Layman’s Report

AIRFRESH

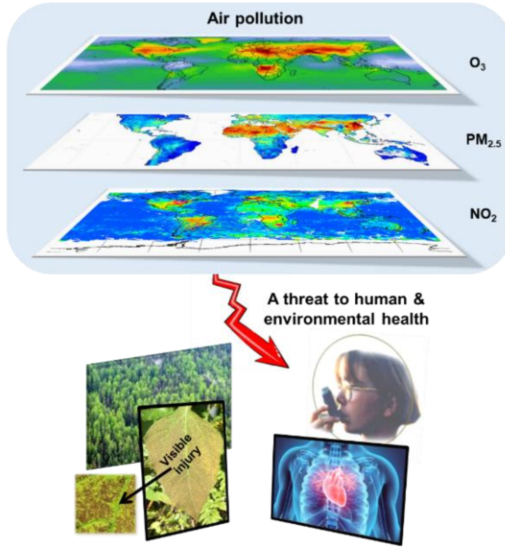
Air pollution removal by urban forests for a better human well-being

by

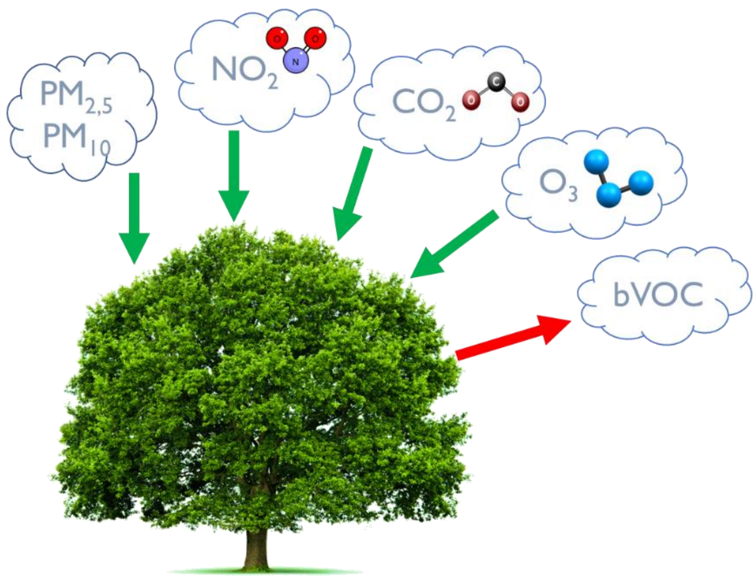
AIRFRESH

LIFE19 ENV/FR/00086

Mass urbanization is one of the most urgent challenges of the 21st century, i.e. 82% of the European Union population will live in cities in 2030. **Air pollution and climate change** are tightly linked, and air pollution is one of the most pressing environmental challenges faced by modern cities urging for international cooperation and **unified research efforts**. Emissions from vehicles, industrial activities, and energy consumption contribute to increased concentrations of key air pollutants such as particulate matter (PM), nitrogen dioxide (NO_2), and tropospheric ozone (O_3). These pollutants are a **threat to human health** (e.g., respiratory and cardiovascular diseases, asthma lung cancer) and natural ecosystems.



Project scope and objectives



Urban reforestation, e.g., by increasing the tree density in cities, and peri-urban reforestation near densely populated cities where it is not easy to plant trees, can help **improve air quality** and meet clean air standards in cities.

Therefore, efforts for **optimizing urban greenness** for healthy cities are needed. The European Union launched the **Biodiversity Strategy for 2030** asking municipalities with at least 20,000 inhabitants to develop ambitious Urban Greening Plans.

However, **careful selection of species** is needed to avoid unintended side effects, such as the emission of biogenic volatile organic compounds (bVOCs) which can contribute to O_3 formation. Some municipalities have hurriedly planted any tree species anywhere, and these strategies have degraded air quality.

