URBAN ENVIRONMENT ANALYSIS AND PM10 PREDICTION MODELS IN MILAN

OBJECTIVE

Our objective is to predict **PM10** concentration levels within the municipality of Milan, using data **exclusively** from **2023**.

After providing an overview of the impact of air pollution, we will leverage meteorological and air quality data from both official and non-official sources, along with spatial data, including greenery and buildings, to improve the performance of our models, evaluated using **R2** and **Mean Squared Error** (MAE).

Finally, we will suggest policies to improve the city's air quality and the well-being of its citizens

"Make cities and human settlements inclusive, safe, resilient and sustainable

United Nations

OBJECTIVE

Tasks

Predict the PM10 concentration in a grid of points spaced 500 meters apart within the city.

Assess whether green areas lower air pollution, by evaluating the impact of Scalo Serafini on PM10 level

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1 Problem description

1.1 Urbanisation and smart cities

1.2 Urban air pollution and PM

1.3 Unique case of Milan

1.1 Urbanisation and smart cities

Urbanisation leads to challenges such as:

- air pollution
- governance complexities,
- socio-economic inequalities

The concept of "**Smart city**" tries to respond to these needs, by leveraging various information technologies (IoT, AI and big data) to facilitate planning, construction, management, and deliver essential services more quickly and efficiently.

A **sustainable city** is a city that manages to maximize energetic efficiency, reduce waste and pollution, support renewable energy, promote sustainable mobility, and preserve urban ecosystems, focusing on the persistence of a desirable outcome for urban environments over time

1.1

Urbanisation and smart cities

Need for Smart Solutions

Adopting a **people-centric approach** in urban development emphasizes the importance of smart solutions that address the needs of citizens and communities:

Empowering citizens to actively participate in decision-making processes

Recognizing the importance of social, economic, institutional, and non-institutional forces is crucial for effective urban governance

Promoting open data initiatives and ensuring transparent access to information. Increasing the use of seasors and leverage data driven approaches to mitigate urban issues

1.2

Urban air pollution and PM

Societal impacts

Air pollution stands out as one of the most pressing issues at global level

Death Attributed to ambient air pollution each year by WHO

4.2 million

Annual economic cost of premature deaths across WHO Eu Regions

US$ 1.431 trillion

1.2

Urban air pollution and PM

Threat of particlaute matter

Particulate matter (PM) is a complex mixture of solids and aerosols composed of small droplets of liquid, dry solid fragments, and solid cores with liquid coatings.

Particle are defined by their diameter →

PM10

Particles ≤ 10μm in diameter

PM2.5

Particles ≤ 2.5 μm in diameter

People who are **physiologically more vulnerable**: children, elderly, those with chronic illnesses, pregnant women, and unborn children

Short-term exposure

Worsening of respiratory diseases

Increased hospital admissions for heart or lung causes

Asthma attacks, acute and chronic bronchitis

Long-term exposure

Respiratory mortality

Premature death

Climate change influences air pollution by altering heat waves, air stagnation events, precipitation, and other meteorological conditions favourable to **pollutant accumulation**

Primary sources are anthropogenic activities

traffic
industry
domenstic fuel burning

natural source such as soil dust
secondary particles

1.2

Urban air pollution and PM

Air quality standards: WHO and EU

In response to the growing number of local monitoring sites and mounting evidence of the harmful effects, the WHO updated its health-based guidelines for outdoor air quality in 2021, while revised Eu standard will be effective by 2030

	Averaging time	**Current EU standards**	**Revisied EU standars (from 2030)**	**WHO standards (from 2021)**
PM10, µg/m3	Year	40	20	15
PM10, µg/m3	24-hour	50 max. exceedance of 35 times per year	45 max. exceedance of 18 times per year	45 max. exceedance of 4 times per year
PM2.5, µg/m3	Year	25	10	5
PM2.5, µg/m3	24-hour	-	25	15

1.3

Unique case of Milan

General Overview

Milan issues

Ranked **3rd** most polluted city globally by IQAir
Ranked **334th** based on PM2.5 levels by European Environment Agency

11.5% of citizens are satisfied with the air quality [1]

Macro-sector description	PM10	PM2.5
Combustion in energy and trasformation industries	0.97%	1.21%
Non-industrial combustion plants	21.96%	26.80%
Combustion in manufacturing industry	6.76%	6.49%
Production processes	4.11%	3.63%
Solvent and other product use	6.45%	6.93%
Road Transport	44.50%	38.03%
Other mobile sources and machinery	1.59%	1.98%
Waste treatment and disposal	0.09%	0.11%
Agriculture	0.71%	0.33%
Other sources and sinks	12.86%	14.47%

Main Factors

Geographical Location

Situated in the center of the Padan plain, in the lombardia region;
Surrounded by large mountain ranges on three sides.

Climate characteristics

Continental:cold winters and hot summers,
Infrequent rainfall and high relative humidity.

Human Activities

The latest update of regional inventory of atmospheric emissions, managed by ARPA Lombardia (2021), shows that **road transport** is the most relevant source of particulate matter emissions in the **metropolitan area of Milan.**

(1) Mosaic, 2023 :Risultati del questionario su informazione e percezione della qualità dell'aria a Milano

