The AirHeritage Hierarchical Network:
Sensing, Calibration, Deployment strategies for fixed, mobile air quality monitoring and modeling in urban scapes.

Saverio De Vito, Grazia Fattoruso, Sergio Ferlito, Girolamo Di Francia, Paolo D' Auria, Roberta Gianfreda, Fabrizio Carteni

Presenter: Saverio De Vito, Ph.D.
Scientific Coordinator Project AirHeritage
ENEA C.R. Portici

saverio.devito@enea.it

Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

DIPARTIMENTO DI AGRARIA

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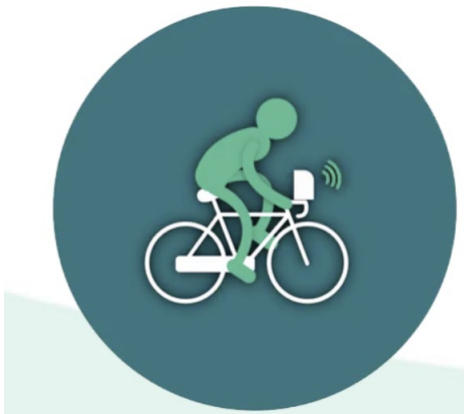
ARPAC Agenzia Regionale Protezione Ambientale CAMPANIA

ASIC Air Sensors International Conference
May 11-13, 2022

Outline:

-Project AirHeritage: Motivation and Methodology
-Calibration, Deployment, Modeling challenges and solutions
-Full scale model data pipeline
-Conclusions



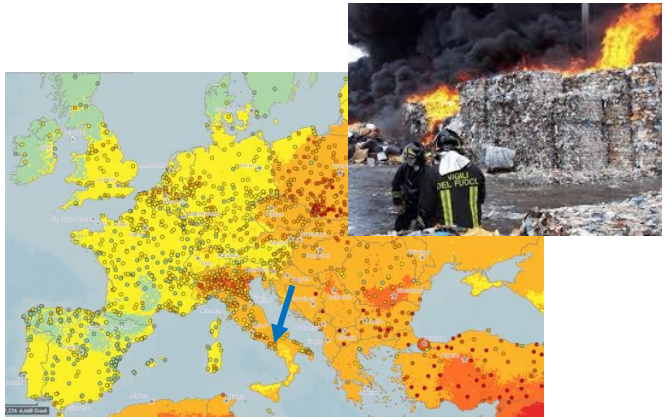
The starting point: Naples Metropolitan area AQ network

- Regulatory AQM network in Naples metropolitan area.
- 8 Stations are currently used for AQ monitoring in the Naples urban area (117Km2, 955k inhabitants).
- **Roughly, that accounts for one station for each 15Km2 and/or one station each 120k inhabitants!**
- It is worth to note that this is one of the most dense network in Europe and it is perfectly in line with the regulating EC directive.
- **As a results small towns have limited knowledge of what happens at their urban scale.**

A relatively dense regulatory grade monitoring network which leaves many densely inhabitated area with limited knowledge on local scale AQ

Social Perception and Health

- Italy has a concerning situation, with **some of the most polluted areas** in Eu.
- South of Italy experiments a **lack of authoritativeness** of main environmental and health protection agencies (citizen does not believe to official statements), prejudices on possibility to impact, fatalism.
- Lack of **scientific approach** to the problem, **lack of trust** in mitigation and regolation actions with consequent lack of participation.



- A quantitative example: Portici is a small city with high population density (**55k people on 4 Km^2 with 33k cars**) in which:
  - •Car traffic and House Heating are the main emission sources
  - •Extremely high propension to use personal car – 60% of students use family car to go to school when maximum distance from school is less than 500m
  - •No targeted information on air quality

EUROPEAN UNION
European Regional Development Fund

UIA URBAN INNOVATIVE ACTIONS

AirHeritage

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Successful Citizen Science for AQ, AirHeritage project goals

What ? Come up with a reasonable but motivating goal with sustainable impact.
How? Clarify and merge your scientific and impact goals, keep the involvement of citizens at a reasonable load.

Reconciliate the primary actors and proceed towards a shared solution …

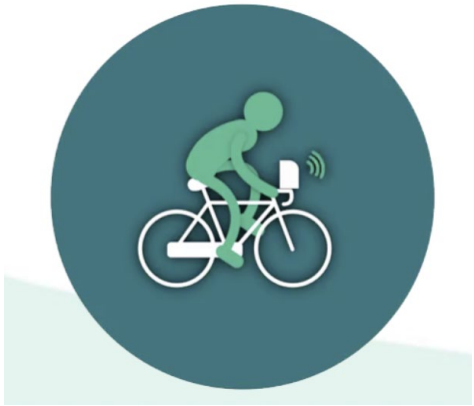
…with a community based, participative approach to…

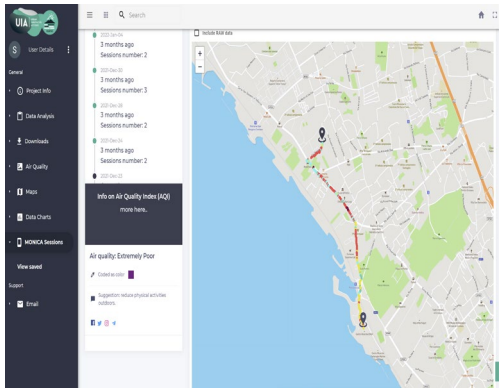
monitoring and….

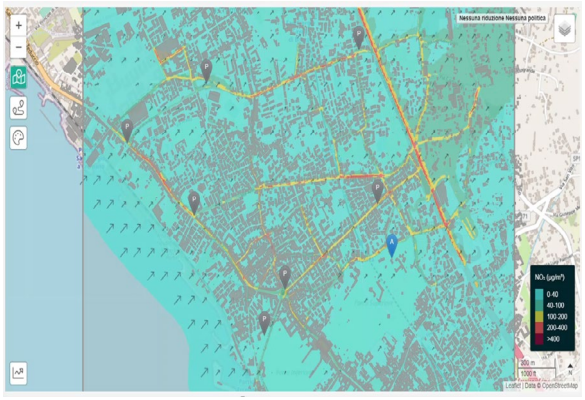
…..car traffic regulation

using technological enablers.