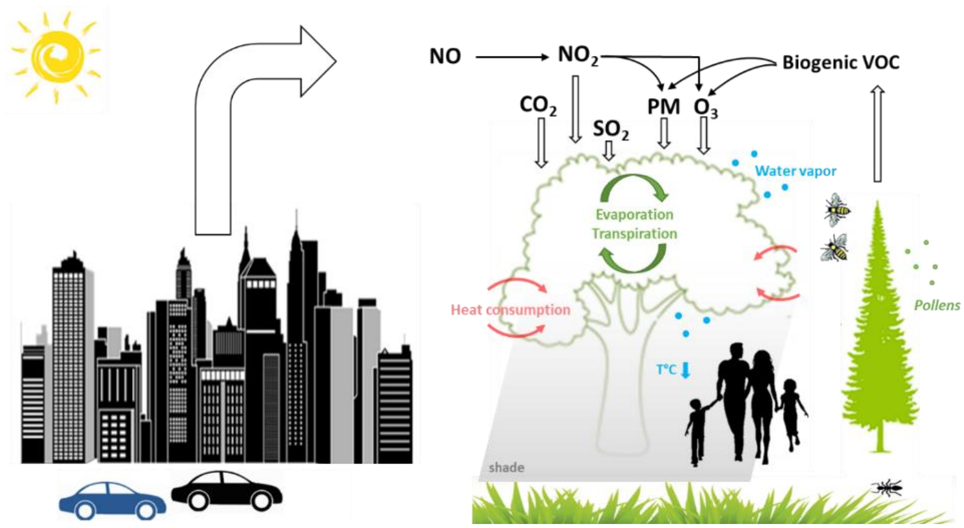
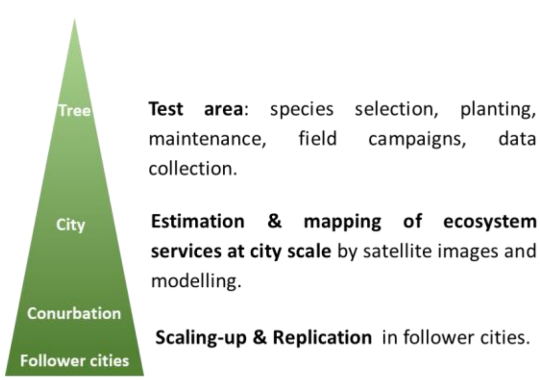


Figure 1 *- Beyond pollution mitigation, urban trees provide additional ecosystem services, including temperature regulation, carbon sequestration, and biodiversity enhancement.*

To efficiently reduce air pollution and target **carbon-neutral and climate-resilient cities**, a quantitative and concrete assessment of the role of urban trees in affecting air quality and thermal environment as well as a **suitable selection of tree species** are needed. In LIFE AIRFRESH, we have selected **Aix-en-Provenc**e in Southeastern France (143,000 inhabitants) and **Florence** in Italy (380,000 inhabitants) as **living labs** where human exposure regularly exceed the World Health Organization protection limits of PM_{10}, NO_2 and O_3.



For the first time, AIRFRESH aimed to:

- Quantify* the **environmental and health benefits** provided by a newly planted test area.

** based on in-situ data*

- Quantify the **air pollution removal by urban trees** at city scale.

- Propose **recommendations for reforestation policies** for meeting air quality standards.

Description of the methodology implemented

Test area: tree planting, maintenance and field campaigns

Two test areas were implemented in January 2022 (400 fast-growing trees, mix of species, > 3 m tall, 1-hectare). The environmental benefits were estimated before and after reforestation through key indicators. Continuous measurements of air pollution concentrations and meteorology were carried out in and around the area, above and below the canopy, before and after tree planting using AirQino sensors (air temperature, relative humidity, wind direction and speed, particles ($PM_{2.5}$, PM_{10}) and gaseous air pollutants (NO_2, CO_2, O_3). Assessment of biodiversity (flora and fauna) were carried out (e.g. soil biodiversity, environmental DNA). Regarding CO_2 emissions, a Life Cycle Analysis was accomplished to calculate the Carbon Footprint linked to nursery cultivation, tree planting, and maintenance over time.

Figure 2 – *Implementation of a newly planted test area in both cities: selection of tree species, tree planting, maintenance, and measurements campaigns using AirQino sensors.*

Distribution, classification, and mapping of green spaces

Sicard et al., 2023 have developed a **satellite-based approach** for detecting, delineating, and classifying urban vegetation in both public and private areas, with the selection of relevant **spectral and texture-based features** for each plant species. The main characteristics of individual trees (e.g., distribution, species, height, canopy cover) are derived using an object-based classification approach, preprocessing techniques including atmospheric correction, pan-sharpening, and spatial correction to derive the Normalized Deviation Vegetation Index from very-high resolution satellite imagery WorldView-2 or Pleiades (0.5 m spatial resolution).