1.3

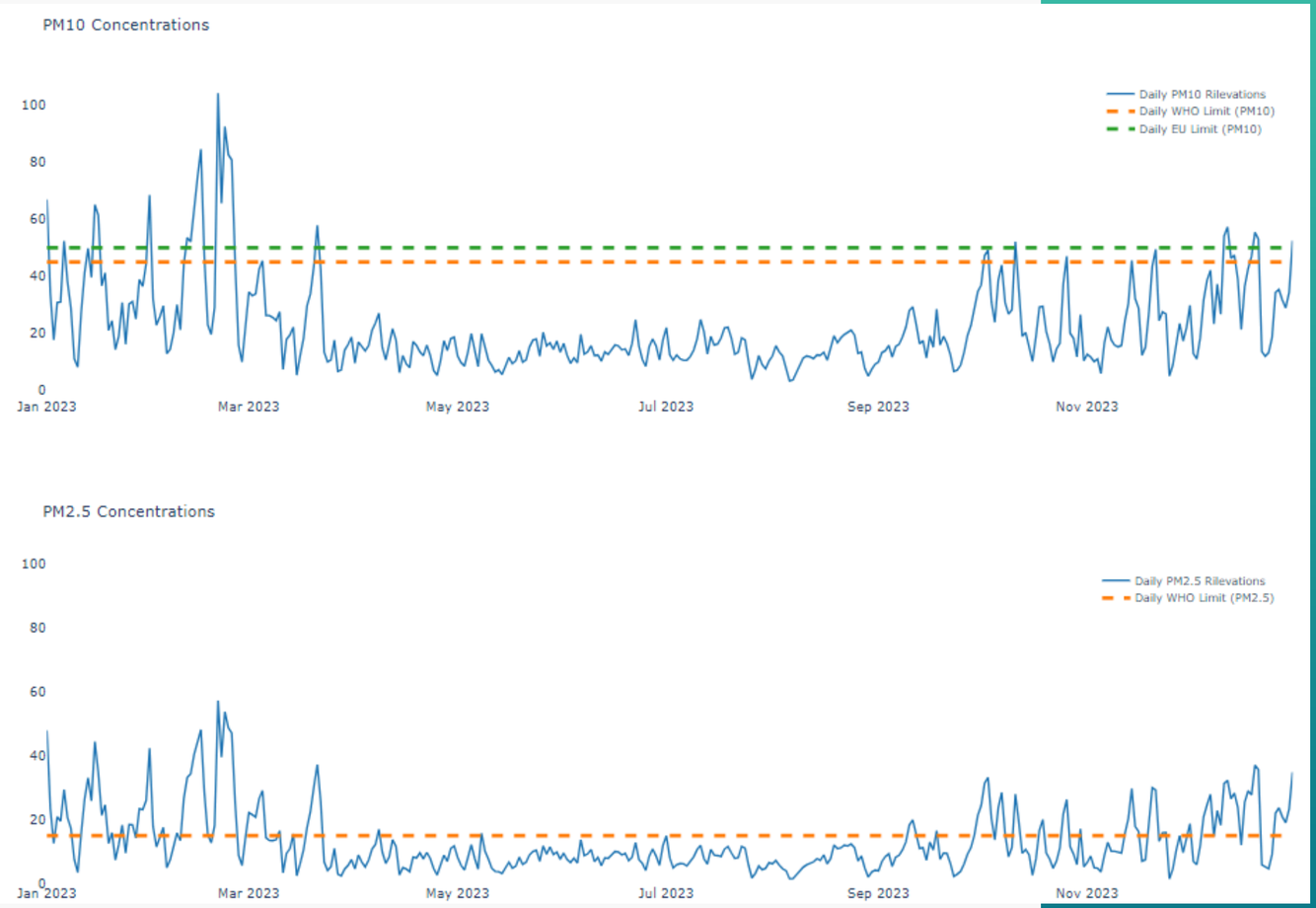
Unique case of Milan

Daily PM concentrations

During 2023, istitutional air quality stations on average exceeded the daily EU limit of concentration of PM10 **22 times**, with the station on Via Senato recording 49 days of violation.

The situation is even worse for PM2.5, where the daily concentration exceeded WHO guidelines for more than **107 days**.

A clear seasonal pattern can be observed for both, with the winter months showing higher values



1.3

Unique case of Milan

PMs impact on communities

City - Urban Audit Cities (LAU)	Tot Premature deaths	Premature deaths per 100,000 inhabitants	Years Of Life Lost
Brescia	356	154	3160
Milano (greater city)	4517	124	40100
Bolzano	90	84	798
Como	96	100	853
Gallarate	90	114	796
Bergamo	199	119	1764
Monza	214	125	1908
Milano	1882	127	16710
Varese	102	99	905
Busto Arsizio	115	115	1024
Saronno	56	118	494

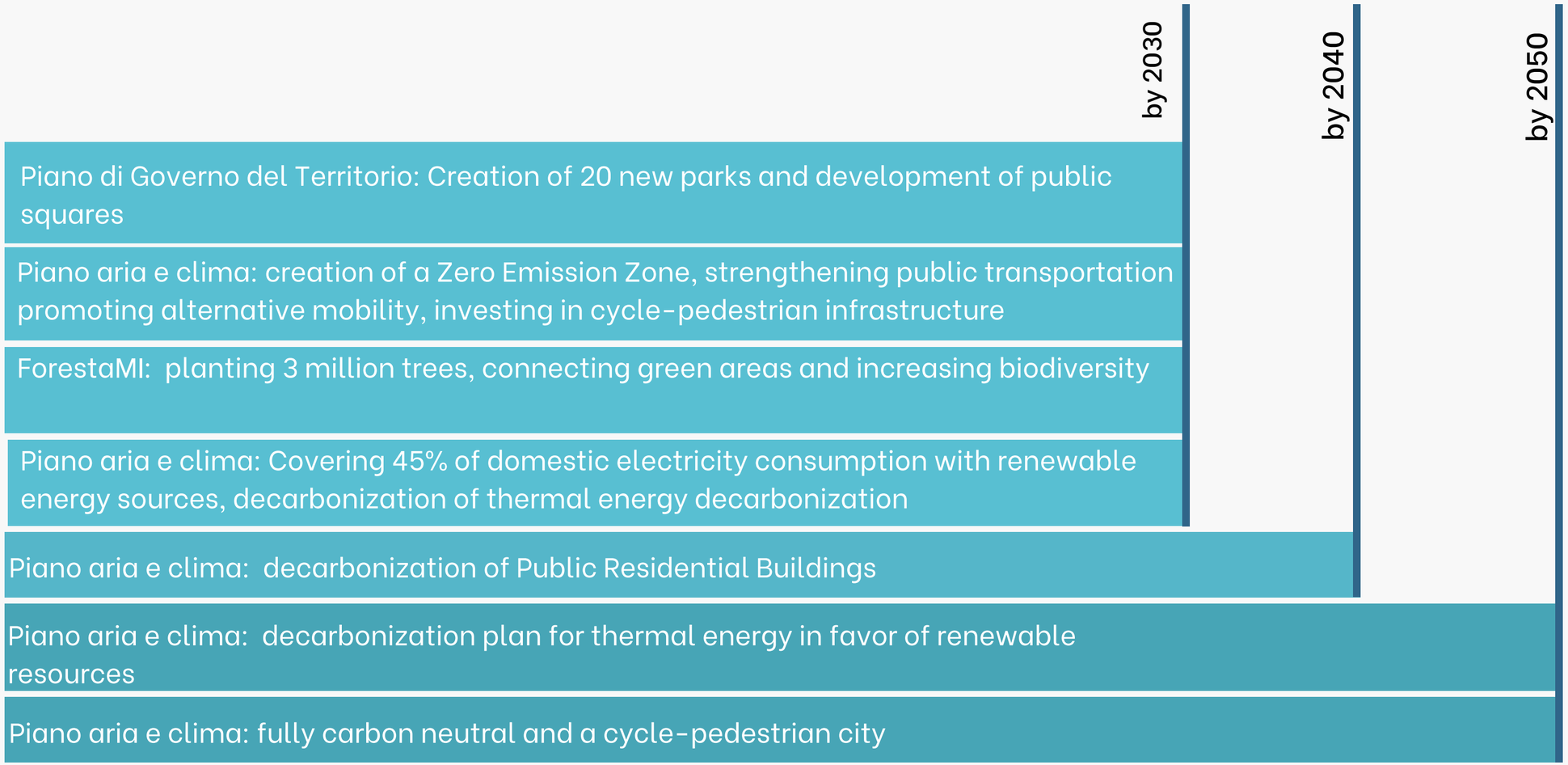
It shows **Brescia** as the city with the highest premature death roll per 100,000 inhabitants in 2021, based on data retrieved from the European Environment Agency.

