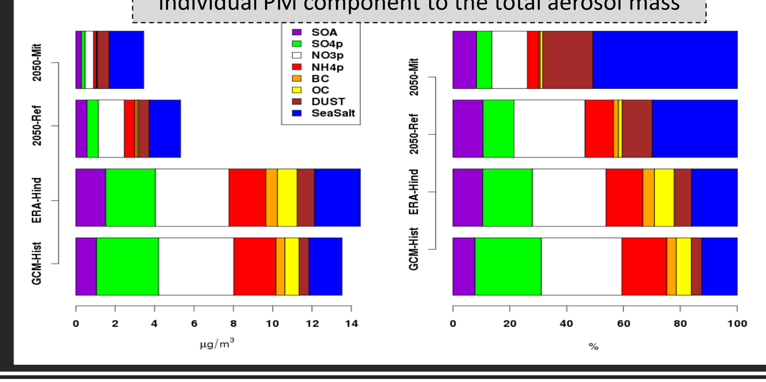
## Particulate Matter Composition

Thanks to the reduction of primary aerosols and precursors, the relative importance of natural PM increase in the future.

Amongst all secondary PM, SOA become prominent, because of the sustained biogenic emissions.

The increase of $NH_3$ emissions is not reflected in the $NH_4^+$ projection (that decrease)

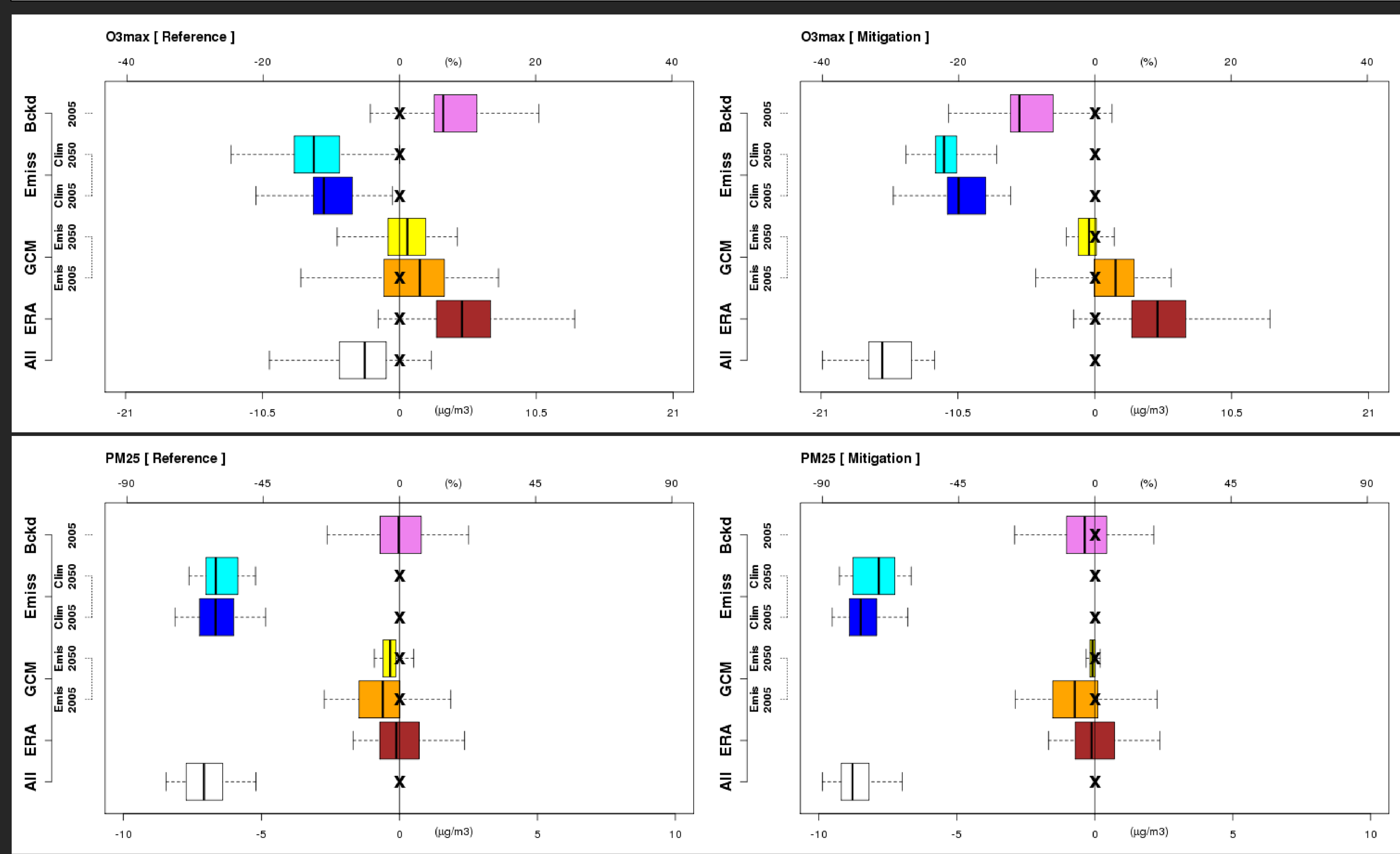
Absolute (left) and relative (right) contribution of individual PM component to the total aerosol mass