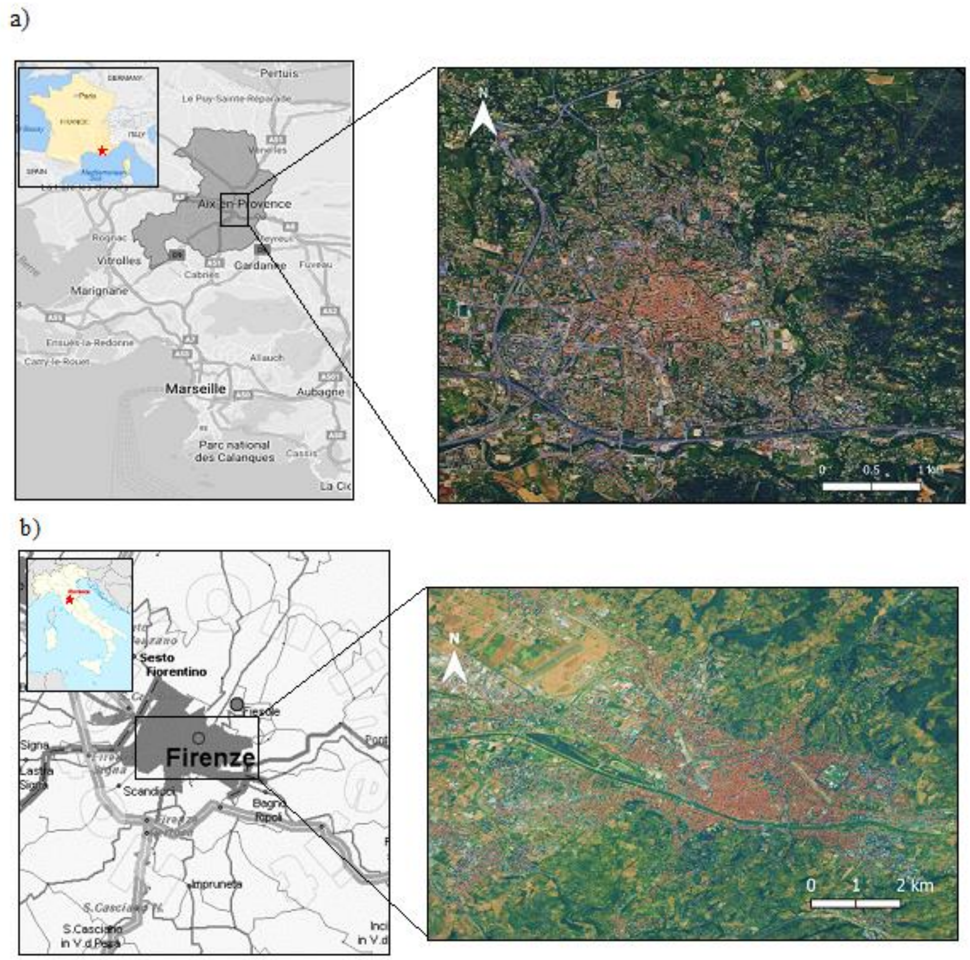


Figure 3 - *Localization of the two study areas in both cities: Aix-en-Provence (a) and Florence (b). The study area, covered by the satellite image extends over 50 km² in Aix-en-Provence and 80km² in Florence.*

Mapping and Assessment of Ecosystems and their Services

We have developed an innovative single-tree model (**FlorTree**) to quantify and map the air pollutants removal capacity of about **220 plant species**, e.g., CO_2, O_3, PM_{10}, $PM_{2.5}$, and NO_2. Cooling effect by vegetation is also quantified. The hourly meteorological data and surface air pollutants concentrations are obtained with WRF-CHIMERE model with a spatial resolution of <1km.

The 3-30-300 Rule Compliance: A Geospatial Tool for Urban Planning

The **3-30-300 rule**, introduced in 2021, mandates that every citizen should see at least three mature trees from their home, live in neighborhoods with at least 30% tree canopy cover, and be within 300 meters of a high-quality green space.

To establish **efficient greening strategies**, we developed a geospatial tool using remote sensing and Geographic Information System (GIS) techniques to assess compliance with the 3-30-300 rule. The tool employs very-high-resolution satellite imagery for detecting trees and estimating canopy cover and integrates **OpenStreetMap** data to assess proximity to green spaces. The **citywide geospatial tool** is instrumental in helping cities to develop **resilient and climate-neutral Urban Greening Plans**. The findings of this study offer a crucial roadmap for identifying priority areas for greening in rapidly developing and densely populated cities.