In terms of absolute numbers, the **Metropolitan area of Milan** records the highest total of premature deaths and YLL

1.3

Unique case of Milan

Main mitigation policies



1.3

Unique case of Milan

Nature based solutions

Nature-based solutions (NBS) have emerged in recent years, as a new approach to strengthen urban resilience and improve urban air quality.

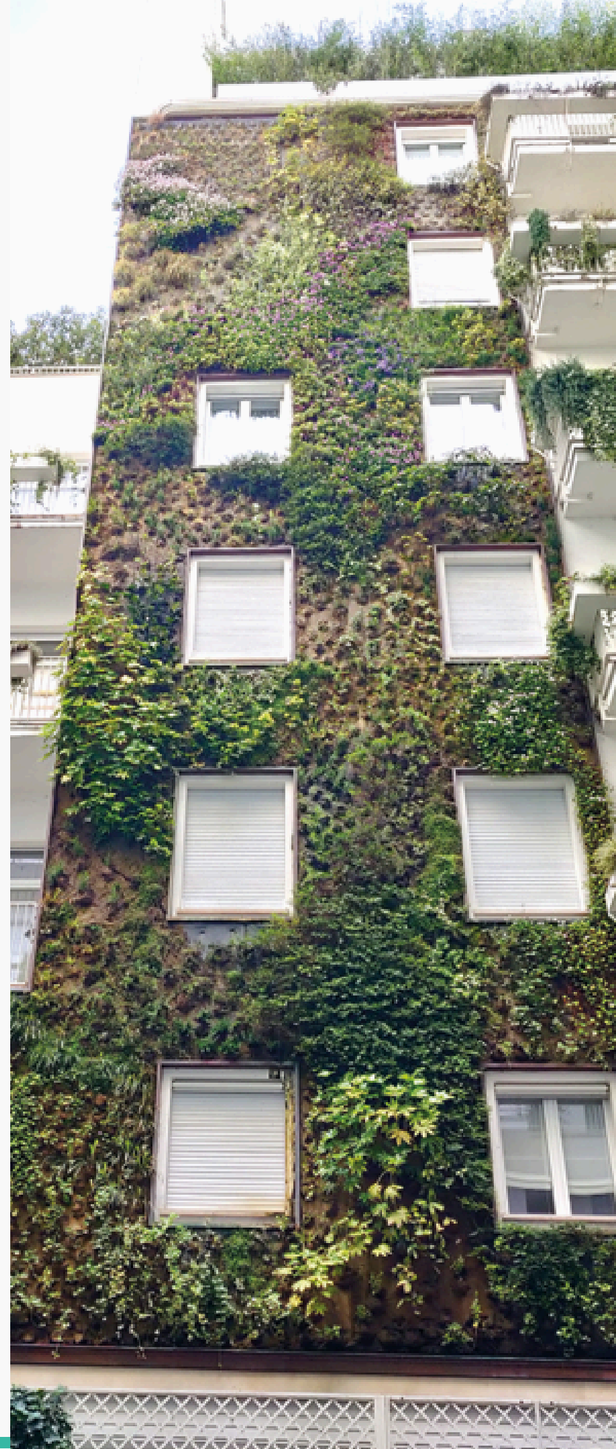
> *A strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services*
>
> European Commission

Trees

Planting trees is one of the most straightforward and cost-effective nature-based solution

Vertical Greenery

Outer surfaces of buildings and roofs offer the largest untapped area to additional green space in cities



1.3

Unique case of Milan

Green areas

Ecosystem Services

Aesthetics functions:increase the aesthetic quality of the urban environment

Social functions: reduce mental healt issues, foster interpersonal relationships and physical activity rates, enhance cultural and educational experiences

Ecological functions: reduce noise and air pollutions, lower the temperature and mitigate the urban heat island effect, increase soil health and pollination, help restoring of anthropized landscapes

Ecosystem disservices

Shelter to harmful animals

Allergies and unpleasant odors

Biodiversity loss due to the development of monoculture

Economic costs related to maintenance and management

Difficulty in controlling the spread of invasive plants and diseases

Reduce freshwater due to irrigation

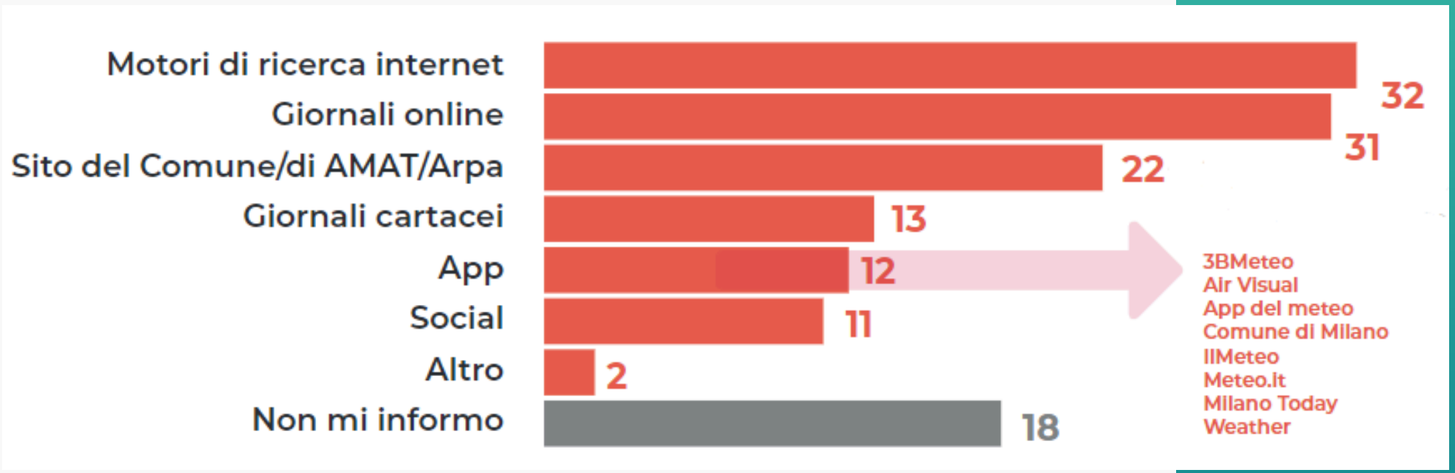
1.3

Unique case of Milan

Current perception of air quality information accessibility

A recent survey(1) revealed that, although most Milan residents are aware of air quality, **46%** rarely receive information.

When navigating the Amat and Arpa websites (visited 21th August 2024), we discovered that the daily air quality reports had not been updated since 30th April 2024 and 21st March 2024.



