# Urban forests as a tool to improve air quality and mitigate heat islands

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# Context & Background

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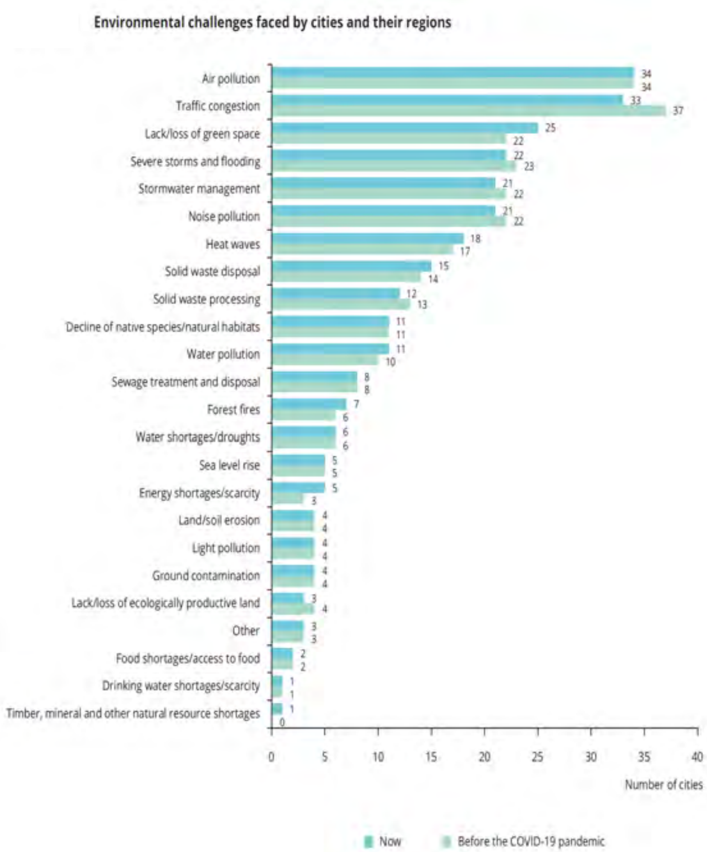
Cities are facing a wide variety of **environmental challenges**: air pollution, climate change, stormwater, loss of bioviversity, noise & light pollution, etc.




**Air pollution & urban heat islands**: 2 major problems affecting the quality of life & well-being of citizens.

Citizens exposed to ~ 200 pollutants/classes of pollutants.


Air temperature up to +12 °C in cities by 2100.


Urban vs. rural areas: +3-5 °C in summer.

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# Context & Background

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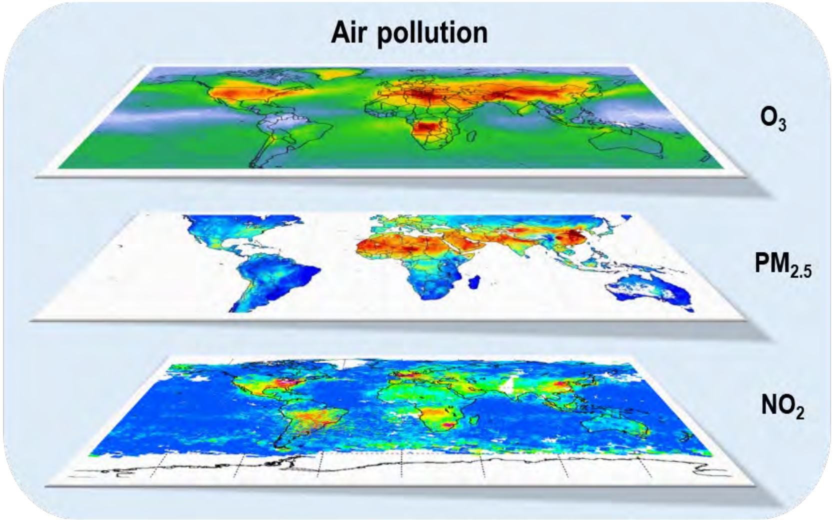
Tropospheric ozone ($O_3$), fine particles ($PM_{2.5}$), and nitrogen dioxide ($NO_2$): **most harmful air pollutants for human health**.

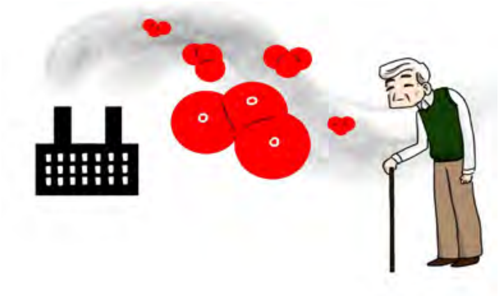
**Outdoor air pollution** - Major public health issue, leading to **4.14 million** premature deaths worldwide in 2019 (GBD, 2019).

In 2019, **billions of people** were exposed to levels of $PM_{2.5}$ (5 µg $m^{-3}$), $O_3$ (*peak season < 30 ppb*), and $NO_2$ (10 µg $m^{-3}$) **above** the 2021 WHO Air Quality Guidelines for human health protection.




**By 2050**, 70% of the world's population will reside in urban areas, and outdoor air pollution => **6.6 million premature deaths** (Lelieveld et al., 2015).

