# APPLICATION OF THE SIRANE STREET-NETWORK MODEL TO TURIN, ITALY: from Input Data to Model Evaluation

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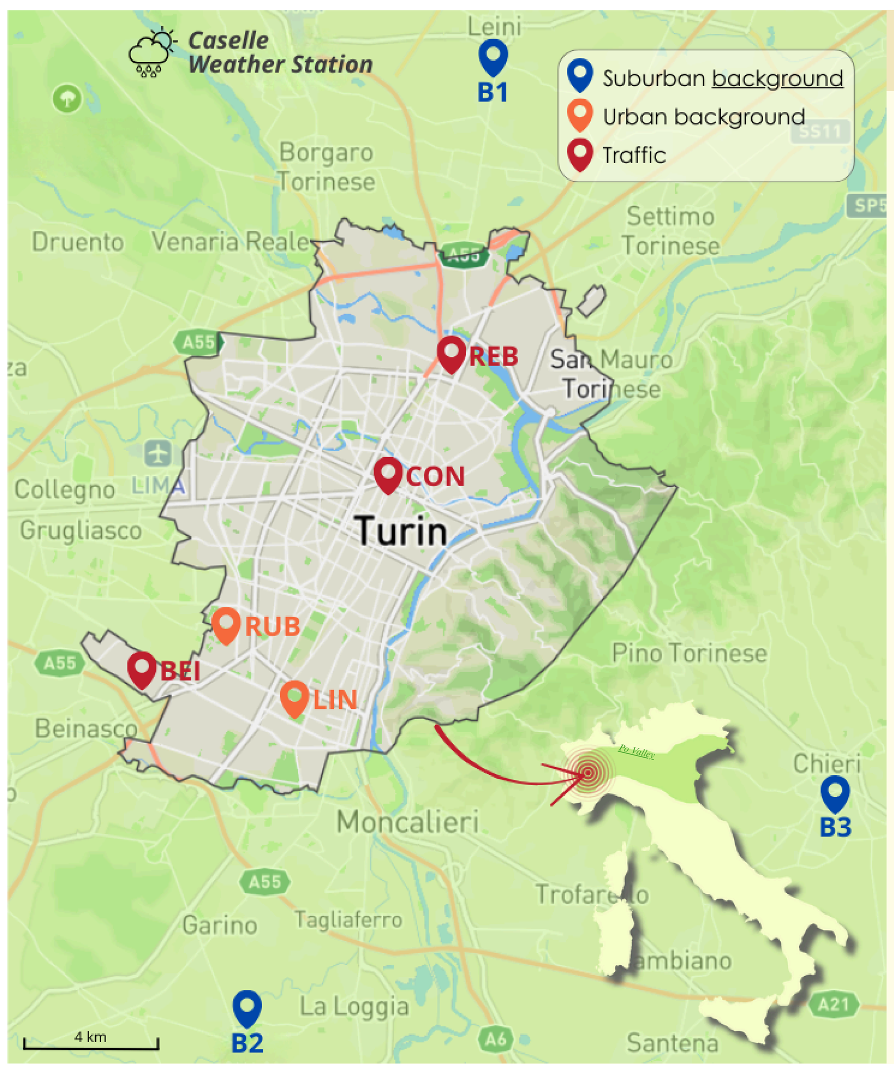
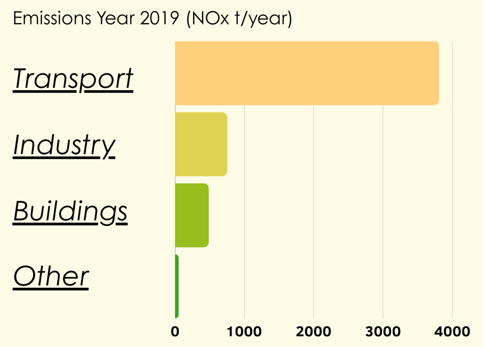



## MOTIVATION & CASE STUDY

Urban air pollution remains one of the main environmental health risks in Europe. In particular, nitrogen dioxide ($NO_2$) and fine particulate matter ($PM_{2.5}$) frequently exceed EU and WHO guidelines, with well-documented impacts on human health.