Successful Citizen Science for AQ: AirHeritage project Pillars







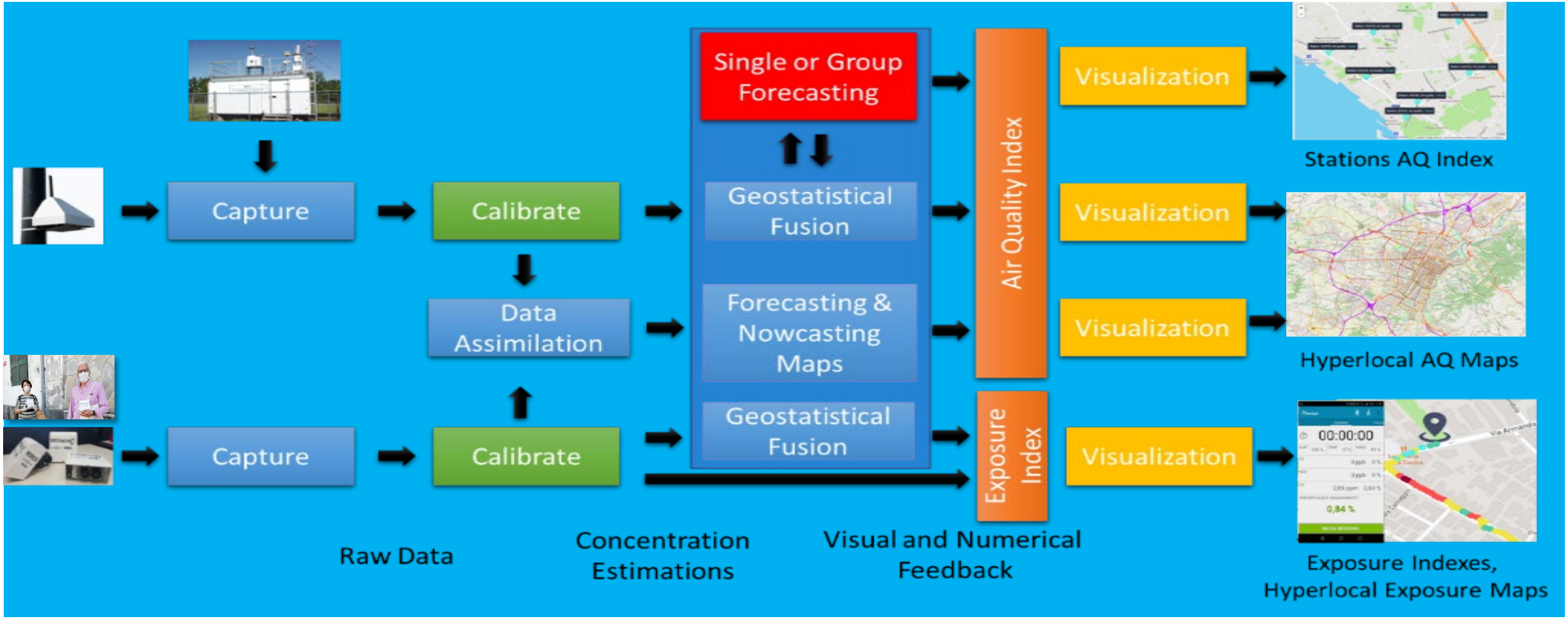
Community based approach:

Monitoring & Sustainable hyperlocal mobility experience:
Volunteers from associations will implement “pedibus” mobility for schools students. Moving back and forth from schools, pedibus users will monitor air quality and produce high spatial and temporal density opportunistic AQ data.

Enhanced Awareness:
Opportunistic Data, Regulatory and fixed monitoring stations Data have been communicated along with data assimilation based air quality mapping model predictions . Hi-res nowcasting and forecasting maps have been returned to citizens.

Traffic Car regulation:
Maps and traffic simulations are at the basis of a DSS that will help MUA to develop participated traffic regulation strategies to improve AQ.

Project Air Heritage: Data pipeline



Project Air Heritage: a Hierarchical Network as a technological basis

Pervasivity

- 1 Regulatory grade ARPAC Station
- 1 Mobile Regulatory grade Multigas Analyzer
- 7 Fixed LCAQM Stations
- 30 Mobile & Personal Gas & PM Multisensors devices

Accuracy

MultiSensors Architectures and Limits

2 Different platforms (Fixed, Mobile) monitoring

Both share sensing technologies:

- EC Sensors based CO, NO2, O3 Estimation
- OPC based PM1, PM2.5, PM10 Estimation

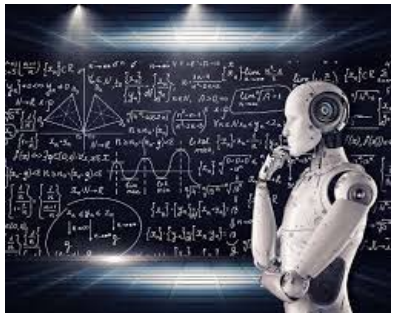
Affected by well known issues:

Environmental interferents (T -> EC Sensors, RH-> PM Sensors)

Non Target gas interferents (O3->NO2 sensors and viceversa)

Significant EC sensors fabrication variance (Sensitivity, ZeroResponse)

Calibration Strategy (1)



FIELD CALIBRATION (I.E. BY COLOCATION: MIN 3 WEEKS EACH NODE)

