Sensitivity analysis to precursor emissions of multi-objective air quality control policies

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- The air quality control problem
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Objectives

To perform uncertainty analysis on a:

- Multi-objective optimization problem:
  - Objective 1: Air Quality Index (*AQI*)
  - Objective 2: Internal Costs (*C*)
- for a mesoscale domain
  - Northern Italy

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Multi-objective problem

$$\min_{\theta} J(\theta)$$

$$J(\theta) = [\Psi(\theta) \quad C(\theta)]$$

emis

PM exposure inde

$$\theta \in \Theta$$

set of the feasible solutions

decision variables: reduction of the

CORINAIR SECTOR

1. public power
2. residential combustion
3. industrial combustion
4. production processes
5. extraction fossil fuels
6. solvent use
7. road transport
8. other mobile sources
9. waste treatment
10. Agriculture
11. nature

The air quality index and Cost functions

- AQI: yearly domain mean PM10 (μg/m3)
  - Nonlinear;
  - Computation by 3D deterministic modelling system too time consuming.
    - ANNs

- C: polynomial functions
  - Using IIASA GAINS DB

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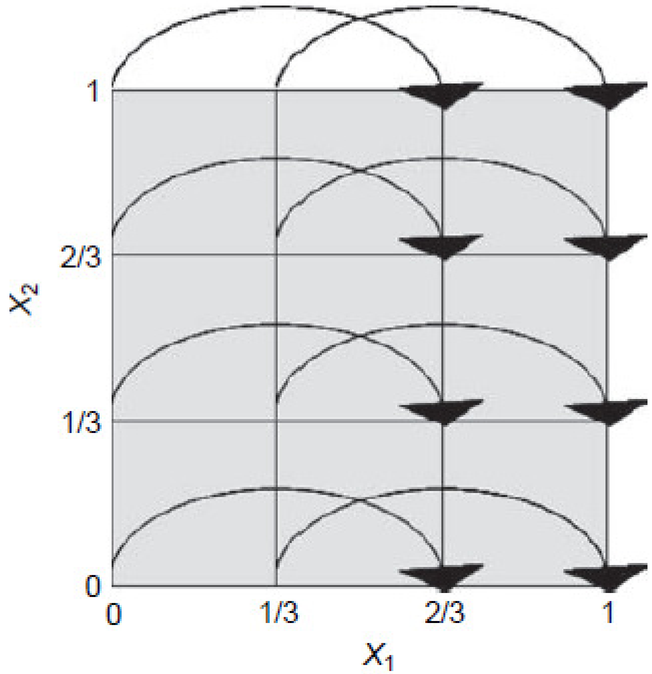
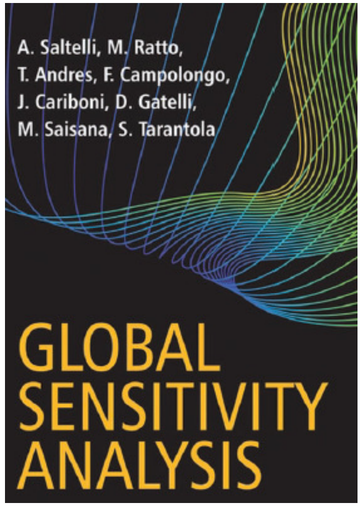
The Elementary Effect approach



FACTORS = 2
LEVELS = 4
DELTA = 2/3

EE_i = 8



$$EE_i = \frac{y(X_1 + \Delta, X_2) - y(X_1, X_2)}{\Delta}$$

Distribution of elementary effects associated with the i_{th} input factor is obtained by randomly sampling different X, and is denoted by F_i.

The sensitivity measures are respectively the mean and the standard deviation of the distribution F_i → GLOBAL UNCERTAINTY ANALYSIS

The Elementary Effect approach

- General expression of EEi:

$$EE_i = \frac{y(X_1, X_2, ..., X_i + \Delta, ..., X_k) - y(X_1, X_2, ..., X_i, ..., X_k)}{\Delta}$$

- $\mu*$: mean of value of the effects
  - total effect of a precursor (the sum of the effect of that factor, plus the interacting terms that involve factor itself)
- σ: std. deviation of value of the effects
  - Interactions/nonlinearities among factors