In this study, the SIRANE model[3],[4],[5] is applied to the municipality of Turin[1]. Turin, located in north-western Italy at the foot of the Alps, lies within the Po Valley, one of the regions most prone to air pollution accumulation. Its geographical setting, combined with dense traffic and residential heating, favors pollutant build-up and makes air quality management a pressing issue.




The study focuses on nitrogen oxides (NO, $NO_2$, $NO_x$) and ozone ($O_3$) during February 2022, a typical winter month.

**KEY QUESTION**

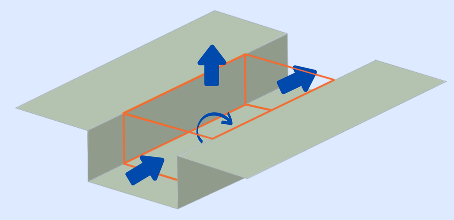
A pilot application of the SIRANE dispersion model to the city of Turin, evaluating its ability to capture air pollution patterns.

... TOWARDS URBAN AIR QUALITY MANAGEMENT

(130 km², 850,000 inhab.)

## SIRANE - Street Network model

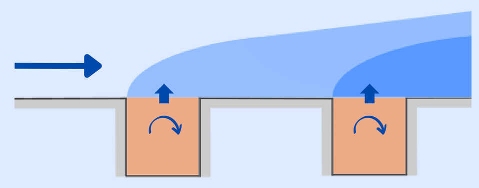
1. **Within urban canopy**



- Advection along the street axis
- Turbulent diffusion across the interface with external atmosphere
- Exchange model at intersections between streets

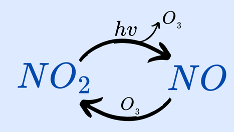
2. **In the atmospheric boundary layer**

- Gaussian plume for roof level transport.



3. **Physico-chemical processes**

$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 + M \rightarrow O_3 + M$$
$$NO + O_3 \rightarrow NO_2 + O_2$$




- NO-$NO_2$-$O_3$ cycle
- Particle transport and deposition
- Wet deposition

**URBAN SCALE + SINGLE STREET ACCURACY**

## RECONSTRUCTION OF INPUT DATA

### 1. Traffic Emissions

Calculation of emissions for each pollutant *i*, on each street *j* of the traffic network:

COPERT (Tier 2) $E_{ij} = L_j Q_j Ef_i$

*Lengths*: 5T input data network.

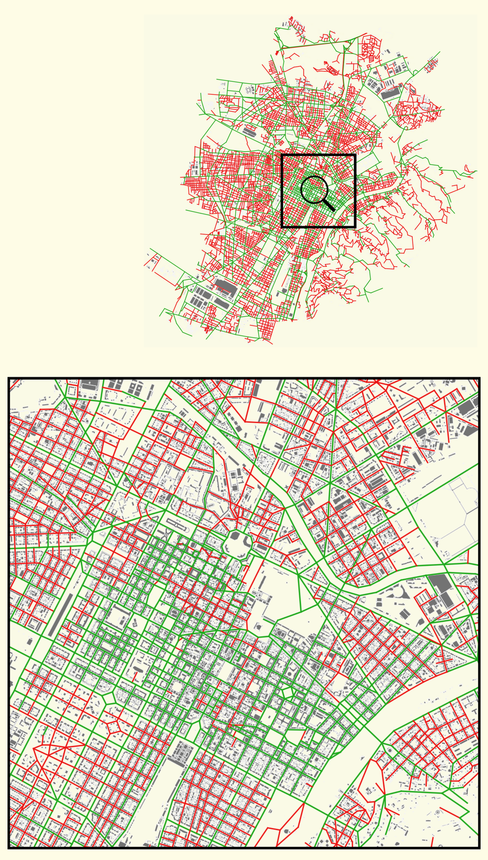
*Daily flow*: number of vehicles / day (averaged over a year).

! cover the main roads of the city and only some secondary roads.

*Typical average emission factors* of pollutant *i*

Weighted average of emission factors (ISPRA) with vehicle fleet data (category, fuel, segment).