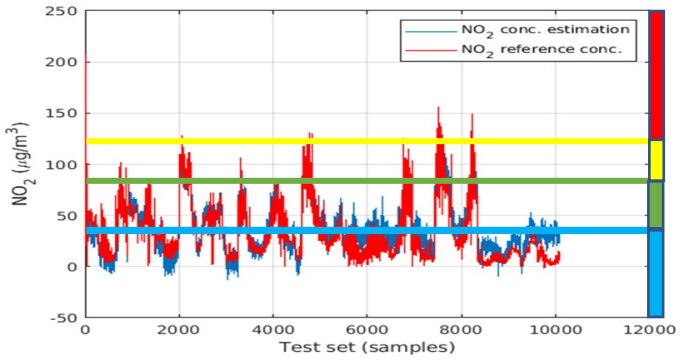
ADDRESSING ROBUSTNESS WITH PERIODICAL (6MONTHS) RE-CALIBRATION

DATA DRIVEN ALGORITHMS (MLR, NN)

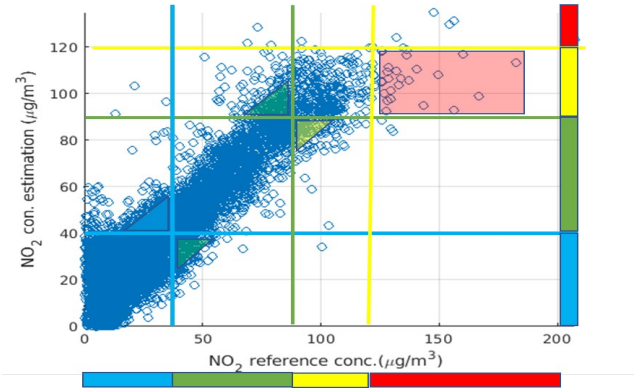
CALIBRATION COEFFICIENTS DOWNLOADED BY MONICA COMPANION APP FOR MOBILE AND OPPORTUNISTIC CITIZEN SCIENCE MONITORING

CALIBRATION COEFFICIENTS IMPLEMENTED IN-CLOUD FOR FIXED STATIONS

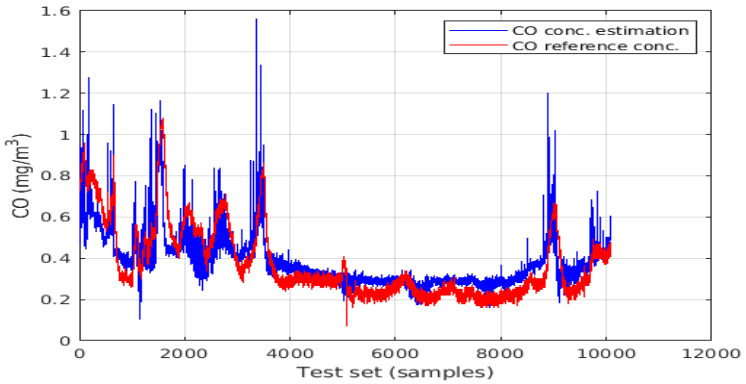
Comparing LCAQMS with Regulatory grade stations



NO2, O3 SENSORS REACT TO THE PROCESS BY FOLLOWING TRUE CONCENTRATIONS NICELY (ON SEPARATE TEST DATA SETS)