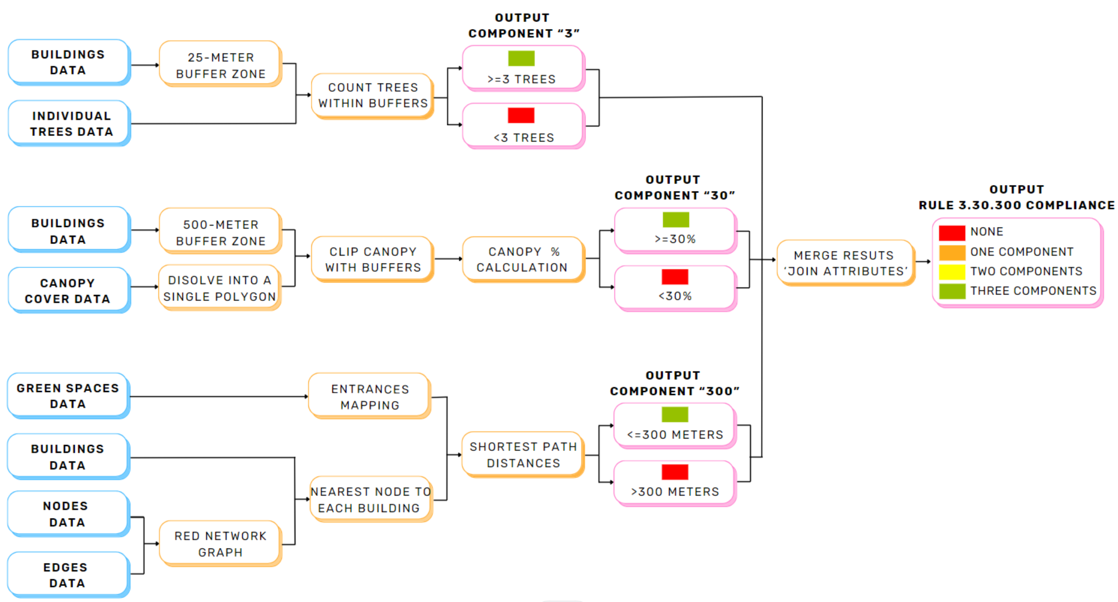


Figure 4 *- Flowchart of the methodology for the algorithm created for 3-30-300 rule compliance: Blue sky boxes depict input data, orange boxes denote main processes, and pink boxes denote outputs.*

Results achieved

Mapping of urban trees at city scale

In Aix-en-Provence and Florence, 22 dominant plant species and grassland were identified and classified with an overall accuracy of 84% (Sicard et al., 2023). The geo-located characteristics of urban trees, green spaces as well as **open areas potentially available for renaturation** are mapped in a GIS environment.

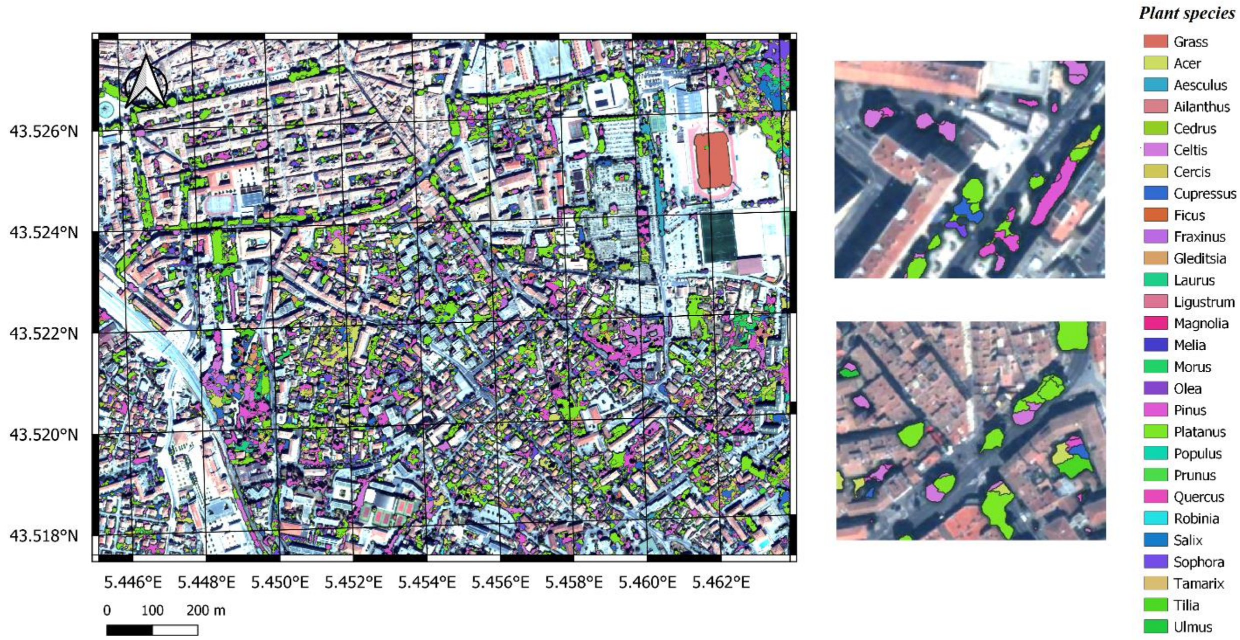


***Figure 5** – Detection, delineation, and classification of urban vegetation over the study area in Aix-en-Provence (zoom over the south-east part of the study area).*

The 3-30-300 Rule compliance: priority areas for greening

In Aix-en-Provence, **18% of buildings** are fully compliant and 4% of buildings are non-compliant with the 3-30-300 rule. In Florence, **4% of buildings** are compliant and 37% of buildings are non-compliant with the 3-30-300 rule. Compliance with two components represents 56% and 19% of the buildings in Aix-en-Provence and Florence.