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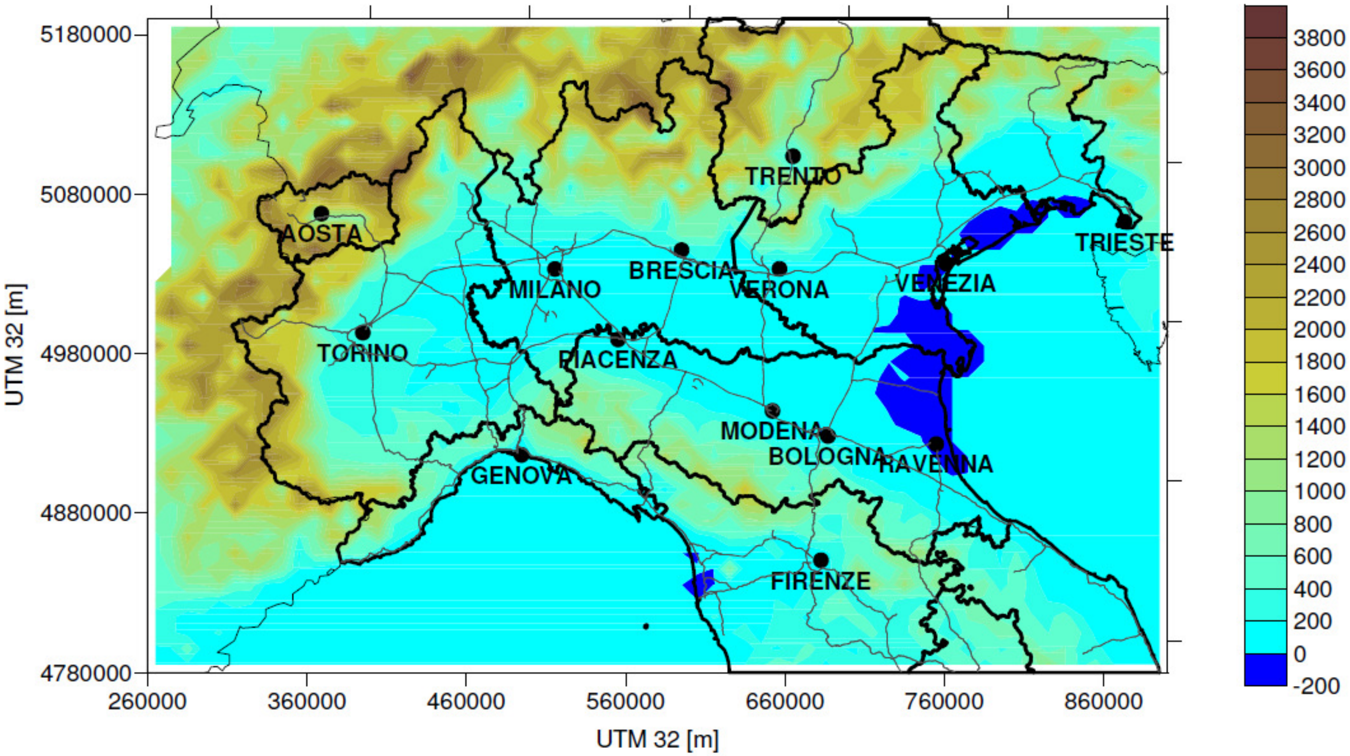
Case study domain & Setup



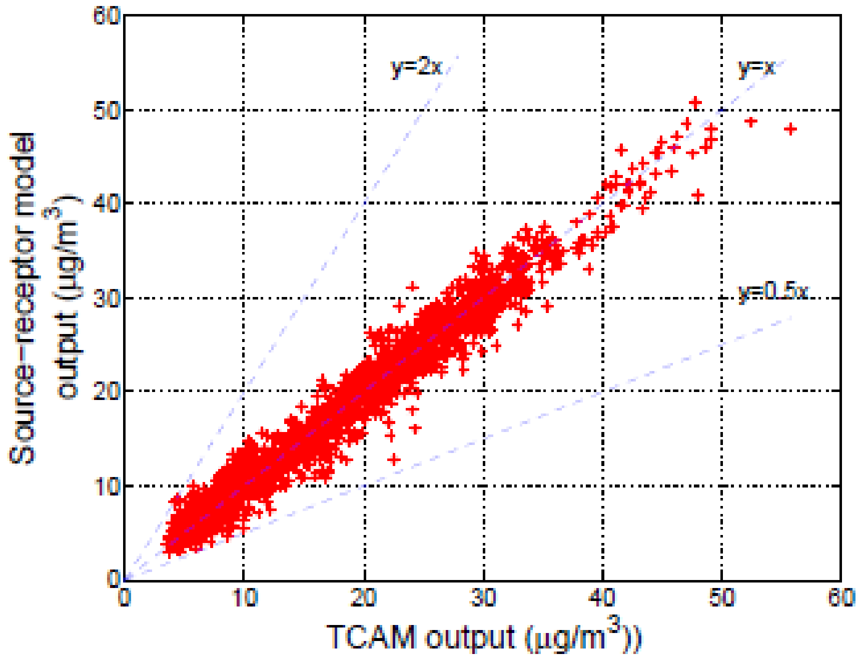
CTM setting
- Horiz. Resolution: 10km
- Nx: 95
- Ny: 62