Modulation of emissions with specific curves.



### 2. Residential Heating

→ Based on Energy Performance Certificates (EPCs)

→ Convert demand to emissions

1. Building Stock Analysis
2. Consumption Estimation
3. Emission Calculation
4. Spatial Aggregation

→ EPC class + surface area → annual heating demand

→ Emissions mapped and averaged on analysis grid

Emissions were distributed evenly over the winter period (15 October - 15 April).

### 3. Meteorology & Background

- Meteorology: hourly data from ARPA Torino-Caselle

*wind speed and direction, precipitation, solar radiation, temperature*

**ATMOSPHERIC STABILITY AND TURBULENCE ABOVE THE STREET NETWORK**

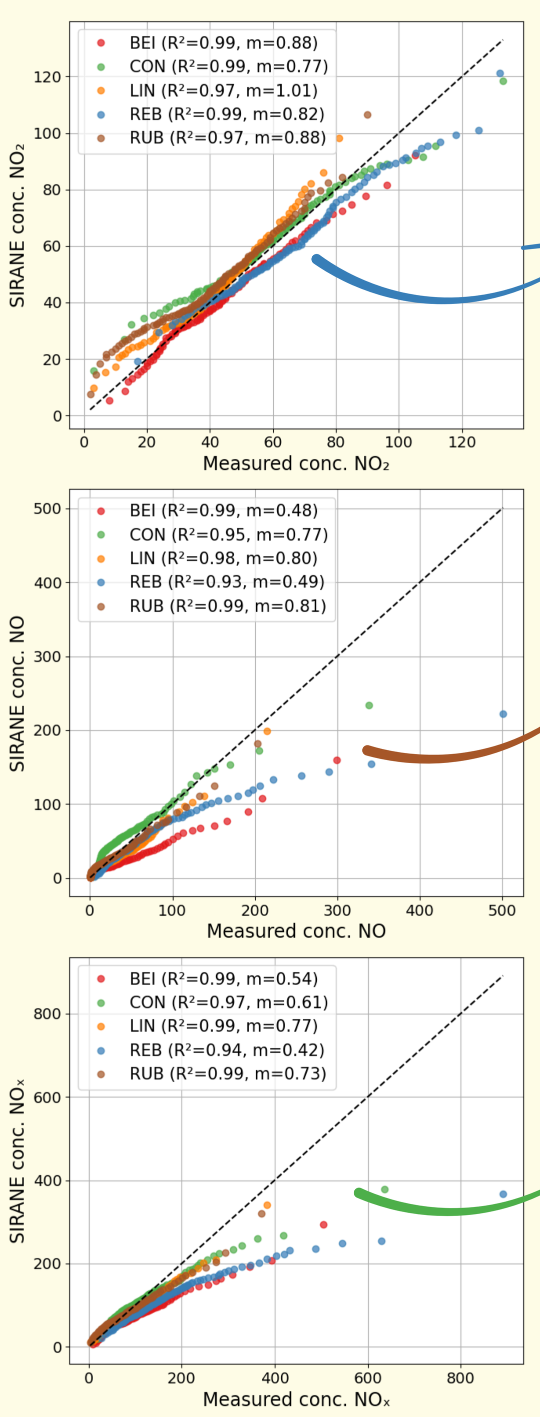
The vertical structure parameterized using *Monin–Obukhov similarity theory.*

$$u(z) = \frac{u_*}{k}\left[\ln\left(\frac{z-d}{z_0}\right)\right] - \psi_m\left(\frac{z-d}{L_{MO}}\right)$$