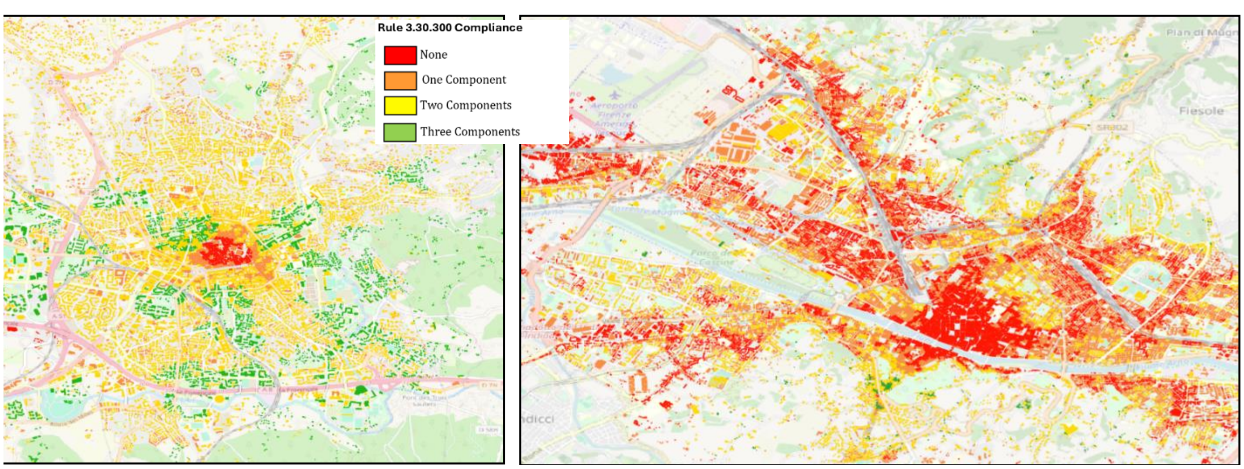


***Figure 6** - Rule 3.30.300 compliance in the study areas of Aix-en-Provence (left) and Florence (right) combining the three components: red for non-compliance, orange for compliance with one component, yellow for two components, and green for full compliance.*

Air pollution removal capacity at city scale

In **Aix-en-Provence**, the vegetated areas (trees and grass) cover 39.6% of the studied area, and the **413,960 adult trees** have eliminated in 2023: 225 tons O_3 (formation: 9 tons, removal: 234 tons), 41 tons NO_2 (6,600 cars[1]), 97 tons PM_{10} (147,400 cars[1]), 16,560 tons CO_2 (10,400 cars[1]) and lawns/herbaceous have eliminated 423 tons CO_2 (about 2.6%). The 414,000 adult trees have eliminated 3.1% and 2.8% of the NO_x and CO_2 local emissions and 36.7% of PM_{10} emissions. In **Florence**, the vegetated areas cover 30.3% of the studied area, and the **553,450 adult trees** have eliminated: 530 tons O_3 (formation: 22 tons, removal: 552 tons), 73 tons NO_2 (17,140 cars[1]), 185 tons PM_{10} (281,550 cars[1]), 25,205 tons CO_2 (15,890 cars[1]).