Source of image: Mosaic (1)

Both websites lack comprehensive information on air pollution exposure, symptoms to watch for, and recommended actions. This is significant, as 81% of those surveyed believe that air quality information is crucial for residents and visitors

(1) Mosaic, 2023 :Risultati del questionario su informazione e percezione della qualità dell'aria a Milano

2 Data analytics

2.1 Data exploration and preparation

2.2 Spatial encoding: rings generation

2.3 Machine learning models

2.4 SA-LSTM

2.1 Data exploration and preparation

Sources

1 – Istitutional sources

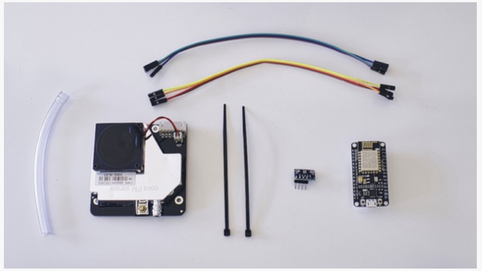
Comune di Milano

RegioneLombardia

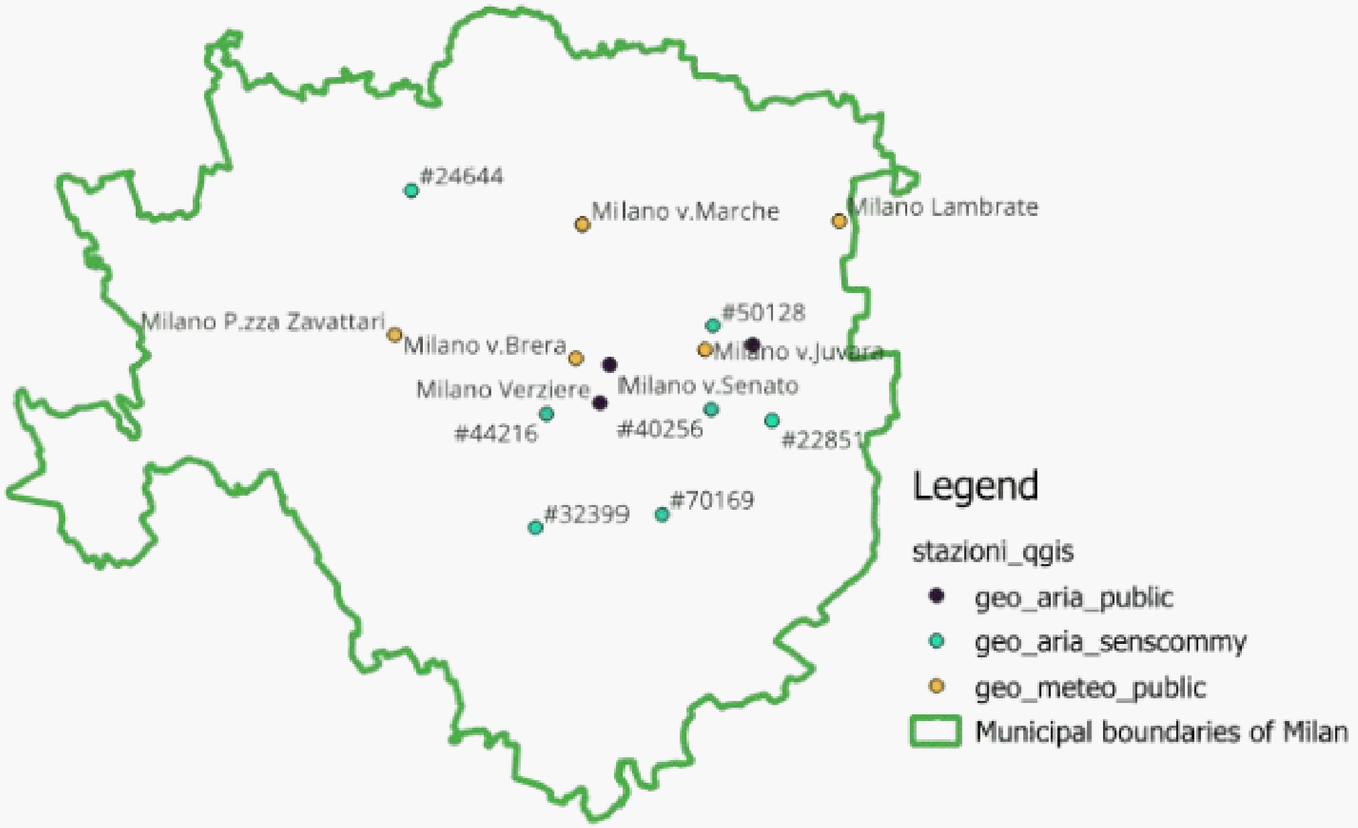
ARPA LOMBARDIA
Agenzia Regionale per la Protezione dell'Ambiente

2 – Unoffical Sources

SENSOR.COMMUNITY



Metereological and Air quality stations considered

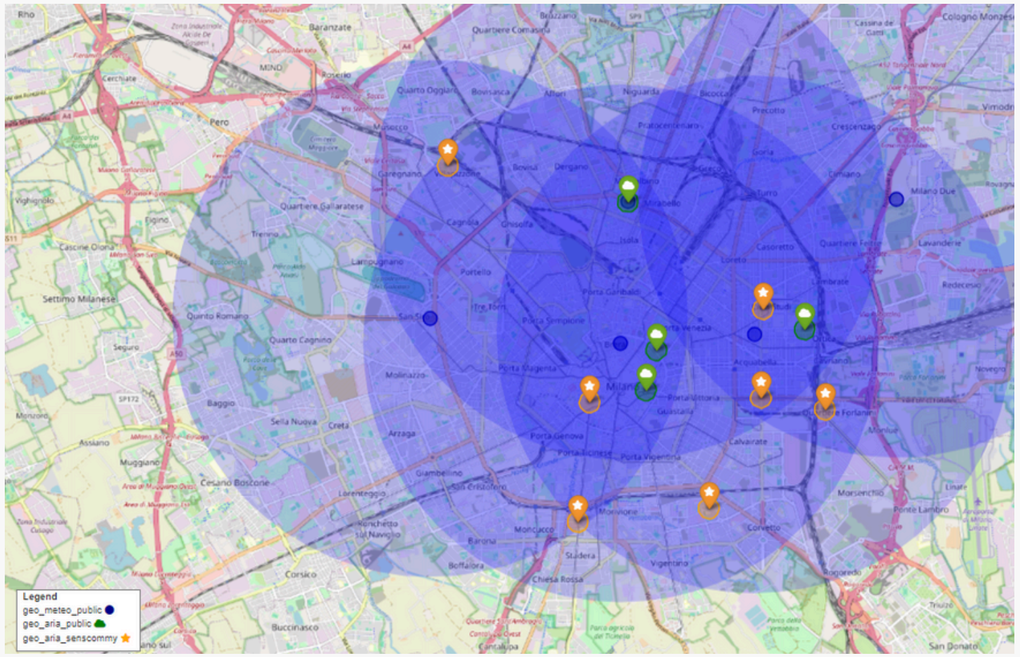


2.1

Data exploration and preparation

Metereological and air quality data integration

We generated **buffers with a 5-kilometre radius** around each meteorological station and assigned the nearest air quality station's data accordingly



Meteorological data ---> Istitutional air quality stations:

* Milano v.Brera ----> Milano v.Marche
* Milano v.Brera ----> Milano v.Senato
* Milano v.Brera ----> Milano Verziere
* Milano v.Juvara ----> Milano Pascal Citta Studi