Rising $O_3$ levels due to lower $O_3$ titration by NO & $PM_{2.5}$ decline => **Major public health issue** (Sicard et al., 2021).



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# Vehicle electrification in cities

Calatayud et al., 2023

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Future vehicle electrification in EU will be fostered by the **ban of thermal engines from 2035**.

Machine learning model for predicting changes in air pollutants levels.

City of Valencia (Spain).

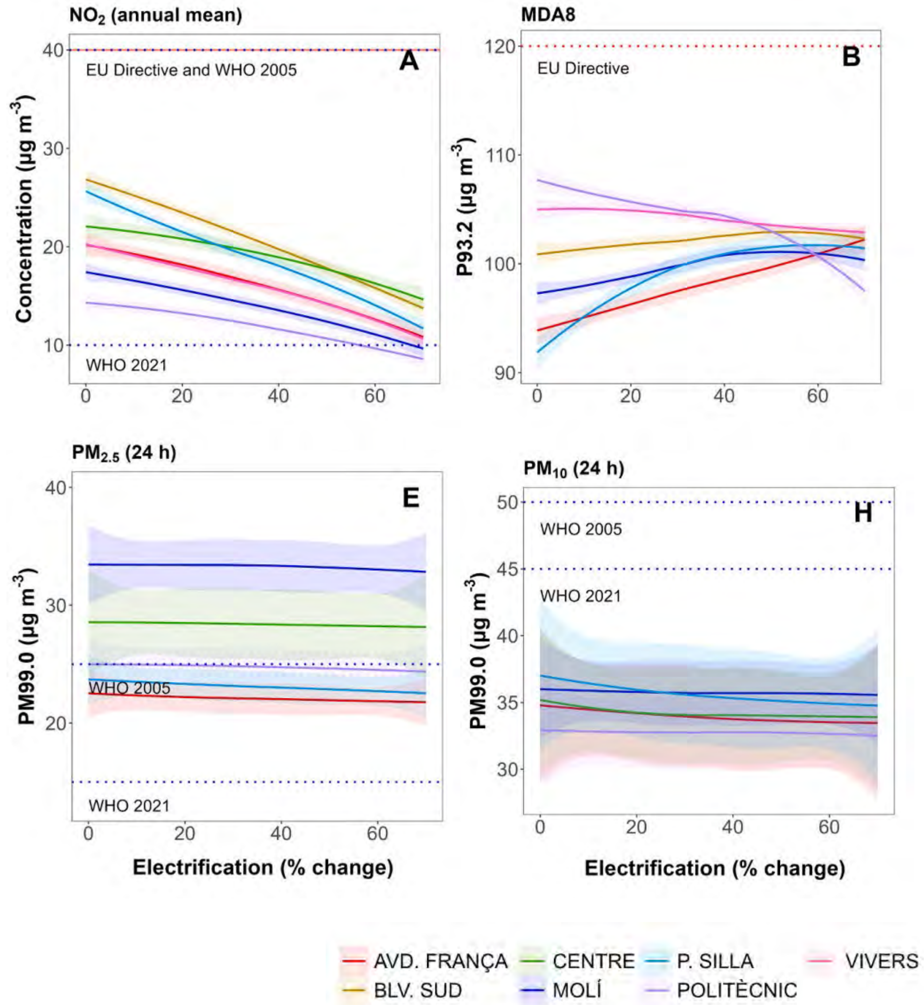
Model was trained with 10 years of AQ & meteo data.