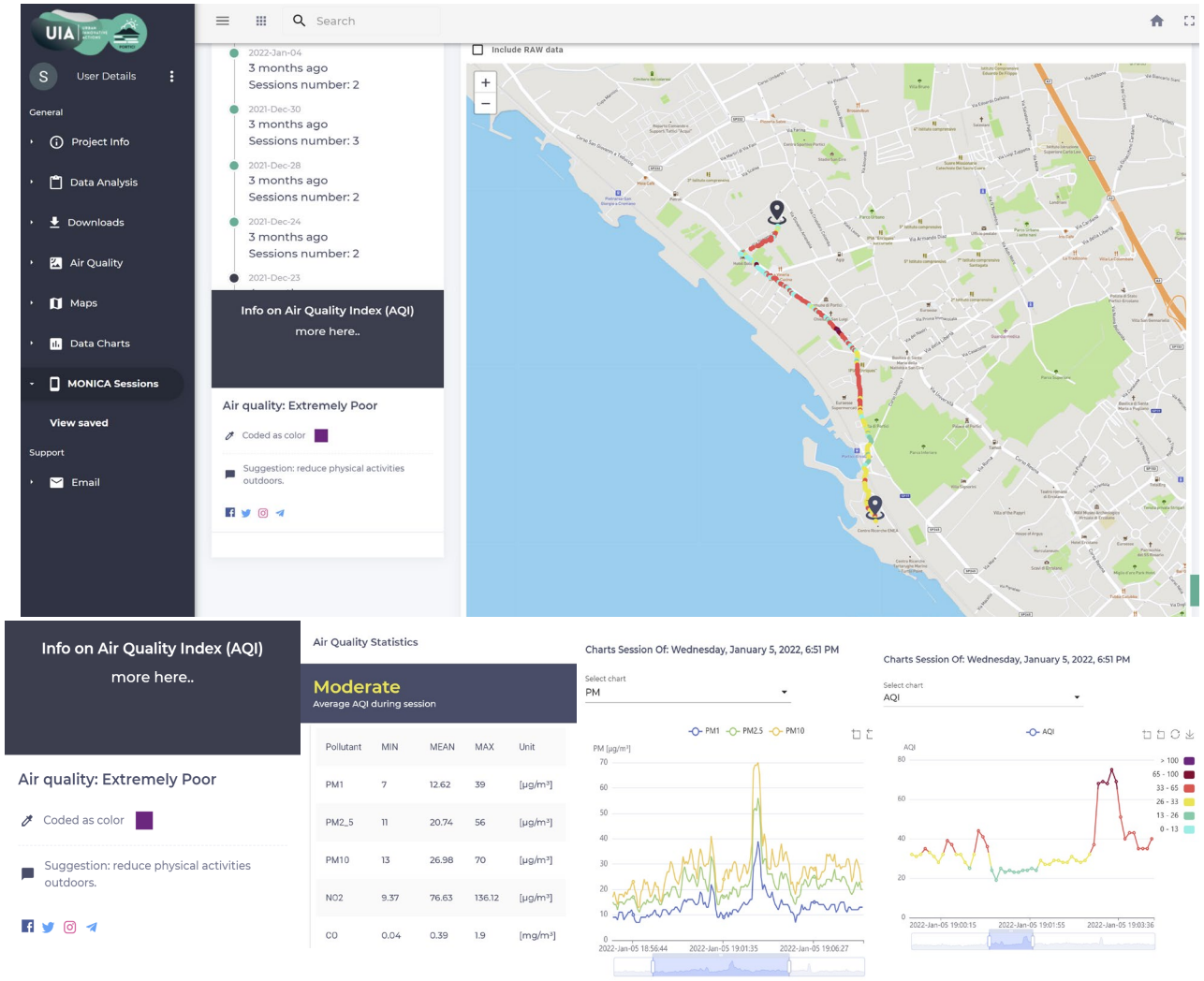


USING SENSORS CONCENTRATION ESTIMATIONS TO EVALUATE EAQI FOR FEEDBACK COMMUNICATION LEADS TO VERY LIMITED ERRORS. THE VAST MAJORITY OF CASE, THE FUNCTION MISCLASSIFY IN THE ADJACENT EAQI CLASS.



CO SENSOR IS FORCED TO WORK CLOSE TO ITS LOD SO SIGNIFICANT RELATIVE ERROR IS EXPECTED AT VERY LOW CONCENTRATIONS

Personal Results @ Airheritage.portici.enea.it

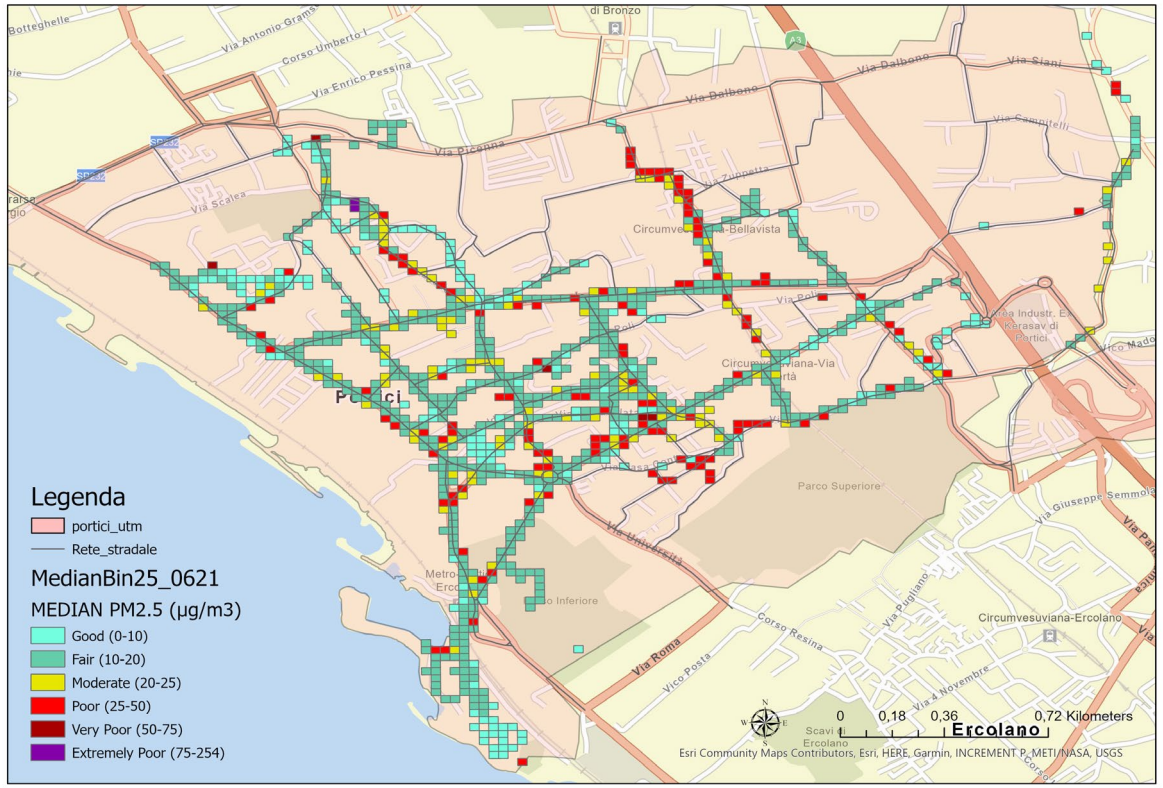


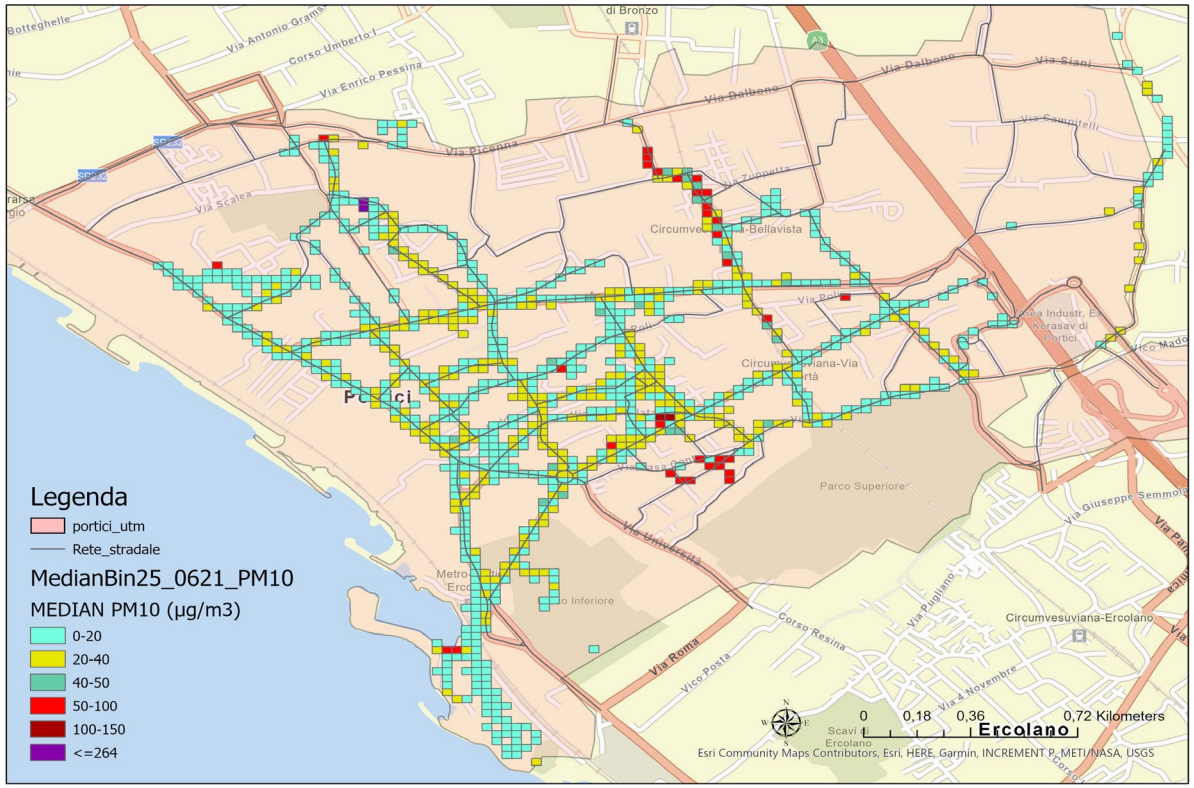
- Personal in city mobility session
- Active Life Feedback (Personal Exposure) based on EAQI estimations
- Simplified Statistics
- Graphical Trends
- Freely downloadable raw and calibrated data