## Disentangling driving factors

Sensitivity experiments (based on decadal simulations) changing only (1) emissions, (2) climate, and (3) boundary conditions allow quantifying the relative contributions of each external factor to the projection.

Anthropogenic emission changes are found to dominate, but long range transport also constitute a major driving force for ozone. The magnitude of the climate penalty is found to evolve over time.



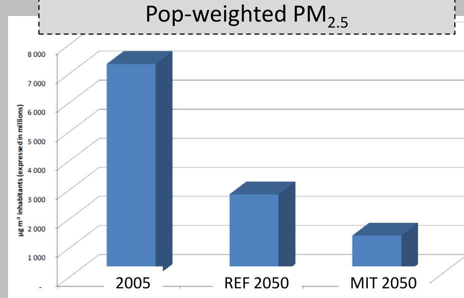

Absolute and relative contribution of climate, boundary conditions and emissions to the total projected change of ozone (top) and $PM_{2.5}$ (bot.) in the reference (left) and mitigation (right) scenarios.

## Exposure to air pollution

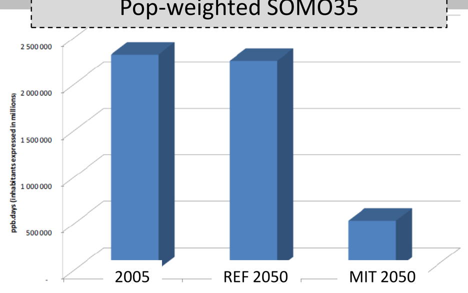
Exposition is quantified as population weighted concentration of relevant indicators: annual mean for $PM_{2.5}$ and SOMO35 for ozone.

Subgrid scale covariance of pollution and population is taken into account as well as the bias brought about by the climate model using quantile matching.

Pop-weighted $PM_{2.5}$




Pop-weighted SOMO35




## Health Impact Assessment

Using relevant concentration response functions we can quantify the health oucome of exposure to air pollution in terms of premature death, number of hospital admissions, life years lost etc.

In turn, using various monetisation reference values (Value of Statistical Life, used for valuing premature deaths or Value Of Life Year, used for valuing loss of life expectancy) we can quantify the overall damage.

The underlying HIA/monetisation model is AlphaRiskPoll (TSAP 2005 (CAFE) and 2013).

Accounting for changes in total population and age distribution yields, for instance, to an increase in premature deaths from acute exposure to ozone in the REF scenario, even if population weighted ozone decreases slightly .