**For a 70% VE**

$NO_2$: - 34% to - 55%

$PM_{2.5}$ & $PM_{10}$: - 1 to - 4%
*electric vehicles are 24% heavier*

MDA8 $O_3$: - 2% to + 12%
*NOx-to-VOCs ratio*



# Urban trees : Choose carefully

## Which tree do we plant ?

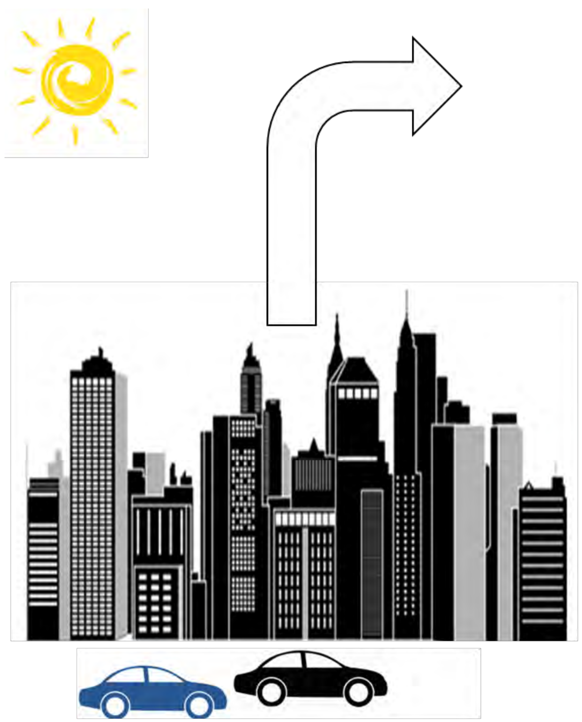
Greening strategies

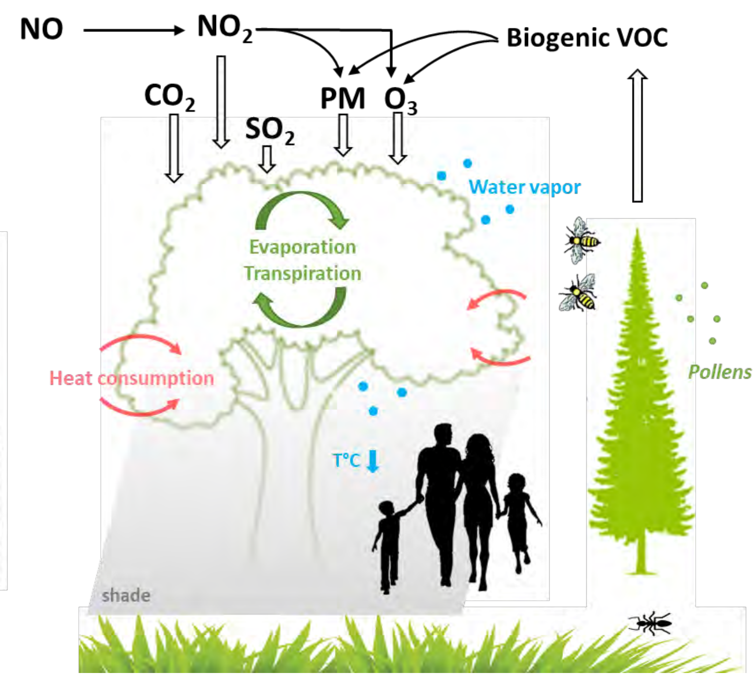
# Benefits of urban trees/shrubs

**The urban trees/shrubs can:**

- Sequester carbon,
- Regulate air temperature,
- Mitigate storm-water runoff,
- Reduce noise,
- Provide recreational & aesthetic benefits,

etc…





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# Benefits of urban trees/shrubs

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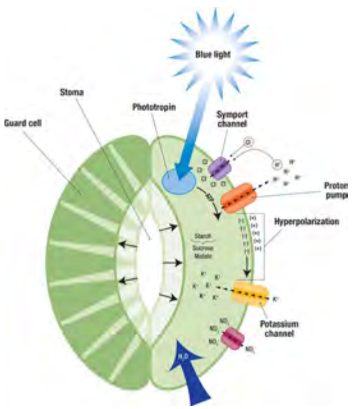
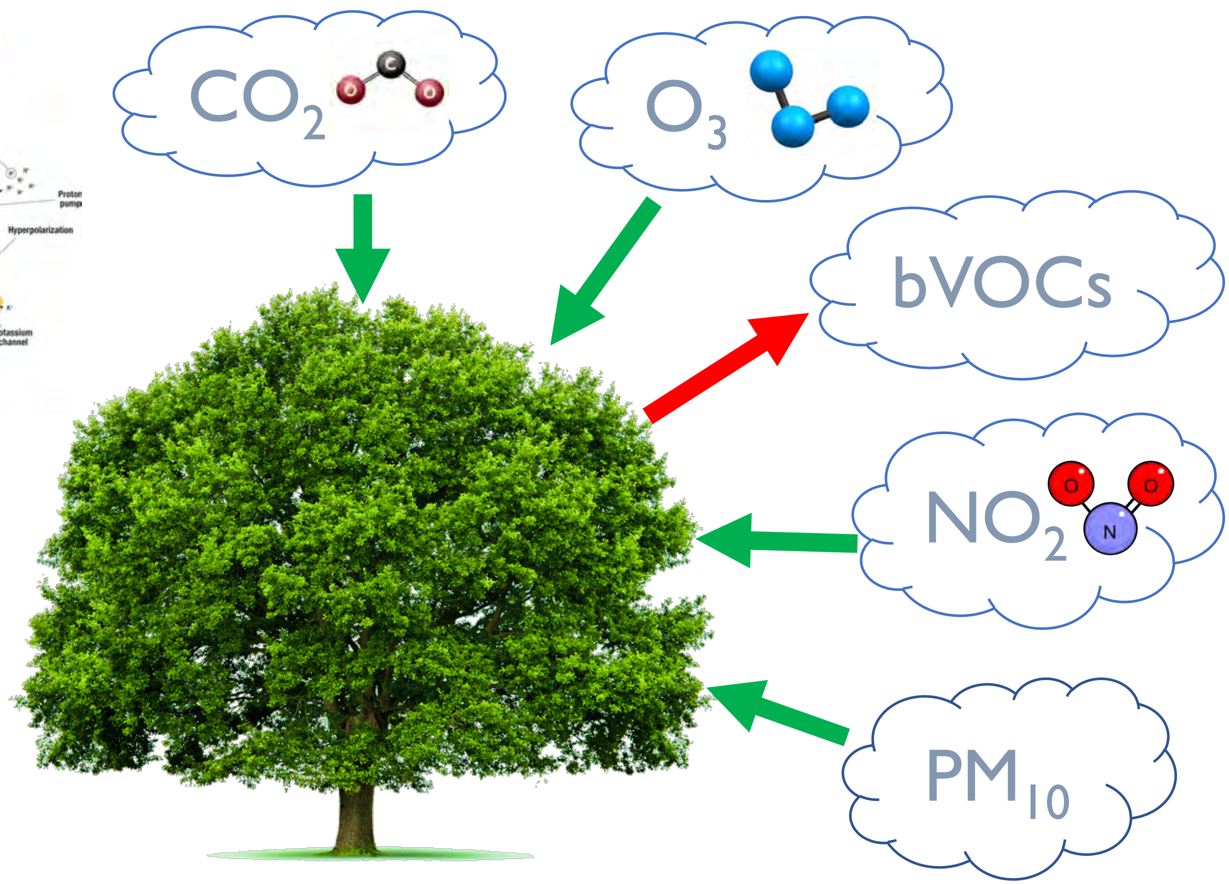
The urban trees/shrubs can **reduce air pollution**: deposition of PM & gases on plant surfaces & **absorb gaseous air pollutants** through stomata & regulates transport of pollutants.