Findable Accessible Interoperable Reusable

{JSON}

Mobile Stations Results



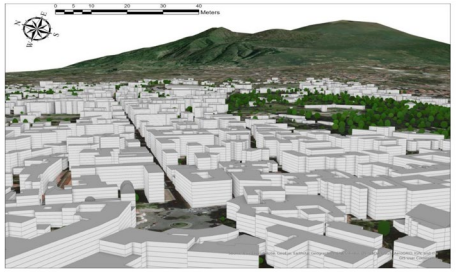


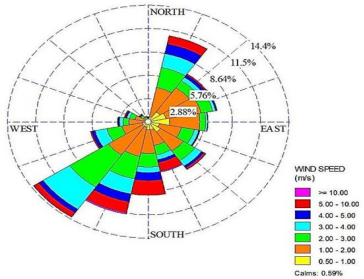
- 25X25MT SPATIAL BINNING MAPS USING SINGLE SEASON OPPORTUNISTIC DATA RECORDED BY CITIZENS WITH MOBILE DEVICES.
- MIN 20 DATA POINTS PER BIN, AVERAGED TO COMPUTE EAQI CORRESPONDING TO SINGLE POLLUTANT
- HOTSPOTS CONSITENTLY DETECTED IN HEAVY TRAFFIC AND CITY CANYONS

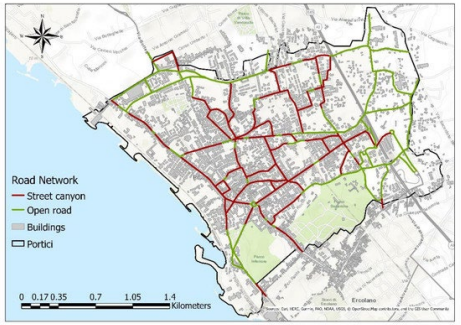
De Vito S. et al., Sensors **2021**, *21*, 5219.

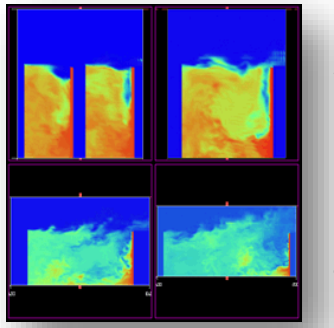
Francia, G. Site Suitability Analysis for Low Cost Sensor Networks for Urban Spatially Dense Air Pollution Monitoring. *Atmosphere* **2020**, *11*, 1215. https://doi.org/10.3390/atmos11111215

Fixed Stations Optimal Deployment (1)

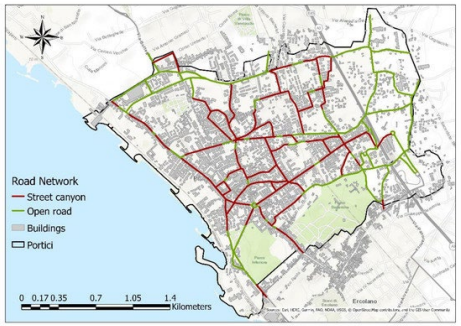


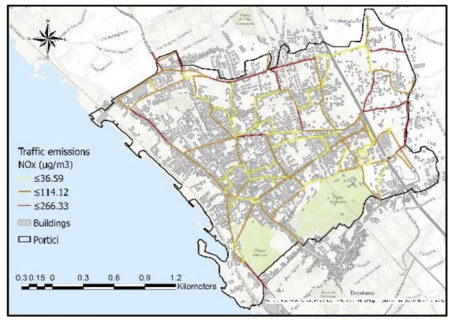


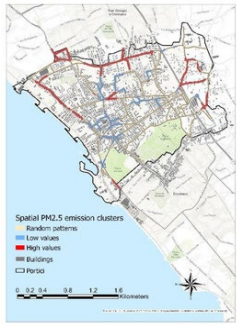




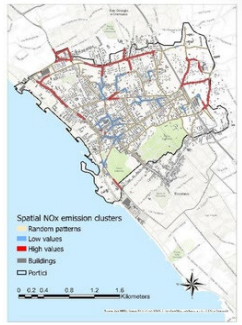
CITY 3D MODEL AND WIND DATA HAVE BEEN EXPLOITED TO DETERMINE POSSIBLE **CANYON EFFECTS AFFECTED ROADS SEGMENTS**