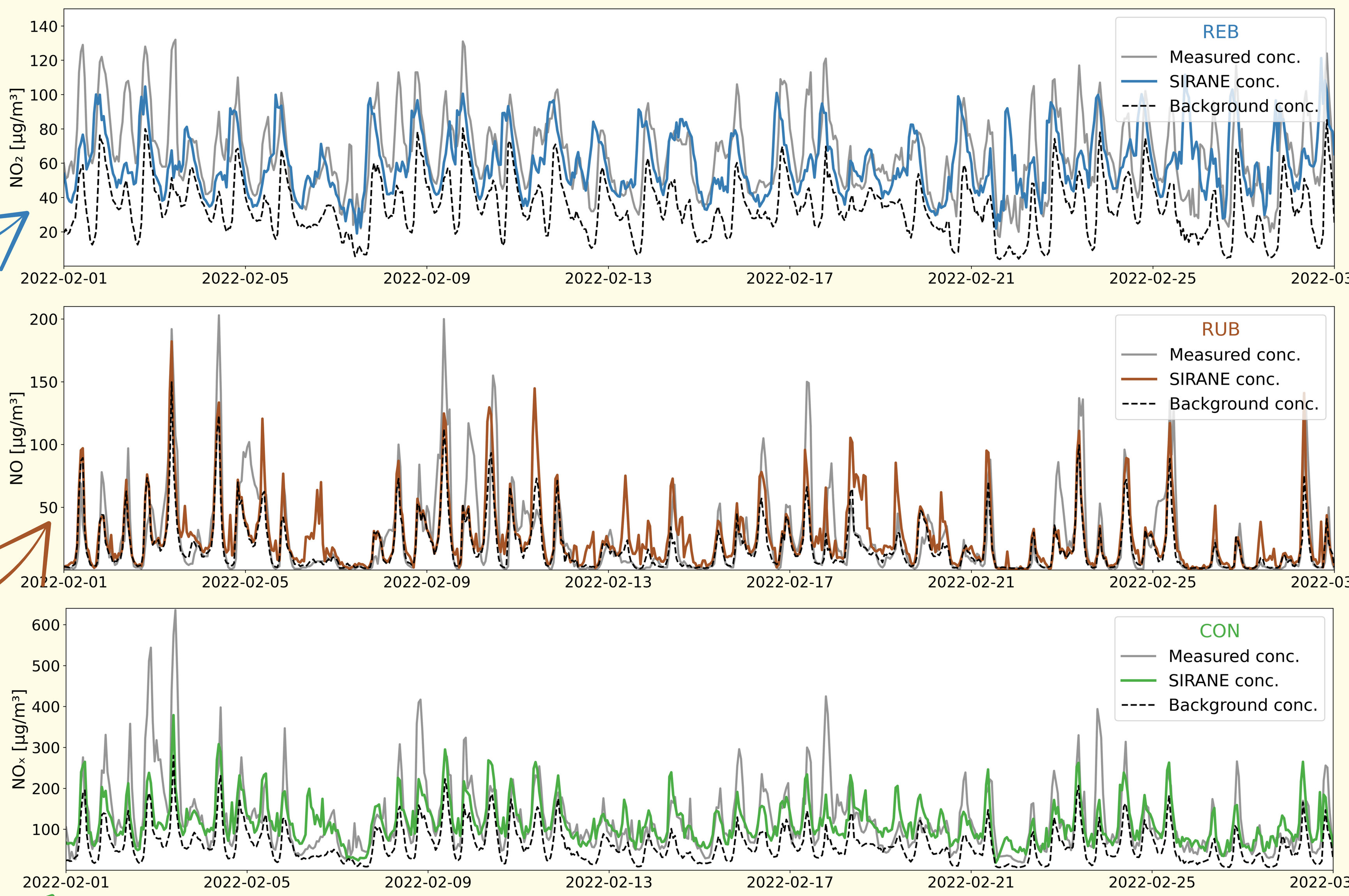
- Background pollutants: mean from ARPA background stations outside city. **B1 B2 B3**