# Which tree do we plant ?

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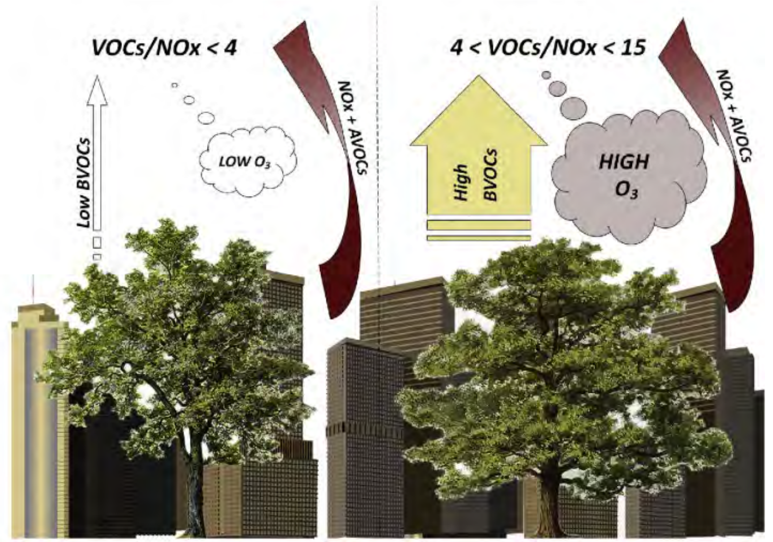
Local $O_3$ formation depends on **$NO_x$-to-VOCs ratio**.

Trees and plants produce **VOCs**, which when exposed to sunlight react with $NO_x$ to **form $O_3$.**

At global scale, **biogenic VOCs contribute up to 90%** of the total VOCs emissions, with 99 % of bVOCs emitted from vegetation.




**Tree selection is a crucial step for proper urban greening strategies:**

- High gaseous pollutant removal capacity
- Low bVOC release
- High PM abatement

For **220 species (trees and shrubs)**:

- Stomatal conductance ($g_s$)
- Emission rates of volatile organic compounds (bVOC)
- Morphometric parameters (e.g., LAI, leaf morphology, height, crown diameter)

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Original article

FlorTree: A unifying modelling framework for estimating the species-specific pollution removal by individual trees and shrubs

Jacopo Manzini[a,b], Yasutomo Hoshika[a,c,*], Elisa Carrari[b], Pierre Sicard[d], Makoto Watanabe[e], Ryoji Tanaka[e], Ovidiu Badea[f,g], Francesco Paolo Nicese[b], Francesco Ferrini[b,h], Elena Paoletti[a,c]

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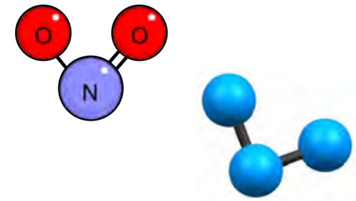
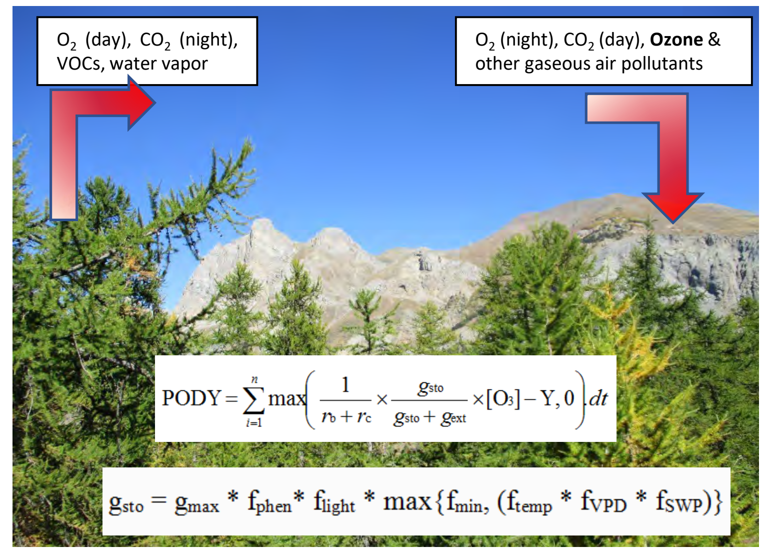
# Quantification & mapping of benefits

The **annual removal** of PM, $NO_2$, $O_3$ and $CO_2$ is quantified.