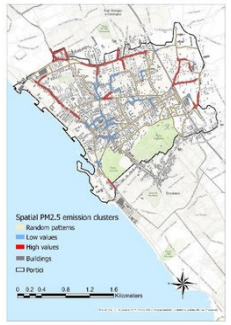


(A)

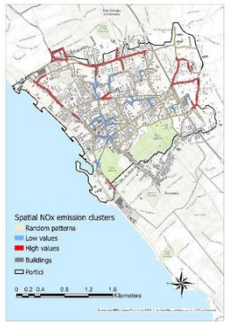


(B)

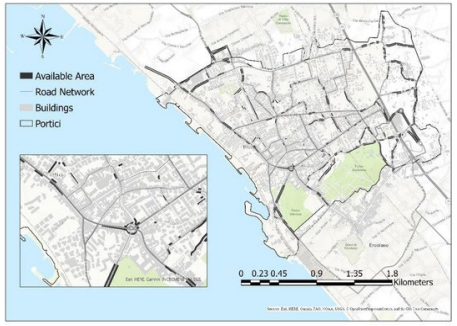
URBAN PLANNING DATA (INBOUND, OUTBOUND MOBILITY, CAR SET AGEING, POPULATION DENSITY,ETC.) HAVE BEEN EXPLOITED TO PREDICT **TRAFFIC AND HOUSE HEATING EMISSIONS** IN THE DIFFERENT URBAN AREAS AND COUPLED WITH URBAN CANYONS DATA

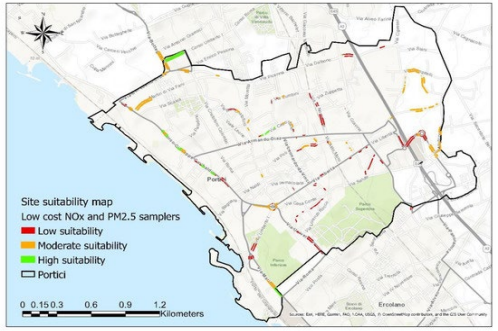


(A)



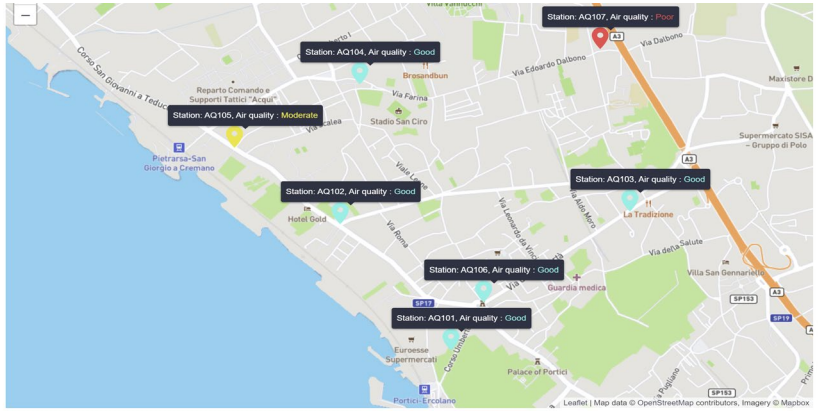
(B)



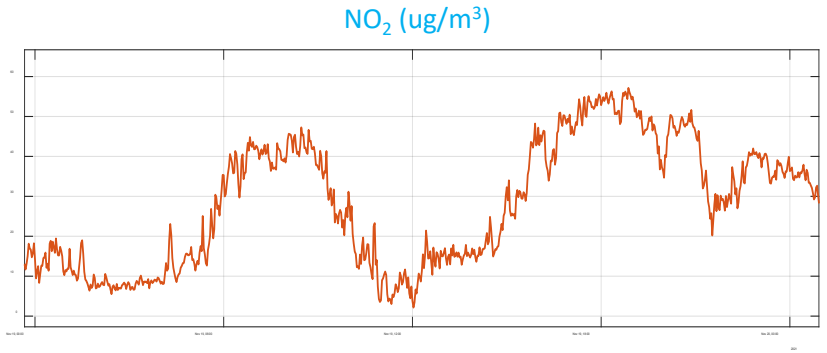


PREDICTED ROAD LEVEL CONCENTRATION MAPS HAVE BEEN JOINED WITH AN AVAILABILITY MAP OBTAINING THE **SUITABILITY MAP** LEADING THE **OPTIMAL DEPLOYMENT** PROCESS (COST VS VARIANCE COVERAGE)

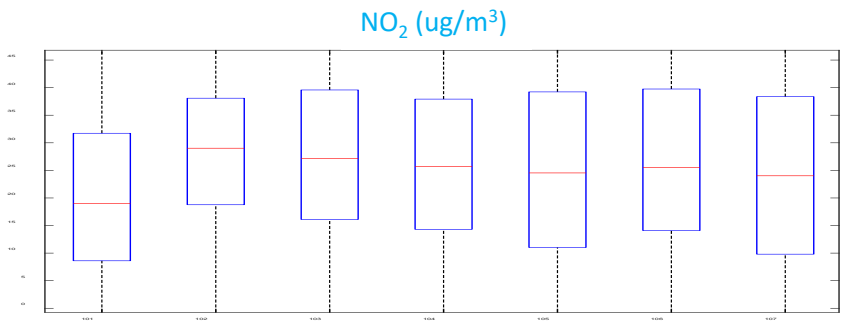
Fixed stations results



7 STATIONS CONTINUOUS MONITORING SERVICE COVERING HOT AND COLD SPOTS



MULTI TIME-SCALE VARIANCE PATTERNS IN SINGLE STATIONS DISCOVERY

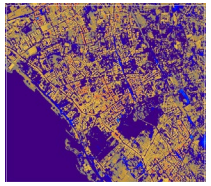


ANNUAL AVERAGE SPATIAL PATTERNS HIGHLIGHTING EXPOSURE ENVIRONMENTAL DISPARITIES

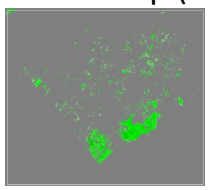
Air Heritage Air Quality Model

INPUTS

- Digital Surface Model (static)