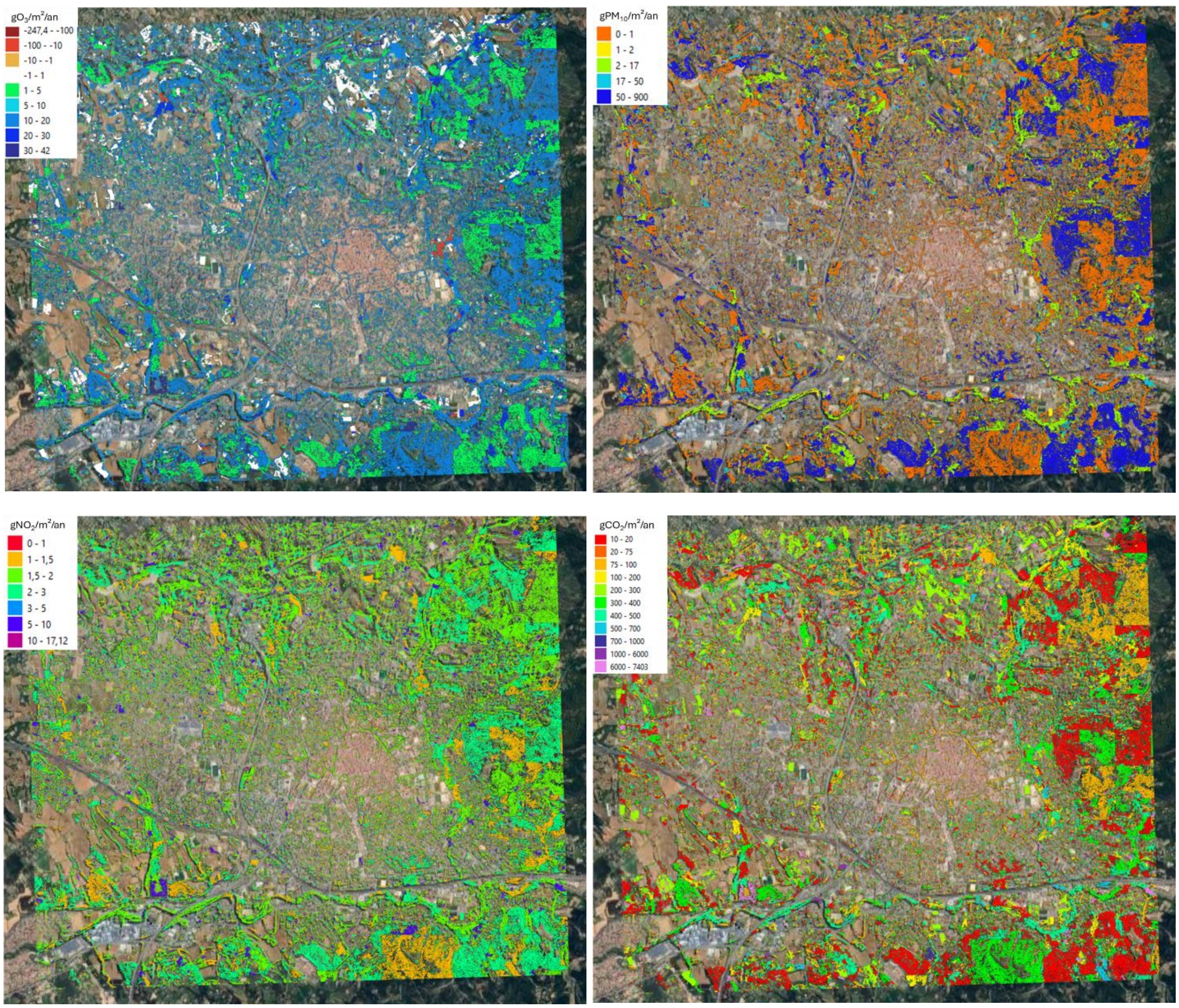


Figure 7 *– Spatial distribution of the removed ozone (top, left), PM_{10} (top, right), NO_2 (bottom, left) and CO_2 (bottom, right) amount by individual trees (g per m² of leaf area per year) in Aix-en-Provence for the year 2023.*

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[1] *emissions of private cars registered in France which has driven an average of 12,200 km during the year with an average speed of 70 km/h.*

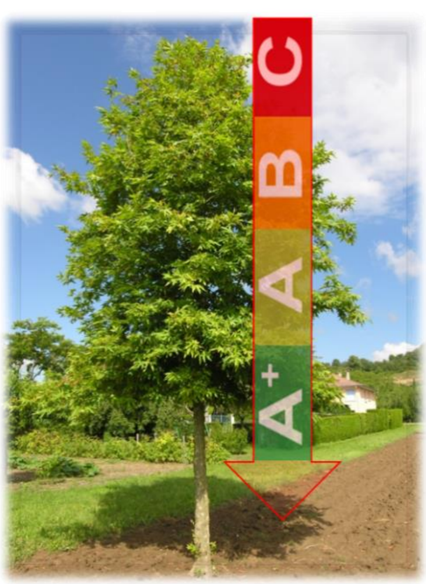
FlorTree: Guidelines for city planners and decision-makers

FlorTree is a "**single-tree" model** designed to assist urban planners and decision-makers in selecting tree species most suitable to mitigate urban air pollution effectively. The model evaluates species-specific traits and environmental conditions, integrating critical factors such as tree morphology, stomatal conductance, leaf surface area, and bVOC emissions. FlorTree allows users to input site-specific data, such as local climate, pollution levels, and urban design constraints, to generate tailored recommendations.

Key Features of FlorTree:

- **Species-Specific Data:** 220 tree and shrub species, assessing their ability to remove air pollutants.
- **Climate and Pollution Integration:** Considers local climate variables along with pollution concentrations.
- **Pollutant-Specific Recommendations:** Enables selection based on targeted specific pollutants.
- **User-Friendly Interface:** Accessible to city planners without advanced technical expertise.

Environmental and Socio-economic benefits of the project



Compared to the current tree cover, **each 5%-point increase in tree canopy cover** could reduce by 3.0% and 1.4% the annual $PM_{2.5}$ and NO_2 mean concentrations, and by 1.3% the summertime mean of the daily maximum 8-hours O_3 concentrations. Each reforested area has eliminated in 2023 1.5 tons O_3, 170 kg NO_2 (40 cars[1]),150 kg PM_{10} (220 cars[1]), 21 tons CO_2 (13 cars) and increase carbon stocks (2.6 tons). Ambient air is 1.5 °C cooler compared to surrounding area. In summer, we observed a **reduction of 55% of O_3 peaks** at tree level. Planting urban forests can mitigate climate change effects as trees remove CO_2 from the atmosphere. However, by setting up a new urban forest, greenhouse gases emissions occur during cultivation in the nursery, planting, and maintenance operations. The Carbon Footprint was equal to 14.7t CO_2 equivalent with maintenance over time as the most CO_2-emitting phase (62%). The model highlighted that **13 years** are needed to reach a positive CO_2 balance. We observed significant increases in i) soil biodiversity; ii) in vertebrates; iii) in species and number of insectivorous birds.