Annual health impacts due to air pollution in 2005 and 2050

| Impacts | WEU & EEU | Pollutant | 2005 | REF - 2050 | MIT - 2050 |
|---|---|---|---|---|---|
| Acute Mortality (All ages) median VOLY | Premature deaths | O3 | 37 736 | 55 767 | 13 102 |
| Respiratory Hospital Admissions (65yr +) | Cases | O3 | 29 669 | 61 361 | 14 399 |
| Minor Restricted Activity Days (MRADs 15-64yr) | Days | O3 | 100 171 110 | 90 021 573 | 21 294 845 |
| Respiratory medication use (adults 20yr +) | Days | O3 | 33 516 583 | 39 475 865 | 9 309 955 |
| Chronic Mortality (All ages) LYL median VOLY | Life years lost | PM | 5 370 638 | 1 761 520 | 891 230 |
| Infant Mortality (0-1yr) median VSL | Premature deaths | PM | 2 161 | 319 | 169 |
| Chronic Bronchitis (27yr +) | Cases | PM | 210 441 | 100 359 | 51 092 |
| Respiratory Hospital Admissions (All ages) | Cases | PM | 83 150 | 35 941 | 18 254 |
| Cardiac Hospital Admissions (All ages) | Cases | PM | 51 282 | 22 166 | 11 258 |
| Restricted Activity Days (RADs 15-64yr) | Days | PM | 453 169 956 | 157 534 882 | 79 757 470 |
| Respiratory medication use (children 5-14yr) | Days | PM | 5 081 740 | 1 871 472 | 952 977 |
| Respiratory medication use (adults 20yr +) | Days | PM | 37 161 881 | 16 944 013 | 8 616 990 |
| LRS symptom days (children 5-14yr) | Days | PM | 249 824 045 | 89 015 374 | 45 007 712 |
| LRS among adults (15yr +) with chronic symptoms | Days | PM | 383 215 915 | 171 076 139 | 86 974 976 |

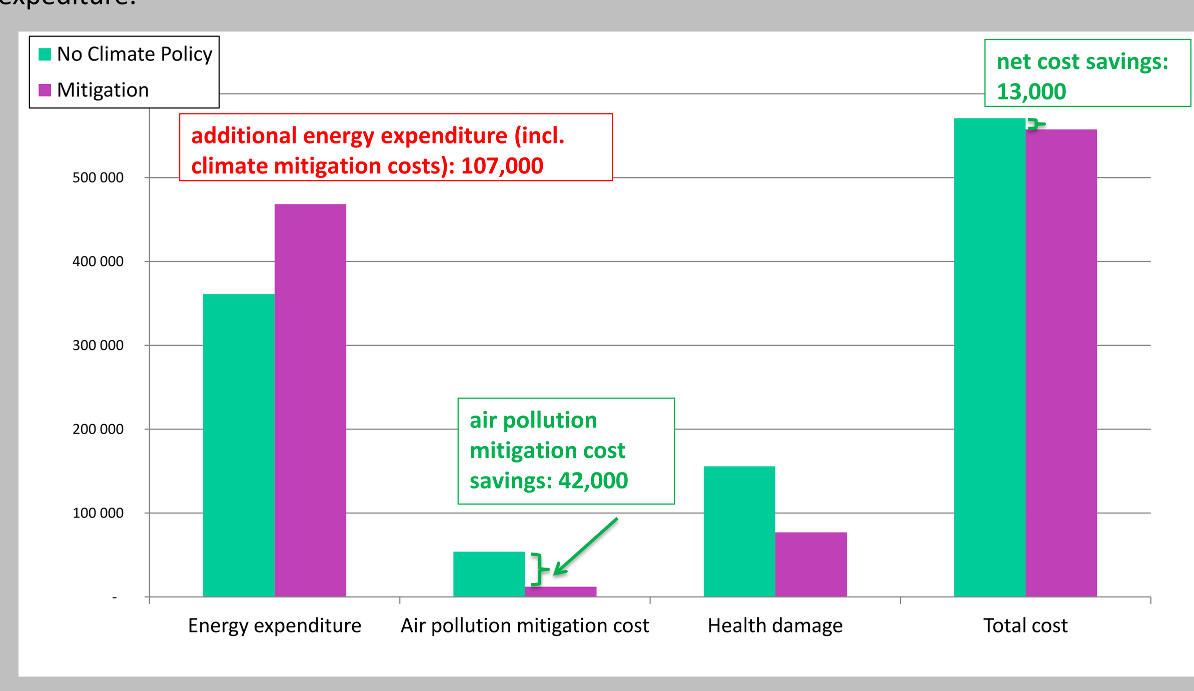
Annual health damage due to air pollution in 2005 and 2050