- Vegetation map (static)

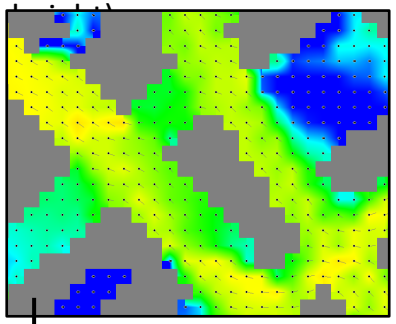


- WARF: mesoscale weather (dynamic)
- Road network (static)

- Traffic flows (dynamic)
- CAMS: background pollution (dynamic)

WIND MODULE

downscaling wind flows at street level (2m



TRAFFIC MODULE

calculate emissions

AIR QUALITY MODEL

Partial Differential Equations calculate pollutants concentration in time

- spatial processes (diffusion & advection)
- local processes (wet deposition, dry deposition, sedimentation, chemical transformations)

Initial state and boundary conditions

Monitoring Stations in UIAQ DSS

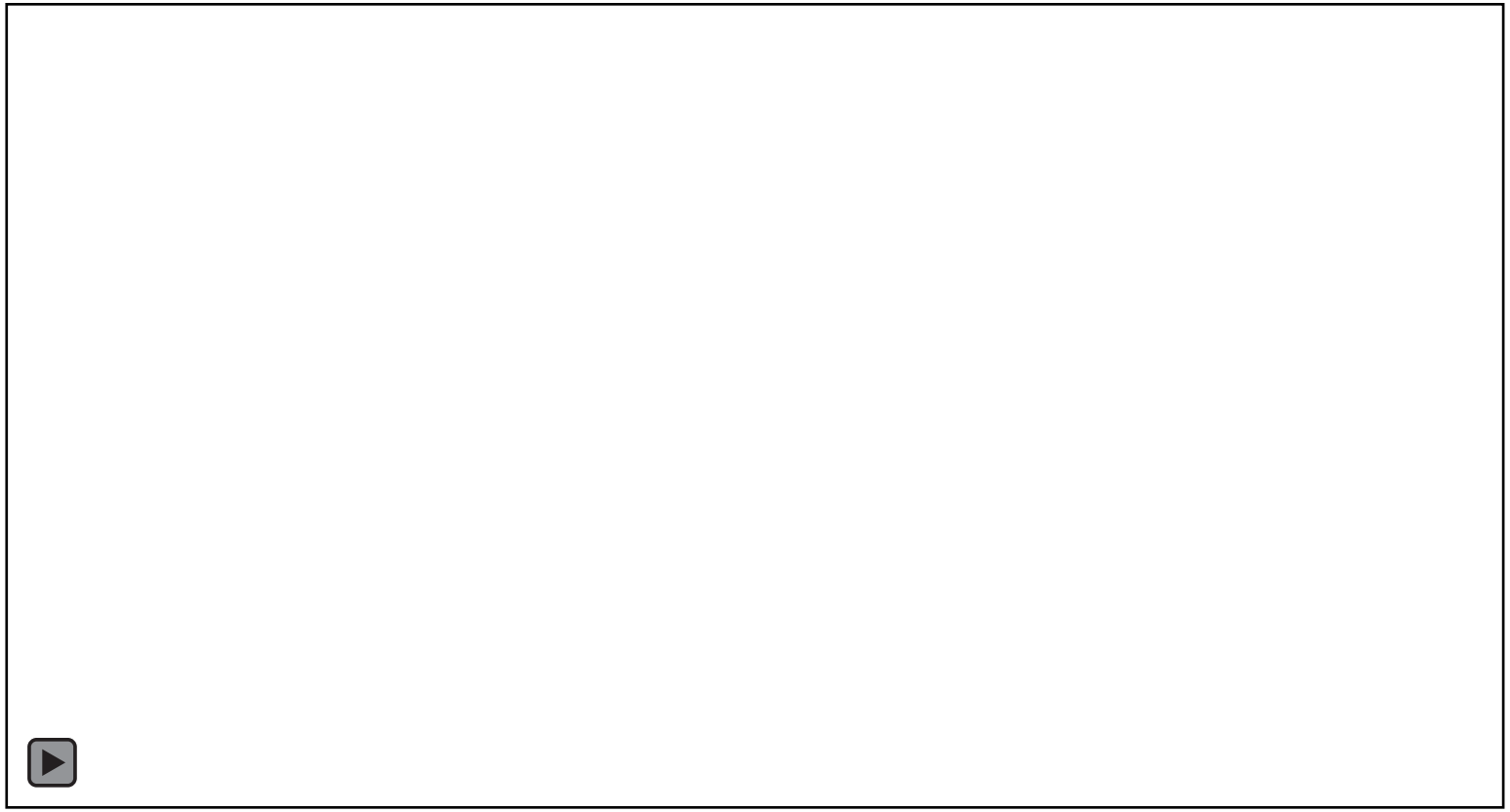
How we integrate data from fixed Monitoring Stations?

UIAQ DSS allows the **real time visualization** of air quality data from fixed Monitoring Stations: the Dashboard shows AQI and the values of pollutant

Thanks to the air quality data from fixed Monitoring Stations a **real time validation** of the UNINA air quality model is available: the chart shows misured air quality data compared to the model's ones.

Air quality data from fixed Monitoring Stations have been used to carry out the **historical validation** of the UNINA air quality model

Air Quality model output and Monitoring Station in UIAQ DSS



Conclusions

- Fixed and Mobile AQMS have been employed in regular and opportunistic campaigns for ultra high resolution AQ assessment
- Several Data sources have been integrated to develop optimal deployment strategies for fixed stations
- Car traffic data, Weather forecasting data, CAMS background data, contributes to AQ model forecasts validated using fixed station data
- An integrated systems allow for personal, city scale real time feedback and AQ forecasts
- Future work will include scalable calibration methods and long term AQ model validation

Thank You for Your Attention!