## RESULTS

*Q-Q plots of simulated and measured hourly concentrations.*




*Time series of simulated, measured and background hourly concentrations.*



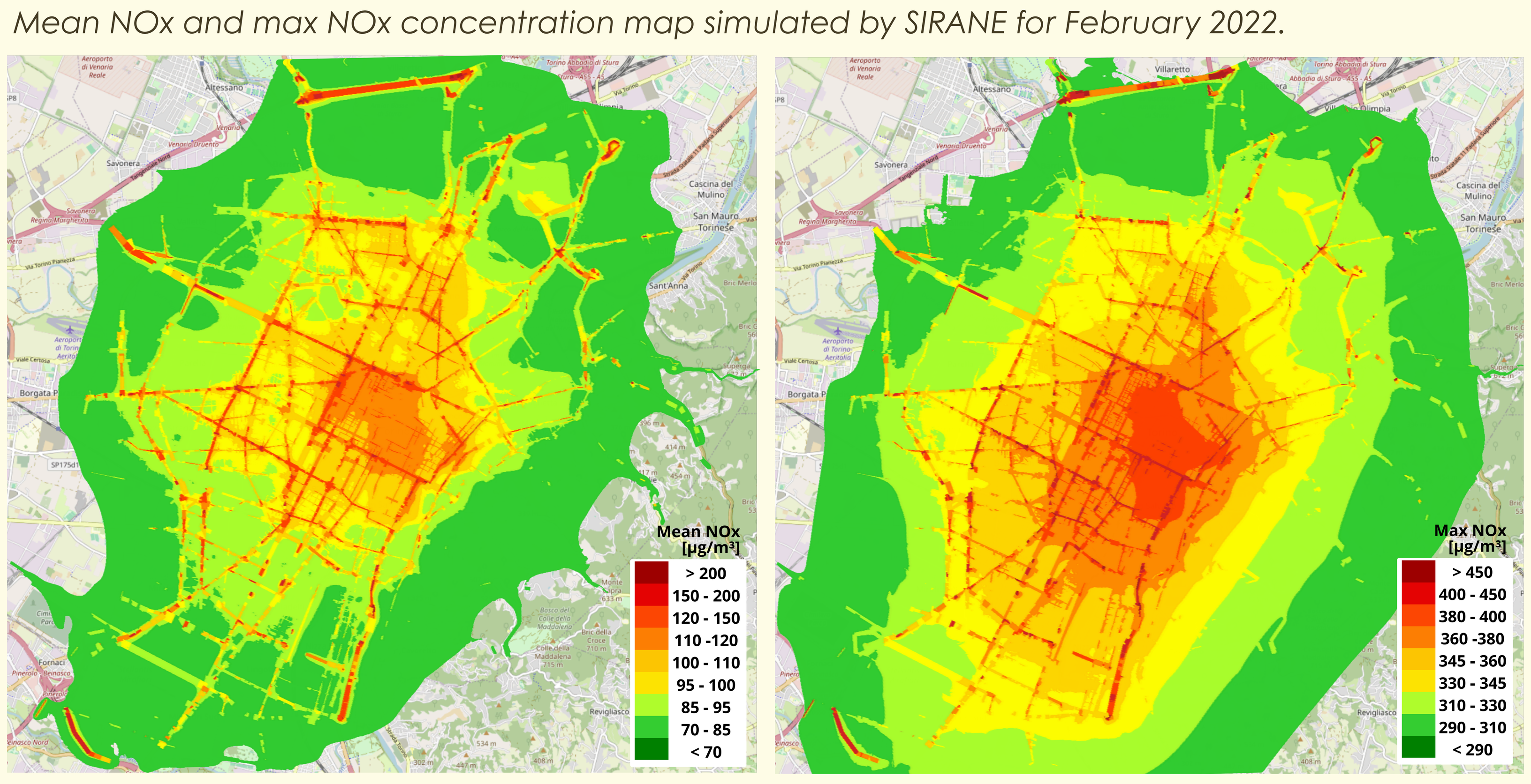

**STATISTICAL METRICS**[2]

**Fractional Bias** → *Mean bias (over/under prediction)* → |FB| ≤ 0.3
**Root Normalized Mean Square Error** → *Variability of error* → rNMSE ≤ 2
**Geometric Mean** → *Tendency to under/over predict* → 0.7 ≤ MG ≤ 1.3
**Geometric Variance** → *spread between model & obs* → VG ≤ 1.6
**FAC2** → *Fraction of points within factor 2 of obs* → FAC2 ≥ 0.5