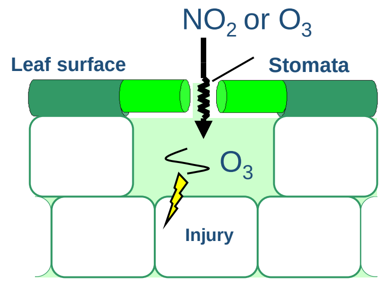

**Deposition** $Q = V_d \times C \times LAI \times T$

Q = amount removed on 1m² of leaf surface (µg $m^{-2}$), $V_d$ = deposition velocity, C = concentration (µg $m^{-3}$), LAI ($m^2$ $m^{-2}$) and T (s) = vegetative period.




**$O_3$ & $NO_2$ absorption**

*Gaseous pollutants*
*Stomatal & non-stomatal*




**Quantification of Ozone Forming Potential (OFP)**

**Carbon stock & $CO_2$ equivalent estimation**

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# Removal capacity of urban tree species

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| Genus | Species | Net O3 uptake | NO2 uptake | PM10 deposition | CO2 seq, |
|---|---|---|---|---|---|
| | | g tree-1day-1 | g tree-1day-1 | g tree-1day-1 | t tree-1year-1 |
| Abies | alba | 3,82 | 4,55 | 2,04 | 0,0421 |
| Acacia | dealbata | 1,16 | 0,93 | 0,1 | 0,0393 |
| Acer | campestre | 2,92 | 2,21 | 0,37 | 0,0623 |
| Acer | japonicum | 0,4 | 0,33 | 0,06 | 0,0092 |
| Acer | monspessulanum | 1,26 | 1,14 | 0,2 | 0,0623 |
| Acer | negundo | 6,51 | 5,14 | 0,81 | 0,0969 |
| Acer | platanoides | 17,69 | 13,32 | 2,04 | 0,0568 |
| Acer | pseudoplatanus | 17,09 | 13,57 | 2,04 | 0,0568 |
| Aesculus | hippocastanum | 13,2 | 9,86 | 0,31 | 0,0568 |
| Ailanthus | altissima | 4,37 | 3,27 | 0,32 | 0,0523 |
| Eriobotrya | japonica | 2,6 | 2,42 | 0,31 | 0,0322 |
| Eucalyptus | camaldulensis | -18,83 | 4,34 | 0,43 | 0,1115 |
| Eucalyptus | glaucescens | -124,62 | 3,59 | 0,37 | 0,1115 |
| Eucalyptus | globulus | -411,49 | 16,04 | 1,62 | 0,1115 |
| Eucalyptus | viminalis | -0,83 | 4,36 | 0,45 | 0,1115 |
| Fagus | sylvatica | 24,76 | 19,37 | 4,8 | 0,1001 |
| Ficus | carica | 0,27 | 1,64 | 0,19 | 0,032 |

**Net $O_3$ uptake = $O_3$ removal - OFP**

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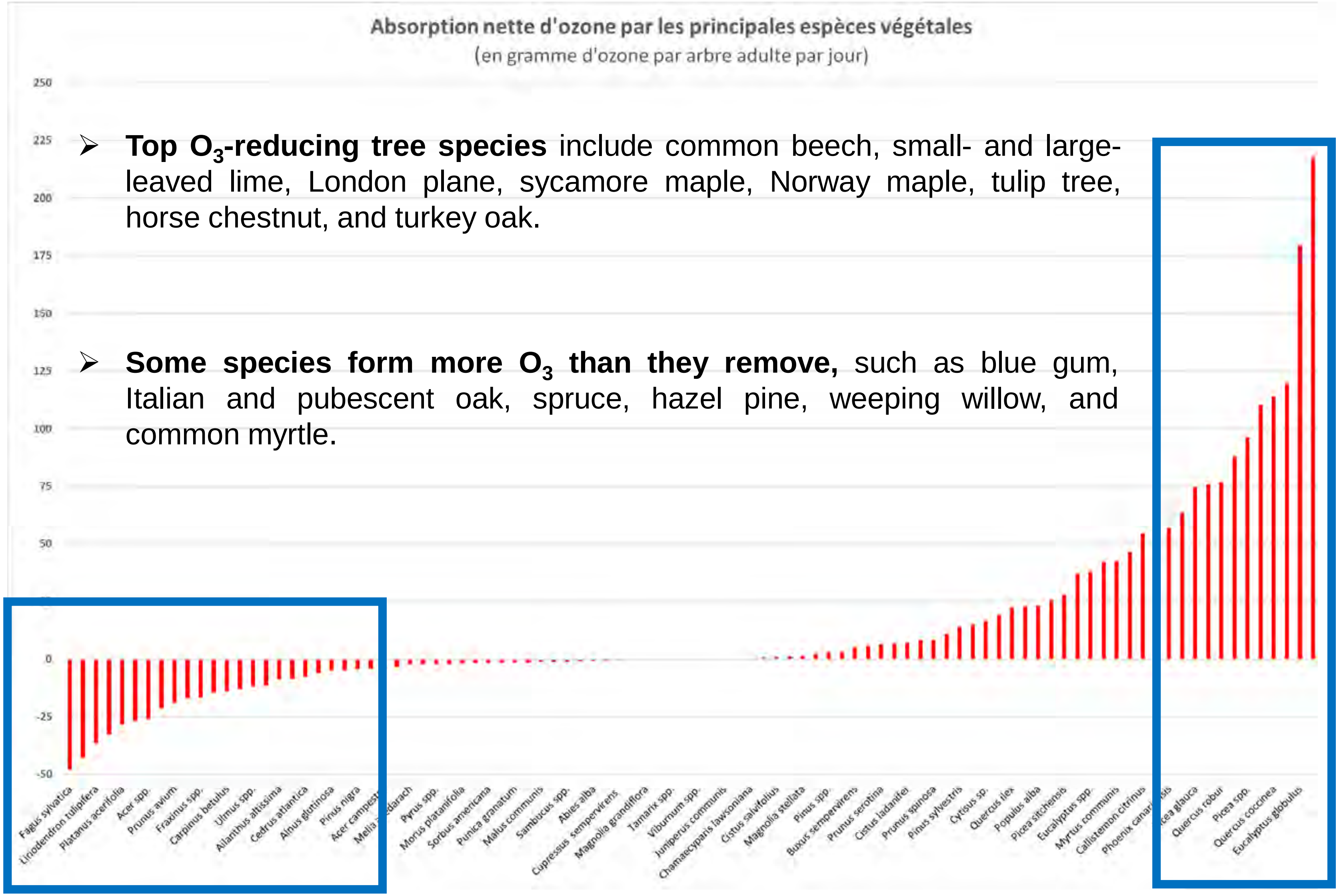
# Ozone-reducing urban plants: Choose carefully