ALERT: AirHeritage AQ Datalake is available on request!

Dr. Roberta Gianfreda
DSS Integration

Dr. Paolo D' Auria
Regulatory Monitoring

Eng. Sergio Ferlito
AI & IoT Ecosystems Design

Dr. Grazia Fattoruso
Geomatics and AQ Modeling

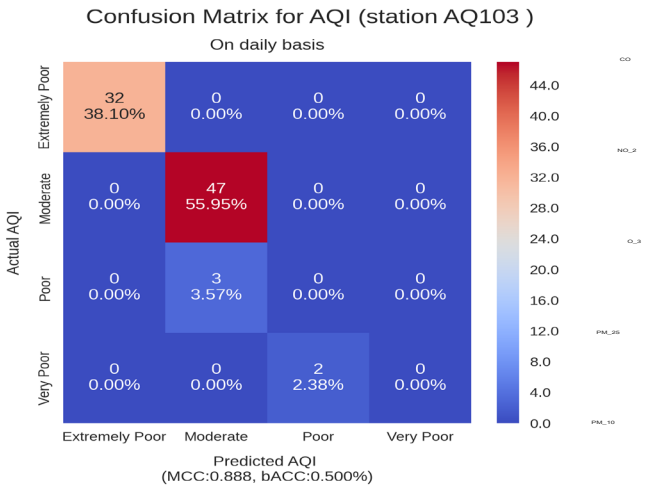
Dr. Fabrizio Carteni
AQ Model Design and Development

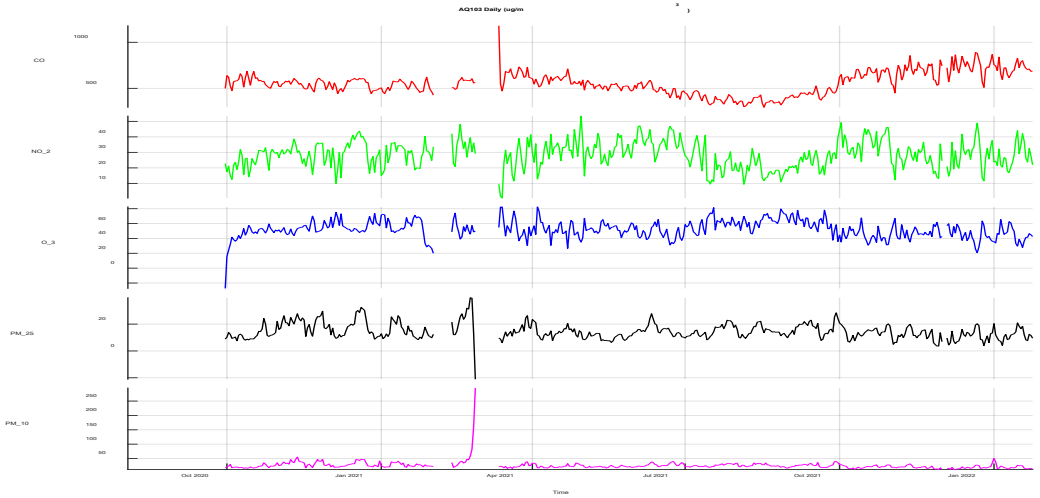
Dr. Saverio De Vito
Project Scientific Coordinator

Dr. Girolamo Di Francia
Lab. Head

saverio.devito@enea.it

- Accuratezza
  - Le centraline hanno dimostrato di essere in grado di identificare la classe corretta di AQI in poco meno del 90% dei casi (su base giornaliera)
  - Presentano una tendenza alla sottostima nei giorni in cui la qualità dell’ aria è molto scadente o estremamente scadente (raramente)





Yearly results by using complete calibration set

Results are in line with consolidated literature in the mid term (3 months) or when using both summer and winter time recorded training data

	R^2 (median)	R^2 (mean)	R (mean)	MAE	Err (%)
PM2.5_AVG	**0.40**	**0.39**	**0.67**	**5.88**	**0.13**
PM2.5_STD	0.12	0.10	0.05	1.04	0.05
PM10_AVG	**0.21**	**0.20**	**0.60**	**9.78**	**0.18**
PM10_STD	0.10	0.10	0.05	2.10	0.07

Yearly results by using complete calibration set

Results are in line with consolidated literature in the mid term (3 months) or when using both summer and winter time recorded training data

	R^2 (median)	R^2 (mean)	R (mean)	MAE	Err (%)
NO2_AVG	**0.60**	**0.40**	**0.81**	**10.73**	**0.13**
NO2_STD	0.12	0.37	0.04	2.89	0.05
O3_AVG	**0.85**	**0.74**	**0.94**	**9.93**	**0.18**
O3_STD	0.05	0.22	0.02	2.86	0.07
CO_AVG	**0.16**	**-0.19**	**0.44**	**0.18**	**0.03**
CO_STD	0.21	0.52	0.50	0.07	0.03

	CO	NO2	O3	PM10	PM25
MEAN	0.50	23.40	59.59	25.60	16.18
SIGMA	0.34	24.53	29.74	17.22	12.91

I risultati ottenuti….
in relazione alle normative esistenti….
valutati nel contesto di Portici….
e in maniera conservativa… (su tutto l' intervallo di concentrazione misurato)

configurano i MONICA come sistma che si **avvicina** alle prerogative delle ***misure indicative***.

Se ne consiglia l' uso:

a) **Per valutazione esposizione personale in termini di EAQI (PERC_ERR ben al di sotto del 20%)**
b) **Mappe di esposizione cooperative per la valutazione del fenomeno su scala geografica**

c) **Utilizzo come misura indicativa se in contesti fissi con medie orarie**

- MAPE= CO<5%; NO2<5%; O3<5%;
- MAE/MEAN-> CO=35%; NO2=45%; O3=20%
- CRMSE-> CO=50%; NO2=45%; O3=30%

- MAPE= PM10<5%; PM25<10%;
- MAE/MEAN-> PM10=50%; PM25=50%
- CRMSE-> PM10=65%; PM25=100%