Uncertainty Analysis:
- precursor emissions (k=5)
- No. Levels l=5
- Cardinality of Subset r=10
- Uncertainty Bounds: -0.1, 0.1

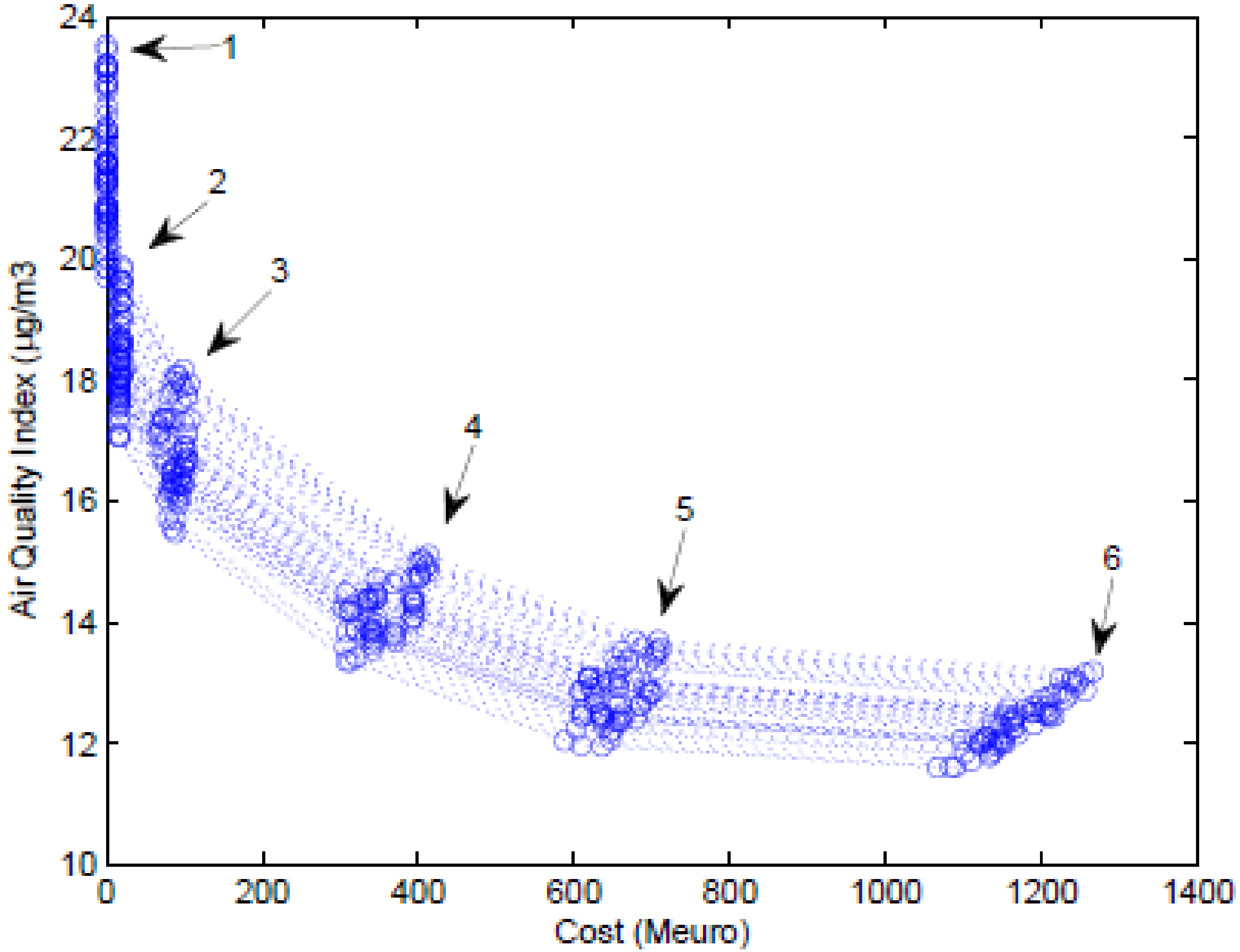
Some details on AQI

Table 1. Reductions applied to PM_{10} precursor emissions, with respect to Quitsat case base, for the 10 reduced emissions scenarios.