- **Top $O_3$-reducing tree species** include common beech, small- and large-leaved lime, London plane, sycamore maple, Norway maple, tulip tree, horse chestnut, and turkey oak.

- **Some species form more $O_3$ than they remove,** such as blue gum, Italian and pubescent oak, spruce, hazel pine, weeping willow, and common myrtle.

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# List of suitable trees species for municipalities

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**<u>Suitable selection of plant species</u>** = Services vs. Disservices

1) **environmental** (e.g., effectiveness in removing air pollutants; $CO_2$ sequestration, release of biogenic VOCs leading to $O_3$ formation);

2) **social** (e.g., allergenic pollen);

3) **financial** (e.g., pruning).

**Co-design workshop** - The list must be discussed with the municipality.

| Genus | Species | Net O3 (g/tree/day) | NO2 (g/tree/day) | PM10 (g/tree/day) | CO2 (t/year) |
|---|---|---|---|---|---|
| *Abies* | *alba* | 0,794 | 3,651 | 8,353 | 0,1095 |
| *Abutilon* | *spp.* | na | 0,021 | 0,000 | 0,0033 |
| *Acacia* | *dealbata* | 1,514 | 1,570 | 0,851 | 0,004 |
| *Acacia* | *sp.* | | | | |
| *Acer* | *campestre* | 4,212 | 4,016 | 0,326 | 0,0282 |
| *Acer* | *japonicum* | na | 0,560 | 0,035 | 0,001 |
| *Acer* | *monspessulanum* | na | 2,040 | 0,147 | 0,0003 |
| *Acer* | *negundo* | 9,232 | 9,274 | 0,884 | 0,0871 |
| *Acer* | *platanoides* | 26,040 | 24,355 | 2,580 | 0,0805 |
| *Acer* | *pseudoplatanus* | 26,124 | 24,355 | 2,580 | 0,0935 |
| *Acer* | *rubrum* | | | | |
| *Actinidia* | *spp.* | na | 0,381 | 0,017 | 0,0033 |
| *Aesculus* | *hippocastanum* | 26,899 | 22,474 | 0,914 | 0,1223 |
| *Ailanthus* | *altissima* | 8,652 | 8,614 | 0,380 | 0,019 |

| Genus | Species | Carbon stored | Pollen allergenicity | Ozone sensitivity | Drought tolerance | P&D tolerance |
|---|---|---|---|---|---|---|
| *Abies* | *alba* | 1 | 2 | 3 | 3 | 3 |
| *Abutilon* | *spp.* | | | | | |
| *Acacia* | *dealbata* | 0 | | | | |
| *Acacia* | *sp.* | 0 | 2 | 3 | 3 | 2 |
| *Acer* | *campestre* | | 1 | 3 | 3 | 2 |
| *Acer* | *japonicum* | | | | | |
| *Acer* | *monspessulanum* | | | | | |
| *Acer* | *negundo* | 1 | 1 | 2 | 3 | 1 |
| *Acer* | *platanoides* | 4 | 2 | 2 | 2 | 3 |
| *Acer* | *pseudoplatanus* | 3 | 2 | 2 | 2 | 1 |
| *Acer* | *rubrum* | | 1 | 1 | 2 | 3 |
| *Actinidia* | *spp.* | | | | | |
| *Aesculus* | *hippocastanum* | | 2 | 1 | 2 | 1 |
| *Ailanthus* | *altissima* | 1 | 2 | 1 | 3 | 3 |
| *Albizia* | *julibrissin* | 1 | 3 | | | |
| *Alnus* | *cordata* | 3 | 1 | 2 | 2 | 3 |
| *Alnus* | *glutinosa* | 3 | 1 | 3 | 2 | 3 |