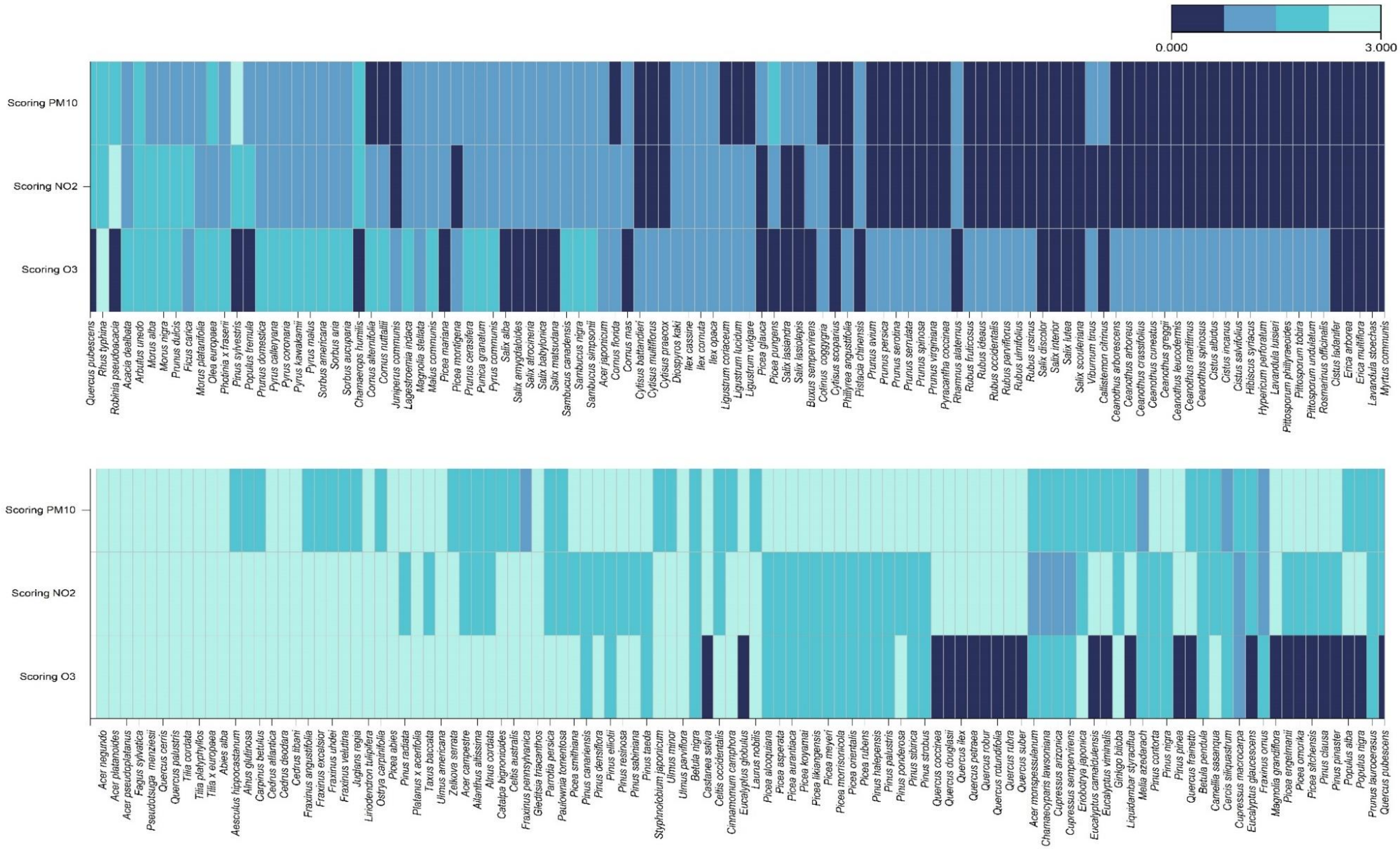
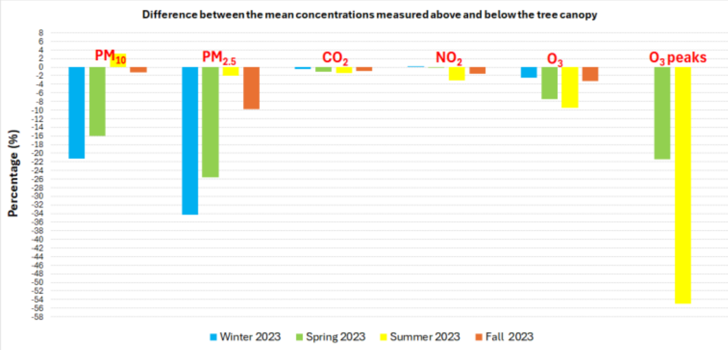