Meteorological data ---> Sensorcommunity air qstations:

* Milano v.Brera ----> #32399
* Milano v.Brera ----> #44216
* Milano v.Juvara ----> #40256
* Milano v.Juvara ----> #70169
* Milano v.Juvara ----> #50128
* Milano v.Juvara ----> #22851
* Milano P.zza Zavattari----> #24644

2.1

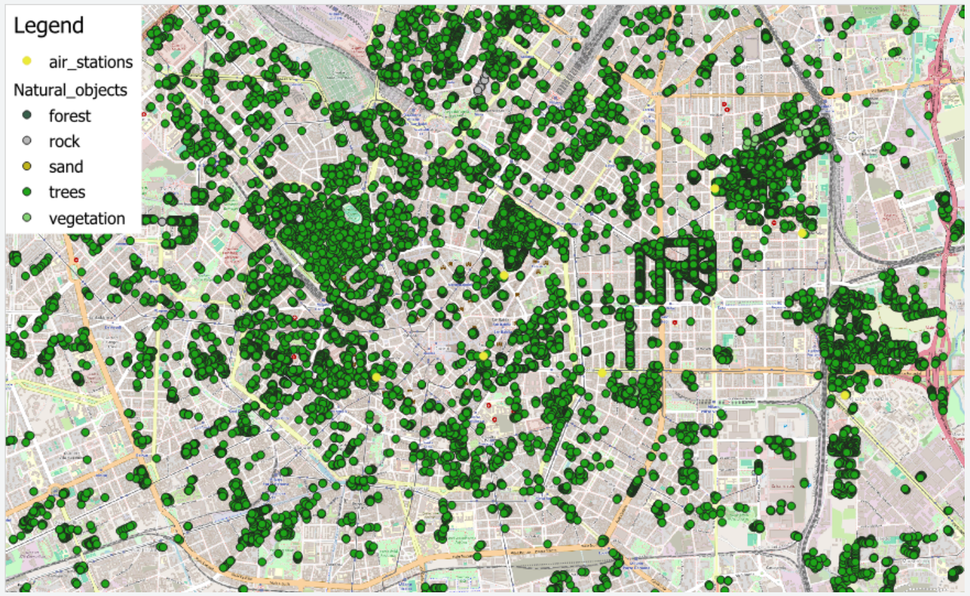
Data exploration and preparation

Spatial features retrieval

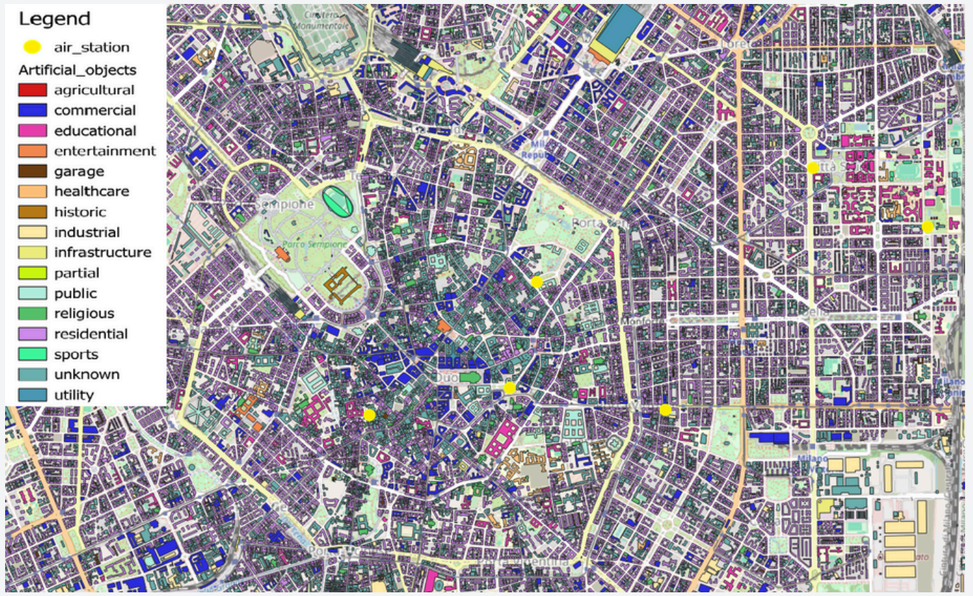
OpenStreetMap provides a wide range of land features. In this work, the natural attributes are defined by their pyshical characteristics, while artificial attributes based on their functional roles within the community.

For non-bidimensional features, we estimated the **circular area** of tree crowns (radius: **3.97 metres**) and vegetation (radius: **2 metres**), while for polygons the area is already provided. For buildings, we estimate the **living area** by multiplying the horizontal area by the number of floors.