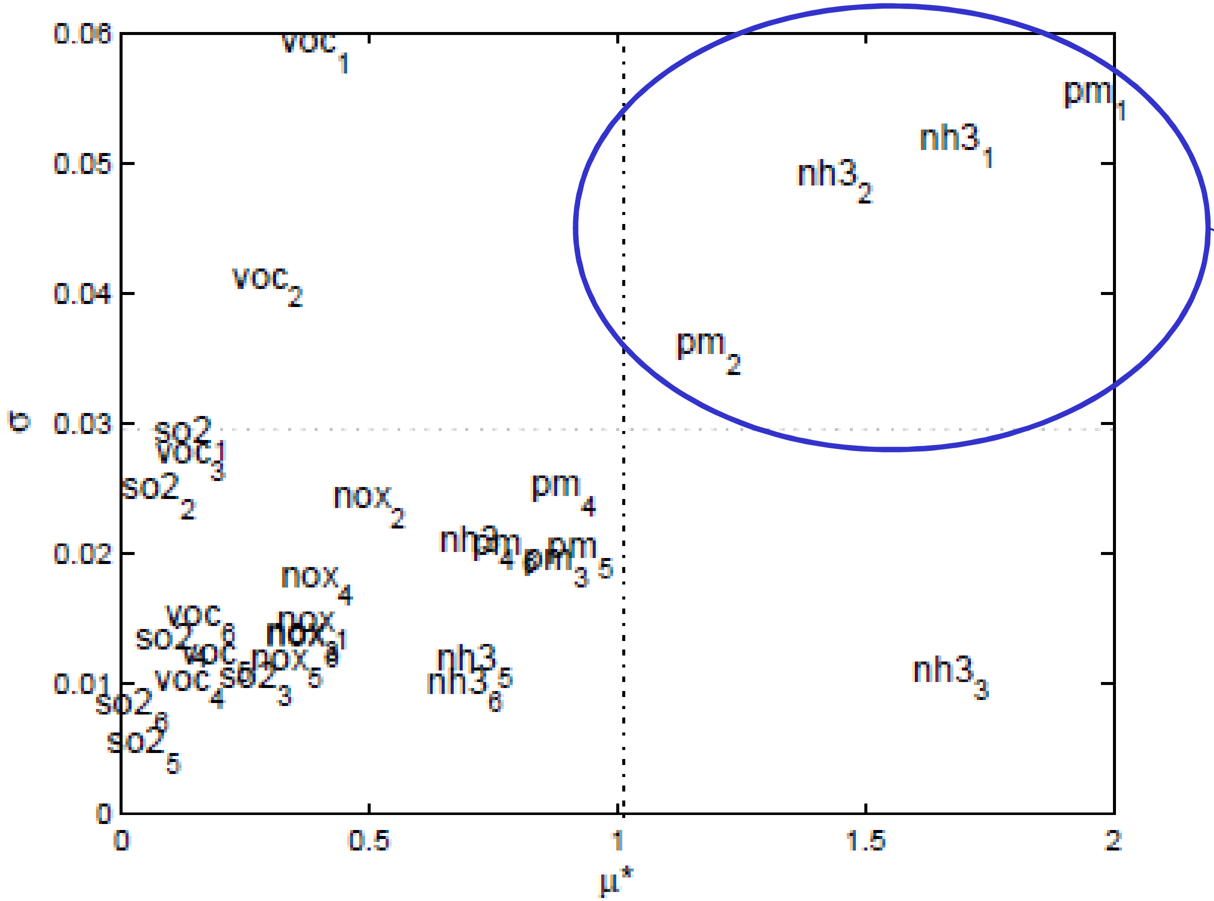
Scenario ID	NO_x	VOC	PM	SO_2	NH_3
1	30.89%	27.26%	21.45%	26.70%	35.85%
2	61.78%	54.52%	42.90%	53.40%	71.70%
3	61.78%	27.26%	21.45%	26.70%	35.85%
4	30.89%	54.52%	21.45%	26.70%	35.85%
5	30.89%	27.26%	42.90%	26.70%	35.85%
6	30.89%	27.26%	21.45%	53.40%	35.85%
7	30.89%	27.26%	21.45%	26.70%	71.70%
8	30.89%	54.52%	21.45%	53.40%	35.85%
9	61.78%	54.52%	21.45%	53.40%	71.70%
10	61.78%	27.26%	42.90%	26.70%	35.85%