*Statistical metrics comparing measured and modeled concentrations.*

| Station | Pollutant | FB | rNMSE | MG | VG | FAC2 |
|---|---|---|---|---|---|---|
| BEI | $NO_2$ | -0.07 | 0.37 | 0.93 | 1.16 | 0.93 |
| | NO | -0.09 | 1.44 | 0.89 | 2.60 | 0.49 |
| | $NO_x$ | -0.23 | 0.80 | 0.79 | 1.29 | 0.79 |
| CON | $NO_2$ | 0.08 | 0.34 | 1.10 | 1.20 | 0.91 |
| | NO | 0.32 | 0.77 | 1.44 | 1.73 | 0.62 |
| | $NO_x$ | 0.03 | 0.51 | 1.03 | 1.19 | 0.89 |
| LIN | $NO_2$ | 0.11 | 0.33 | 1.13 | 1.15 | 0.92 |
| | NO | 0.13 | 0.99 | 1.20 | 2.55 | 0.54 |
| | $NO_x$ | -0.01 | 0.59 | 0.99 | 1.29 | 0.82 |
| | $O_3$ | 0.26 | 0.62 | 1.33 | 1.47 | 0.70 |
| REB | $NO_2$ | -0.06 | 0.34 | 0.94 | 1.12 | 0.94 |
| | NO | -0.20 | 0.87 | 0.79 | 1.57 | 0.69 |
| | $NO_x$ | -0.32 | 0.76 | 0.71 | 1.20 | 0.80 |
| RUB | $NO_2$ | 0.20 | 0.40 | 1.26 | 1.31 | 0.85 |
| | NO | 0.37 | 0.96 | 1.59 | 2.66 | 0.50 |
| | $NO_x$ | 0.16 | 0.56 | 1.19 | 1.37 | 0.78 |
| | $O_3$ | 0.03 | 0.62 | 1.03 | 1.49 | 0.75 |

*Mean NOx and max NOx concentration map simulated by SIRANE for February 2022.*




## CURRENT WORK & FUTURE DIRECTIONS

1. **Sensitivity analysis**
   - quantifying the impact of different emission sources and input parameters.
2. **Input data refinement**

**HEATING EMISSIONS**: Introducing hourly, daily, and seasonal modulations, correlated with atmospheric temperature.

**TRAFFIC PROFILES**: Replacing generic temporal patterns with high-resolution profiles (10-min) derived from local monitoring in Turin.

**EXTENDED RUNS**: Moving beyond February 2022 to capture different meteorological conditions

**TRAFFIC NETWORK COMPLETION**: Extending measured flows to fill gaps in the traffic network.

3. **More pollutans**
   - PM10 and PM2,5

- Model evaluation: several years, several pollutants.
- Operational perspective: towards near real-time forecasts of urban air quality at street level.
- Integration with policy tools: development of a configuration that can be used by local authorities to test scenarios.

## REFERENCES

[1] Bo, M., Charvolin-Volta, P., Clerico, M., Nguyen, C. V., Pognant, F., Soulhac, L., & Salizzoni, P. (2020). Urban air quality and meteorology on opposite sides of the Alps: The Lyon and Torino case studies. Urban Climate, 34, 100698. https://doi.org/10.1016/j.uclim.2020.100698

[2] Chang, J. C., & Hanna, S. R. (2004). Air quality model performance evaluation. Meteorology and Atmospheric Physics, 87(1), 167–196. https://doi.org/10.1007/s00703-003-0070-7

[3] Soulhac, L., Nguyen, C. V., Volta, P., & Salizzoni, P. (2017). The model SIRANE for atmospheric urban pollutant dispersion. PART III: Validation against NO2 yearly concentration measurements in a large urban agglomeration. Atmospheric Environment, 167, 377–388. https://doi.org/10.1016/j.atmosenv.2017.08.034

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[5] Soulhac, L., Salizzoni, P., Mejean, P., Didier, D., & Rios, I. (2012). The model SIRANE for atmospheric urban pollutant dispersion; PART II, validation of the model on a real case study. Atmospheric Environment, 49, 320–337. https://doi.org/10.1016/j.atmosenv.2011.11.031

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