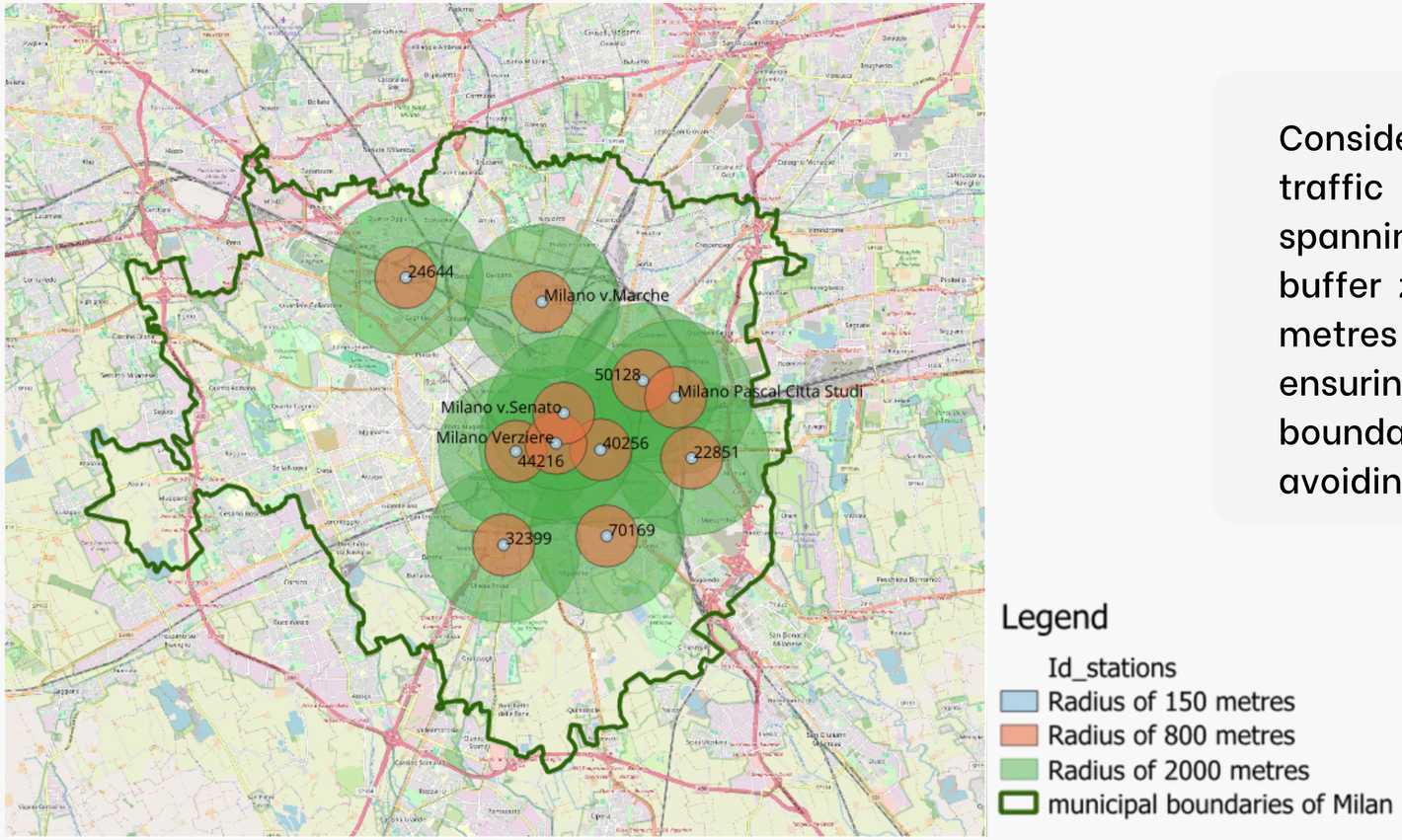
Natural attributes



Artificial attributes



2.2 Spatial encoding: rings generation



Considering that the measurements of urban traffic sites are representative of areas spanning a few kilometres, we created three buffer zones with radii of 150, 800 and 2000 metres around each air quality station, ensuring that the spatial elements at the boundaries belong exclusively to a buffer zone, avoiding overlaps.

2.3 Machine learning models

Machine Learning: boosted tree

Deep Learning dense-based: a simple dense neural network

Deep Learning RNN-based: A variant of the LSTM model that we called Surrounding-Augmented LSTM SA-LSTM

Model	R2 on test set	MAE on test set
Boosted Tree	49.00%	8.60
Dense NN	51.90%	8.16
SA-LSTM	84.59%	4.17

2.3

Machine learning models

SA-LSTM

The dataset is split into training (80%), validation (10%), and testing (10%) sets. For each observation, the model ingested **7 days** of time-dependent data per station plus the time-invariant attributes and we used **MinMAxScaler** to adjust the values fed in the model.

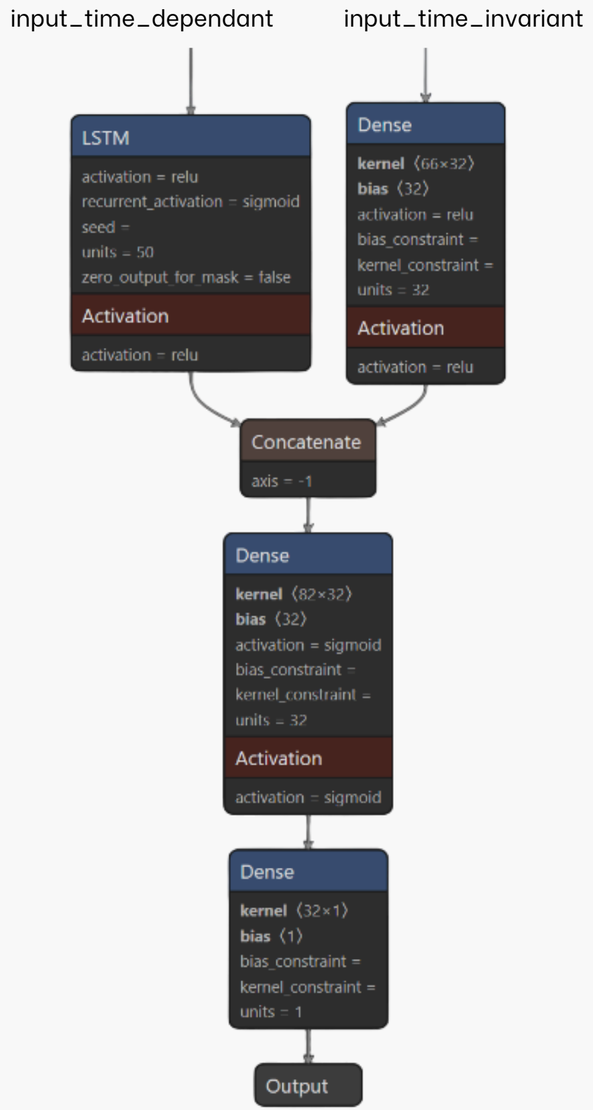
Time-dependent attributes

Weather and date-related variables
(36 covariates in total)

Time-invariant attributes

Spatial variables
(66 covariates in total)

After 600 epochs, the model achieved an MAE of 4.16



2.3

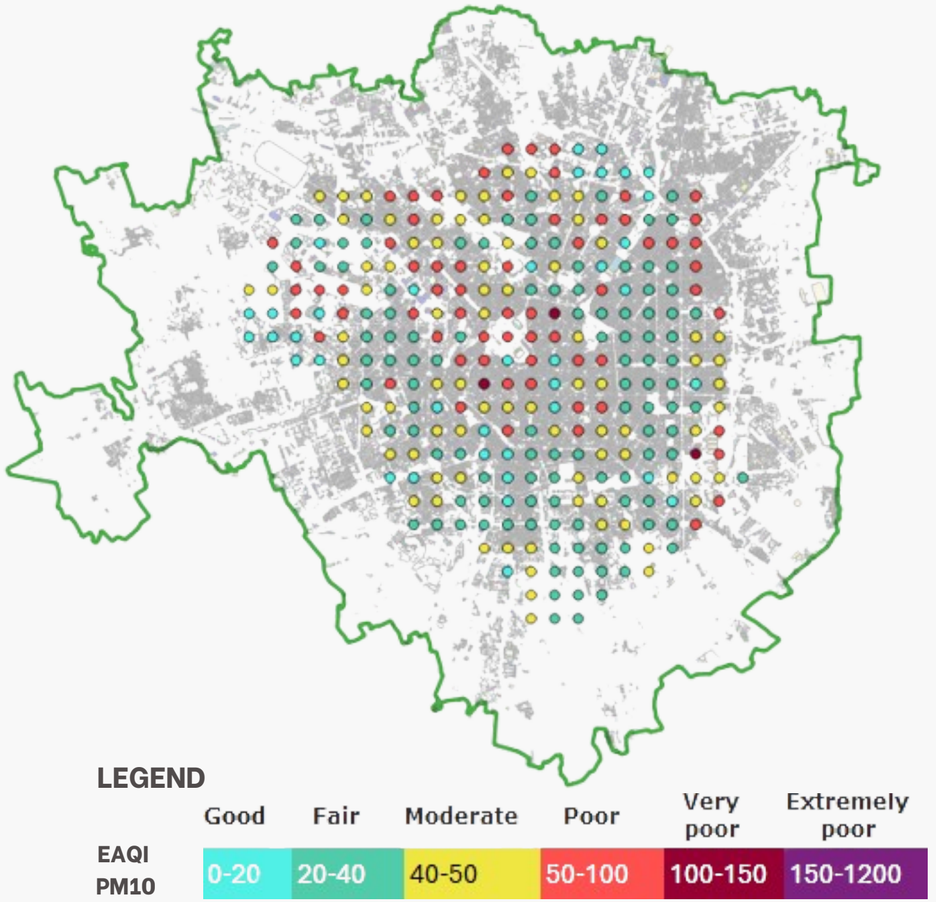
Machine learning models

Model use cases: spatial precision prediction across city points

City life PM10 prediction on **August 15th** based on 7-Days Weather forecast:

- **Sunny** 81.76 µg/m3
  previous days: sunny, sunny, sunny, sunny, sunny, sunny, sunny
- **Cloudy** 72.67 µg/m3
  previous days: sunny, sunny, cloudy, sunny, sunny, cloudy, cloudy
- **Rainy** 42.61 µg/m3
  previous days: sunny, sunny, cloudy, cloudy, rainy, cloudy, rainy
- **Stormy** 35.56 µg/m3
  previous days: sunny, sunny, sunny, sunny, rainy, rainy, stormy

Prediction example for **January 30th** after a sunny week



2.3

Machine learning models

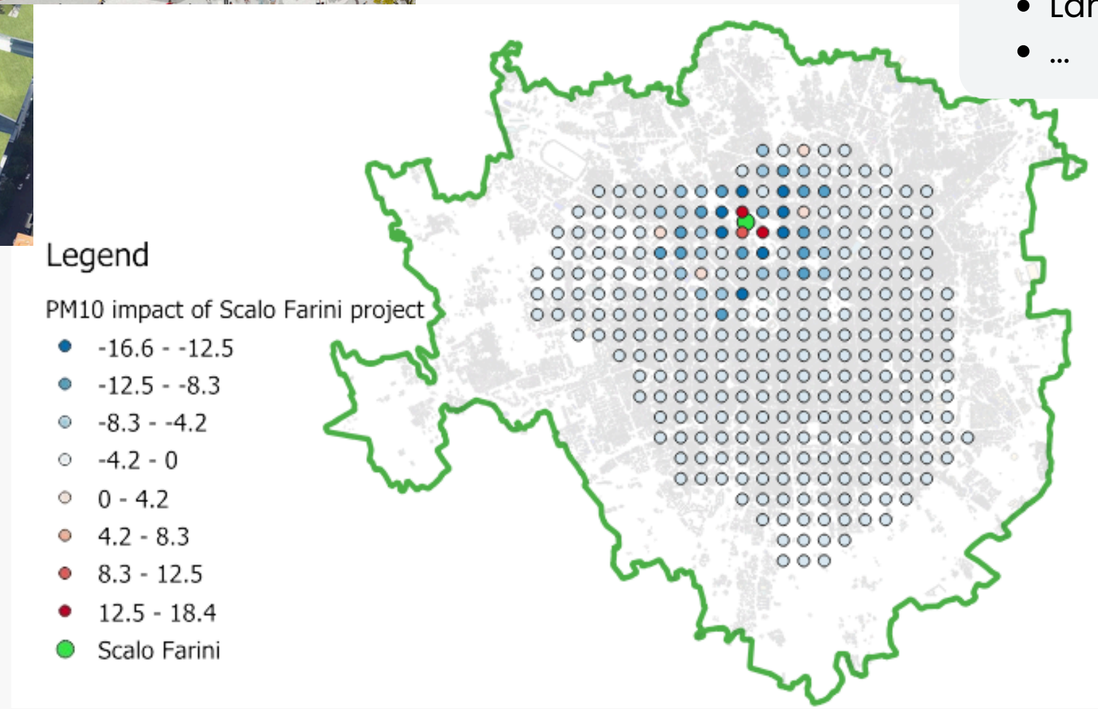
Model use cases: impact of Scalo Serafini on PM10 level

Scalo Farini masterplan:

- 300.000 mq green areas
- Focus on sustainability
- Focus on green spaces
- Public spaces
- Old buildings renewal
- Bicycle lanes
- Landbridges
- ...

Scalo Farini project has a **positive impact** on the reduction of PM10 concentration values more in distant areas than in the proximity.

We hypothesize that this may be due to the lack of green areas calculated in the first 150-meter ring around the air quality stations, used as input for the model



3 Policy suggestions

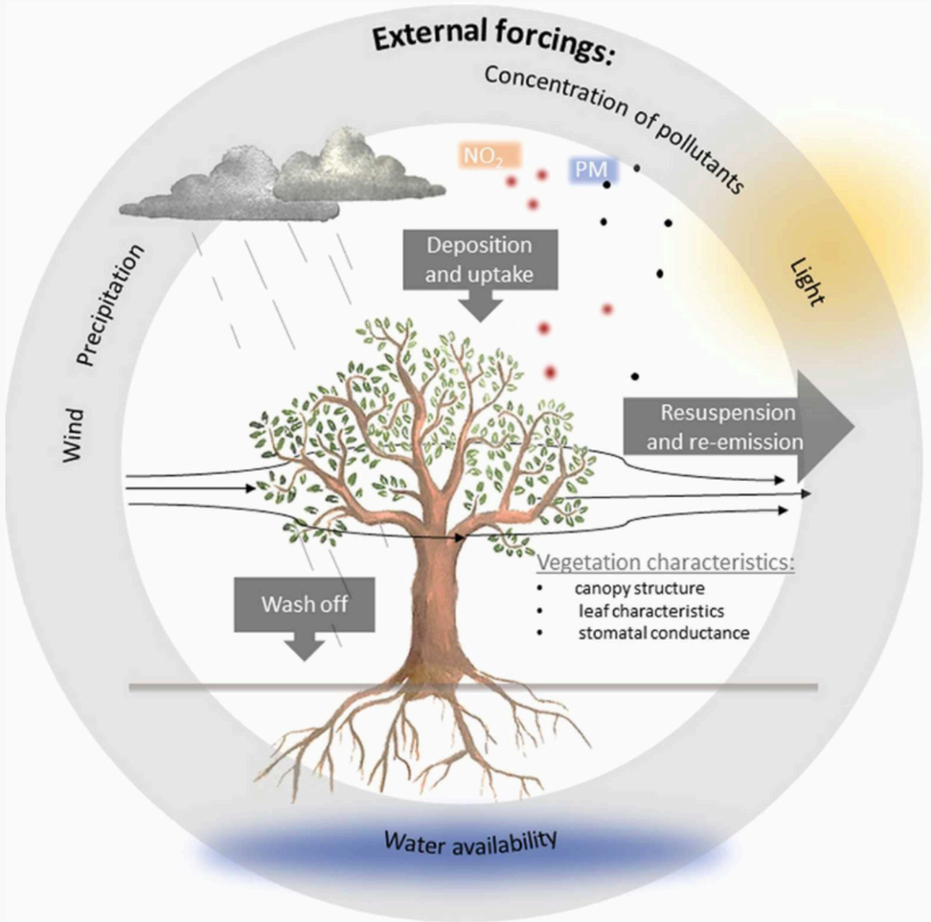
3.1 Urban trees

Role of urban trees

The ability of removing particulate matter from the air depend mainly by the process of **dry deposition**, where fine particles settle onto surfaces like leaves and are either absorbed by the plant or later removed by rain or dispersed by the wind.