| Damage, €M/year | WEU & EEU | Pollutant | 2005 | REF - 2050 | MIT - 2050 |
|---|---|---|---|---|---|
| Acute Mortality (All ages) median VOLY | Premature deaths | O3 | 2 177 | 3 218 | 756 |
| Respiratory Hospital Admissions (65yr +) | Cases | O3 | 66 | 136 | 32 |
| Minor Restricted Activity Days (MRADs 15-64yr) | Days | O3 | 4 207 | 3 781 | 894 |
| Respiratory medication use (adults 20yr +) | Days | O3 | 34 | 39 | 9 |
| Chronic Mortality (All ages) LYL median VOLY | Life years lost | PM | 309 886 | 101 640 | 51 424 |
| Infant Mortality (0-1yr) median VSL | Premature deaths | PM | 3 533 | 521 | 276 |
| Chronic Bronchitis (27yr +) | Cases | PM | 43 772 | 20 875 | 10 627 |
| Respiratory Hospital Admissions (All ages) | Cases | PM | 185 | 80 | 41 |
| Cardiac Hospital Admissions (All ages) | Cases | PM | 114 | 49 | 25 |
| Restricted Activity Days (RADs 15-64yr) | Days | PM | 41 692 | 14 493 | 7 338 |
| Respiratory medication use (children 5-14yr) | Days | PM | 5 | 2 | 1 |
| Respiratory medication use (adults 20yr +) | Days | PM | 37 | 17 | 9 |
| LRS symptom days (children 5-14yr) | Days | PM | 10 493 | 3 739 | 1 890 |
| LRS among adults (15yr +) with chronic symptoms | Days | PM | 16 095 | 7 185 | 3 653 |
| Total with VOLY median | | | 432 295 | 155 775 | 76 975 |

## Cost Benefit Analysis

The sanitary benefits brought about by air pollution improvement as a result of climate policies can be compared to the cost of mitigation.

We find that the expected health improvement largely compensates the increase in energy expenditure.



Energy, AQ mitigation and sanitary costs in M€(2005)/year in 2050 for WEU&EEU

## Conclusion

Using a new modelling suite, relying on the latest quantitative projections, and analysed in a cost-benefit framework, we could assess future air quality pointing out the relative role of external factors and concluding on the balance between the technological cost of mitigation and expected sanitary benefits.

The main conclusions of the work regarding (1) the dominating role of emission reduction compared to external penalties and (2) the compensation of costs by projected sanitary benefits clearly argue in favor of the effectiveness and efficiency of climate mitigation.

The comprehensiveness of the present modelling suite includes a number of assets, and also offers the possibility to highlight the main uncertainty sources and future research needs. Implementing a state-of-the-art chemistry transport model (Chimere) driven by regional climate projection (CORDEX) and using future boundary conditions (ACCMIP) allows quantifying the non-linear role of external factors. It also make the results more sensitive to possible biases in driving data than using fitted transfer functions. The main route to improve the robustness of the present findings consists in moving towards ensemble approaches, raising significant computational challenges for the years to come.

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