Pareto curve variability



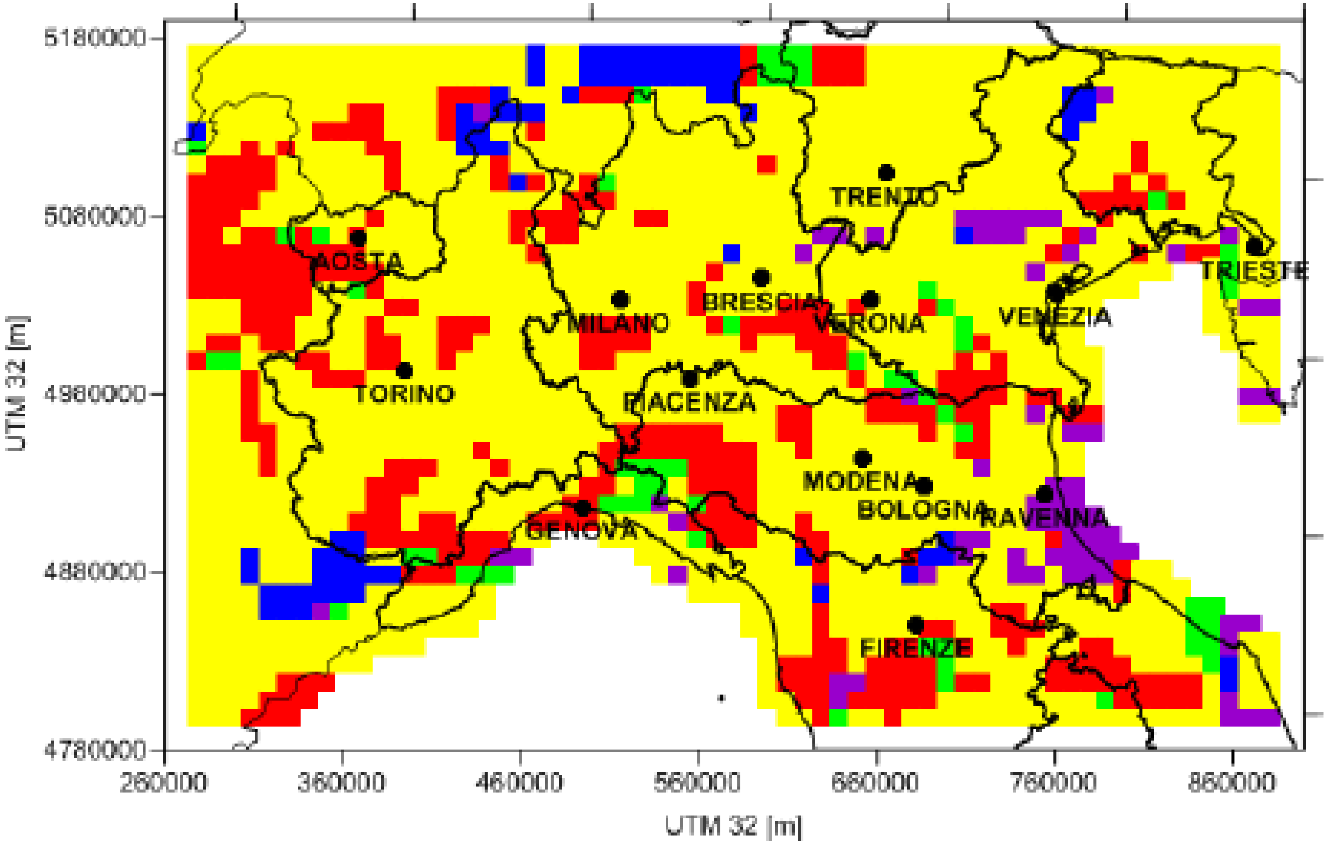
Sensitivity measures on AQI



non linearities
Total impact

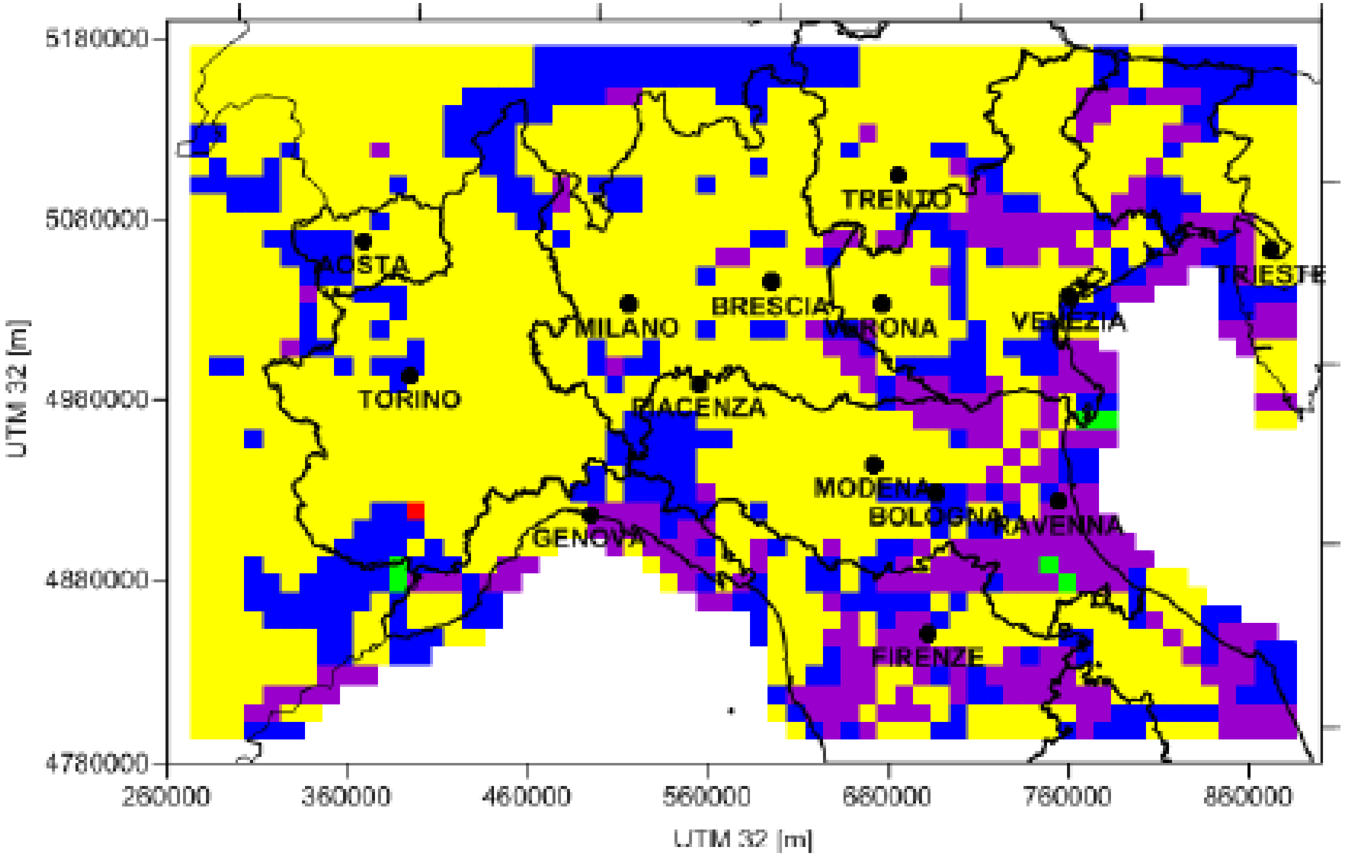
Mean and standard deviation of the Elementary Effect for precursors, computed using 60 optimizations (6 pareto points).

Mu* predominant pollutant



Precursor pollutant with highest Air Quality Index μ (spatial).
VOC (blue), NOx (green), NH3 (yellow), PM (red), SO2 (violet).

Sigma predominant pollutant



Precursor pollutant with the highest Air Quality Index σ (spatial).
VOC (blue), NOx (green), NH_3 (yellow), PM (red), SO_2 (violet).

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Conclusions

- Elementary Effect approach formalized and applied for a multiobjective nonlinear optimization problem

- Application to the Northern Italy domain
  - AQI variability: mainly due to NH3 uncertainties

- Future work:
  - Robustness from a policy maker point of view
  - Reduce uncertainty on NH3 emissions
  - Quantitative uncertainty/sensitivity analysis