*Fagus sylvatica*
*Cedrus atlantica*
*Cedrus libani*
*Fraxinus excelsior*
*Liriodendron tulipifera*
*Pinus pinea*
*Platanus x acerifolia*
*Tilia cordata*
*Tilia platyphyllos*
*Acer spp.*
*Acer saccharinum*
*Celtis australis*
*Celtis occidentalis*

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# List of suitable trees species for municipalities

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| | | Capacité d'élimination | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Espèce | Nom commun | O3 | NO2 | PM10 | CO2 | Stock carbone | Résilience au changement climatique | Atténuation des Ilots de chaleur urbain |
| *Acer campestre* | Érable champêtre | | | | | | | |
| *Acer monspessulanum* | Érable de Montpellier | | | | | | | |
| *Acer platanoides* | Érable plane | | | | | | | |
| *Acer pseudoplatanus* | Érable sycomore | | | | | | | |
| *Acer rubrum* | Érable rouge | | | | | | | |
| *Acer saccharinum* | Érable argenté | | | | | | | |
| *Acer x freemanii* | Érable de Freeman | | | | | | | |
| *Aesculus hippocastanum* | Marronnier d'Inde | | | | | | | |
| *Aesculus x carnea* | Marronnier à fleurs rouges | | | | | | | |
| *Alnus glutinosa* | Aulne glutineux | | | | | | | |
| *Brachychiton populneus* | Kurrajong | | | | | | | |
| *Carpinus betulus* | Charme commun | | | | | | | |
| *Castanea sativa* | Châtaignier commun | | | | | | | |
| *Casuarina cunninghamiana* | Pin australien | | | | | | | |

**Resilience is essential!**

| | | Biodiversité | | Caractéristiques de l'arbre | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Espèce | Nom commun | Nourriture pour oiseaux | Pollinisateur | Croissance | Racines déformantes | Hauteur (m) | Hauteur moyenne (m) | Pollens allergisants | Origine |
| *Acer campestre* | Érable champêtre | | | Lente | non | 10-15 | 13 | | Europe, Asie de l'Ouest |
| *Acer monspessulanum* | Érable de Montpellier | | | Lente | oui | <10 | 7 | | Europe, Asie de l'Ouest, Afrique du Nord |
| *Acer platanoides* | Érable plane | | | Modérée | oui | >20 | 25 | | Europe, Asie de l'ouest |
| *Acer pseudoplatanus* | Érable sycomore | | | Rapide | non | >20 | 25 | | Europe centrale |
| *Acer rubrum* | Érable rouge | | | Rapide | oui | >20 | 30 | | Amérique du Nord |
| *Acer saccharinum* | Érable argenté | | | Rapide | oui | >20 | 25 | | Amérique du Nord |
| *Acer x freemanii* | Érable de Freeman | | | Modérée | non | 15-20 | 18 | | Amérique du Nord |
| *Aesculus hippocastanum* | Marronnier d'Inde | | | Modérée | non | >20 | 25 | | Chine |
| *Aesculus x carnea* | Marronnier à fleurs rouges | | | Lente | oui | 15-20 | 18 | | Europe, Asie de l'Ouest |
| *Alnus glutinosa* | Aulne glutineux | | | Modérée | oui | 15-20 | 18 | | Europe, Asie de l'Ouest, Afrique du Nord |
| *Brachychiton populneus* | Kurrajong | | | Rapide | non | 10-20 | 15 | | Australie |
| *Carpinus betulus* | Charme commun | | | Lente | non | 15-20 | 18 | | Europe |
| *Castanea sativa* | Châtaignier commun | | | Rapide | non | >20 | 20 | | Europe, Asie de l'Ouest, Afrique du Nord |
| *Casuarina cunninghamiana* | Pin australien | | | Rapide | non | 15-35 | 18 | | Australie |

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# List of suitable trees species for municipalities

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| | | Conditions environnementales | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Espèce** | **Nom commun** | **Exposition** | **Tolérance à la sécheresse** | **Tolérance à la chaleur** | **Tolérance au gel** | **Tolérance aux sols humides** | **Tolérance au sel** | **pH** |
| *Acer campestre* | Érable champêtre | Soleil, mi-ombre | | | | | | 5.5-8.0 |
| *Acer monspessulanum* | Érable de Montpellier | Soleil, mi-ombre | | | | | | 5.5-7.5 |
| *Acer platanoides* | Érable plane | Soleil, mi-ombre | | | | | | 4.8-8.2 |
| *Acer pseudoplatanus* | Érable sycomore | Soleil, mi-ombre | | | | | | 5.5-8.2 |
| *Acer rubrum* | Érable rouge | Soleil, mi-ombre | | | | | | 4.7-7.3 |
| *Acer saccharinum* | Érable argenté | Soleil, mi-ombre | | | | | | 4.0-7.3 |
| *Acer x freemanii* | Érable de Freeman | Soleil, mi-ombre | | | | | | 5.5-7.5 |
| *Aesculus hippocastanum* | Marronnier d'Inde | Soleil, mi-ombre | | | | | | 5.5-7.5 |
| *Aesculus x carnea* | Marronnier à fleurs rouges | Soleil, mi-ombre | | | | | | 5.5-8.2 |
| *Alnus glutinosa* | Aulne glutineux | Soleil, mi-ombre | | | | | | 4.4-7.5 |
| *Brachychiton populneus* | Kurrajong | Soleil | | | | | | 5.5-6.5 |
| *Carpinus betulus* | Charme commun | Soleil, Ombre | | | | | | 5.0-8.0 |
| *Castanea sativa* | Châtaignier commun | Soleil, Ombre | | | | | | 4.0-7.5 |
| *Casuarina cunninghamiana* | Pin australien | Soleil | | | | | | 5.5-7.0 |