The effectiveness of urban trees in providing the ecosystem services is highly dependent on the specific traits of each tree species and the deposition velocity.

Weerakkody et al., 2018 highlights that the effectiveness of particle uptake by trees is increased if their leaf and bark surfaces are rough or sticky, with complex shape and hairy or waxy surfaces rather than smooth surfaces. Examples include conifers and picea species.



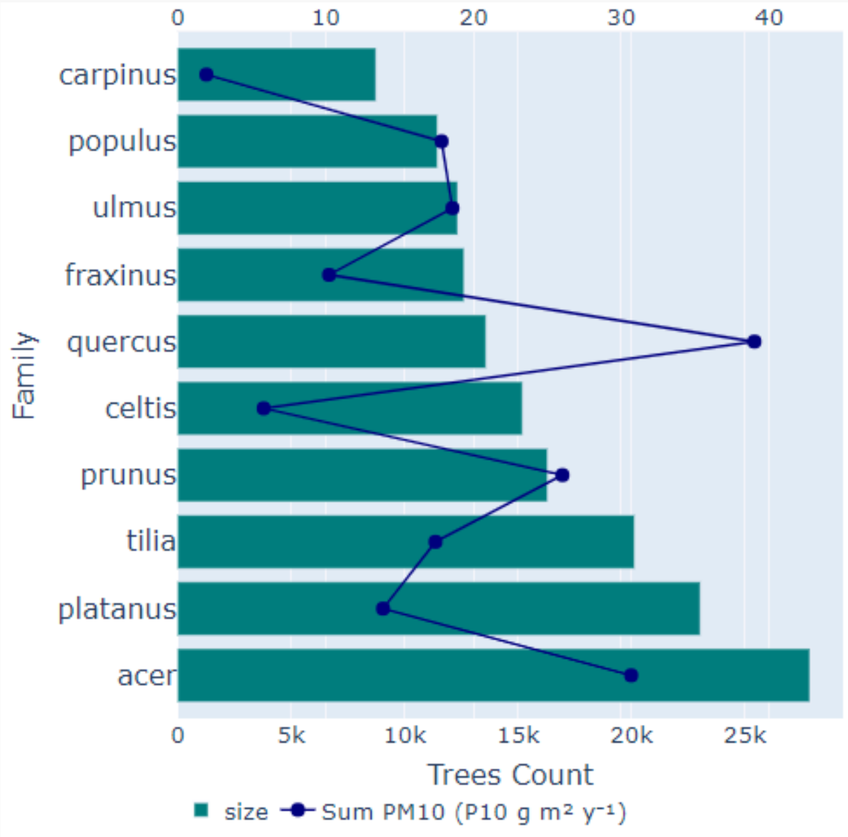
Source of image: Linden et al., 2023(1)

(1) Linden et al., 2023 :Air pollution removal through deposition on urban vegetation: The importance of vegetation characteristics

3.1 Urban trees

Pm removal ranking

A recent study by **Zappitelli et al., 2023** mapped and measured the capacity of urban greenery in Milan to capture PM and and found that the **evergreen Pinus family** captures the highest amount of pollutants.



P10 g m² y⁻¹
96.84

Cedrus
4 species
3692 tress

P10 g m² y⁻¹
115.36

Picea
7 species
1162 trees

P10 g m² y⁻¹
184.17

Pinus
11 species
2890 trees

3.1

Urban trees

Integrating effective indicators in decison-making process

People's health and well-being are closely linked to the state of the environment

Policumakers should rethink its approach by resorting to trees – not just for aesthetic purposes but also for their functionality in addressing multiple enviromental factors , **ensuring that the best tree species are selected for specific spatial planning contexts and local environments.**

Designing green areas with high PM mitigation capacity requires **developing pratical indicators** that integrate several considerations about ecosystem disservices and services into the decision-making process:

- Favourable physiological, morphological and micromorphological characteristics
- Low allergenicity
- High resistance to disease, and greater resilience to pollution and climate change
- Low maintenance requirements
- Respect for local biodiversity

tree roots lift the pavement

fallen tree after cloudburst

tree pruning

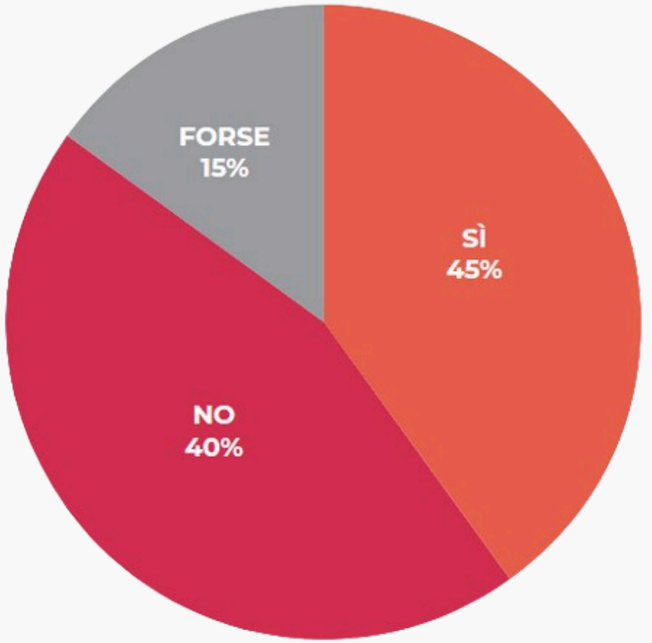
3.2 Increasing public partecipation

To further promote and expand citizen participation, the city could implement more extensive awareness campaigns aimed at encouraging greater citizen participation in the care and preservation of urban green spaces such as through education and promotion of environmental information.

Despite various municipal initiatives, public acceptance of these initiatives can be challenging. For instance, a survey revealed that only **45% of respondents are willing to change their habits to improve the air quality in their city**.

This underlines the need for environmental initiatives that effectively translate proactive environmental behavior into the private sphere, by ensuring the clearness of goals, maintaining continuous dialogues, and adopting modern social marketigs strategies to better engage younger generations

Do you think you could change your habits if you were aware of the effects of air quality on you?



Source of image: Mosaic (1)

(1) Mosaic, 2023 :Risultati del questionario su informazione e percezione della qualità dell'aria a Milano

3.3 Future developments

Green areas are crucial drivers to increase livability and make the territory more resilient. Policymakers should address the public's need for accessible information to foster a sense of responsibility among residents and encourage public partecipation

The result of SA-LSTM model demonstrates that predicting PM10 in Milan with high precision is feasible. To create an accurate pollution impact assessment, it will necessary to integrate additional data such as traffic variables and more information near emission sources.

THANKS!