Figure 8 *- FlorTree ranking: Removal ability per air pollutant (low 0 to high 3).*



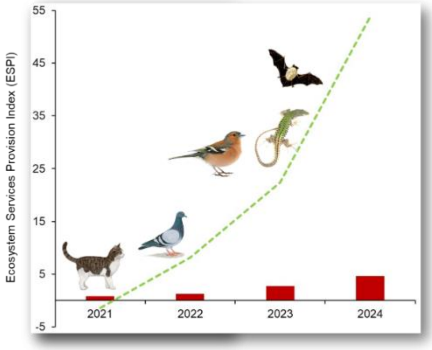


Figure 9 *- Difference of seasonal mean concentrations above and below tree canopy within the test area in Aix-en-Provence for the year 2023 (left) and Ecosystem Services Potential Index before and after reforestation in 2022.*

Each 5%-point in tree canopy would prevent about 4,700 air pollution-related premature deaths annually across the 744 European urban centers with more than 50,000 inhabitants. Reaching a canopy cover of 30% within each urban center could prevent almost 12,000 premature deaths each year. In Aix-en-Provence and Florence, each 5%-point in tree canopy could **prevent a total of 18 premature deaths** annually. An excess of 61 premature deaths would be observed by reducing the mean city tree coverage from the current tree cover to a hypothetical “no tree” scenario. To translate the annual reduction in premature deaths into economic savings, the Value of a Statistical Life can be used as a proxy. In Europe, the average statistical value of life is estimated at € 4.3 million.

Beyond LIFE AIRFRESH - Transferability of project results

FlorTree can be applied in any city. By expanding the sets of socio-economic, climatic, urban planning, soil, phenology, and air pollution data (Zagreb, Bucharest, Vilnius, Tokyo), our approach has been validated and guidelines refined. Follower cities will build on the evidence and knowledge base generated in front-runner cities to develop their own local urban plans for replicating and adapting nature- based solutions to suit their local settings.

Digital Twin as a decision-making and planning tool

By combining the LIFE AIRFRESH approach with climate change and air quality scenarios, a Digital Twin can be designed to help urban planners assess the benefits of various planning scenarios. Digital Twin helps accelerate urban climate resilience by simulating climate change scenarios, identifying areas prone to the urban heat island effect and high-risk populations, and locating opportunities to incorporate more nature into cities. Data and models are available (Manzini et al., 2023; Sicard et al., 2023; Anav et al., 2024) for launching the actual replication works.

AIRFRESH key messages

- A new methodology was developed to detect, classify, and map individual trees and green spaces at city scale, and quantify the amount of pollutants they remove from the urban air.
- The results allow identifying priority areas for greening in densely populated cities.
- Peri-urban forests influence climate conditions and air quality within the cities. Thus peri-urban areas can be a target for greening strategies.
- Private trees in Aix-en-Provence and Florence were more than 80% of the total, stressing the need of policies for private owners.
- Trees remove air pollutants from the air, e.g. PM_{10}, NO_2, O_3 and CO_2, but their efficiency depends on the species and local climate conditions.
- Scientifically-sound recommendations of the best/worst woody species for urban polluted environments were made available. Recommendations differ in different cities.
- The amount of removed pollutants can compensate the emissions from thousands of cars, e.g. in Aix-en-Provence, trees remove every year 41 tons NO_2 (corresponding to the emissions from 6,600 cars), 97 tons PM_{10} (147,400 cars) and 16,560 tons CO_2 (10,400 cars)
- A methodology was developed for checking compliance of each building with the 3-30-300 rule.
- Increasing tree cover in Aix-en-Provence and Florence to 30% could prevent 50 premature deaths each year.
- The economic value of air pollution removal and Urban Heat Island reduction by current vegetation, as estimated in terms of avoided premature deaths, was 550 M€ for the city of Florence, and 150 M€ for Aix-en-Provence. The economic value is city dependent.
- This is the first time that air pollution and warming reductions by urban forests are quantified in tandem.
- These results help the implementation of the EU strategies, e.g. on biodiversity protection and Green Deal, that target planting of 3 billion trees by 2030 in the EU.

Start date: September 1st, 2020

End date: December 1st, 2024

Coordinator: Dr Pierre Sicard, ACRI-ST, France

Partners: ACRI-ST (FR), AIR-Climat (FR), ENEA (IT), IRET-CNR (IT), municipalities of Aix-en-Provence (FR) and Florence (IT)

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Contribution European Commission: €661,250