***"The right tree in the right place"***

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# Greening strategies

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Urban green infrastructure can bring about positive health outcomes through **reducing the public's exposure to air pollution & mitigating UHI**.

Guide for Cities on Health-Oriented Planning and Use of Urban Green Spaces


**Action:** Using greenery to improve air quality along roads

**Action:** Using greenery to invite people to areas with better air quality

**Action:** Installing green roofs and green walls for air pollutant removal

**Action:** Introducing hedges around child care facilities and play spaces to filter pollutants

**Action:** Developing larger green spaces for air pollutant deposition

**Action:** Developing green spaces to support ventilation

# Recommendations

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Urban vegetation (cost-effective & nature-based approach) aids in **meeting clean air standards.**

Plant species adapted to **local conditions** (& multiple stressors) should be selected.

**Hedges**: important sources of animal & plant biodiversity.

**Greening of parking lots & Greening around buildings.**

*Rue Trachel, Nice*

Trees have a capacity to eliminate air pollutants.

Vegetation at the tree base: each tree base can support up to 20 plant species & capture vehicle emissions.

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# Recommendations

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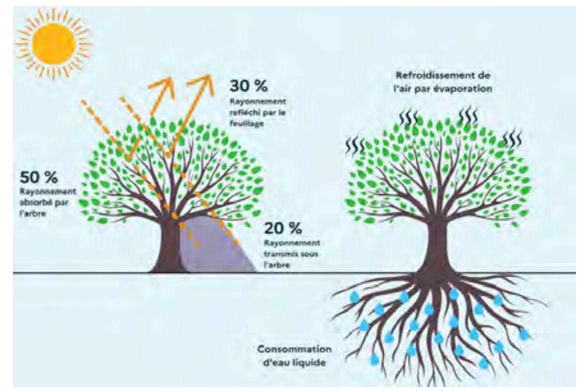
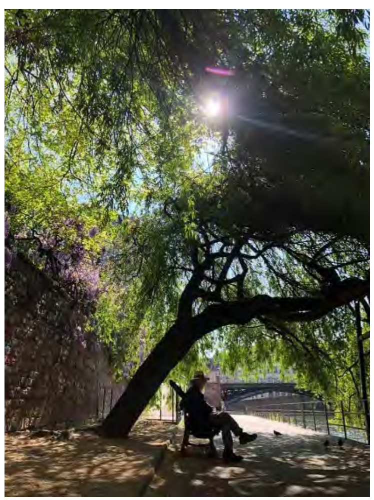
**Approach 3-30-300** - Everyone must be able to see > 3 trees from home; move to quarter with > 30% tree cover; and have access to a green space <300 m from home.



**Urban park**

Air temperature difference: 3-5°C.

The **creation of a park** in the city center to replace buildings: reduction in temp. surrounding air by 2-6°C.

Regular access to water.

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# Recommendations

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**Trees show higher $O_3$ removal capacity** (3.4 g $m^{-2}$ $year^{-1}$ on av.) **than green roofs** (2.9 g $m^{-2}$ $year^{-1}$) with lower installation & maintenance costs (± 10 times).

**Green roofs** can be used to **supplement the use** of urban trees in densely populated cities.

**Green roofs**: during a sunny day of 26°C, dark roof ~ 80°C, white roof ~ 45°C & green roof ~ 29°C.

**Green walls**: lowering the temperature of the building & improving its energy behavior.

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# Conclusions

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**Plane trees** - Among the most effective species for mitigating UHIs and improving air quality.

By planting **400 “effective” trees can eliminate annually:**

> 3 tons $O_3$

~ 4 t de $NO_2$

~ 500 kg $PM_{2.5}$ & $PM_{10}$

~ 33 tons $CO_2$

Planting trees cannot counterbalance all anthropogenic pollution, but **choosing the right species** can maximize the benefits of such valuable air quality strategy.


Aix-en-Prov
Plan vert des écoles pour que les élèves ne voient plus rouge

**Private gardens & co-ownerships** = good vector for greening.
~ 80-90% of a city’s tree heritage

**Communication with population & in schools -** Key user & essential actor. Guidelines, e.g., right plant species to plant at home.

**Knowledge transfer to city planners**

Findings are summarized as guidelines of **good practices** with a set of recommendations to create cities-for-healthy-people (**local urban masterplan**).

# Perspectives: Tree detection by satellites in public and private areas

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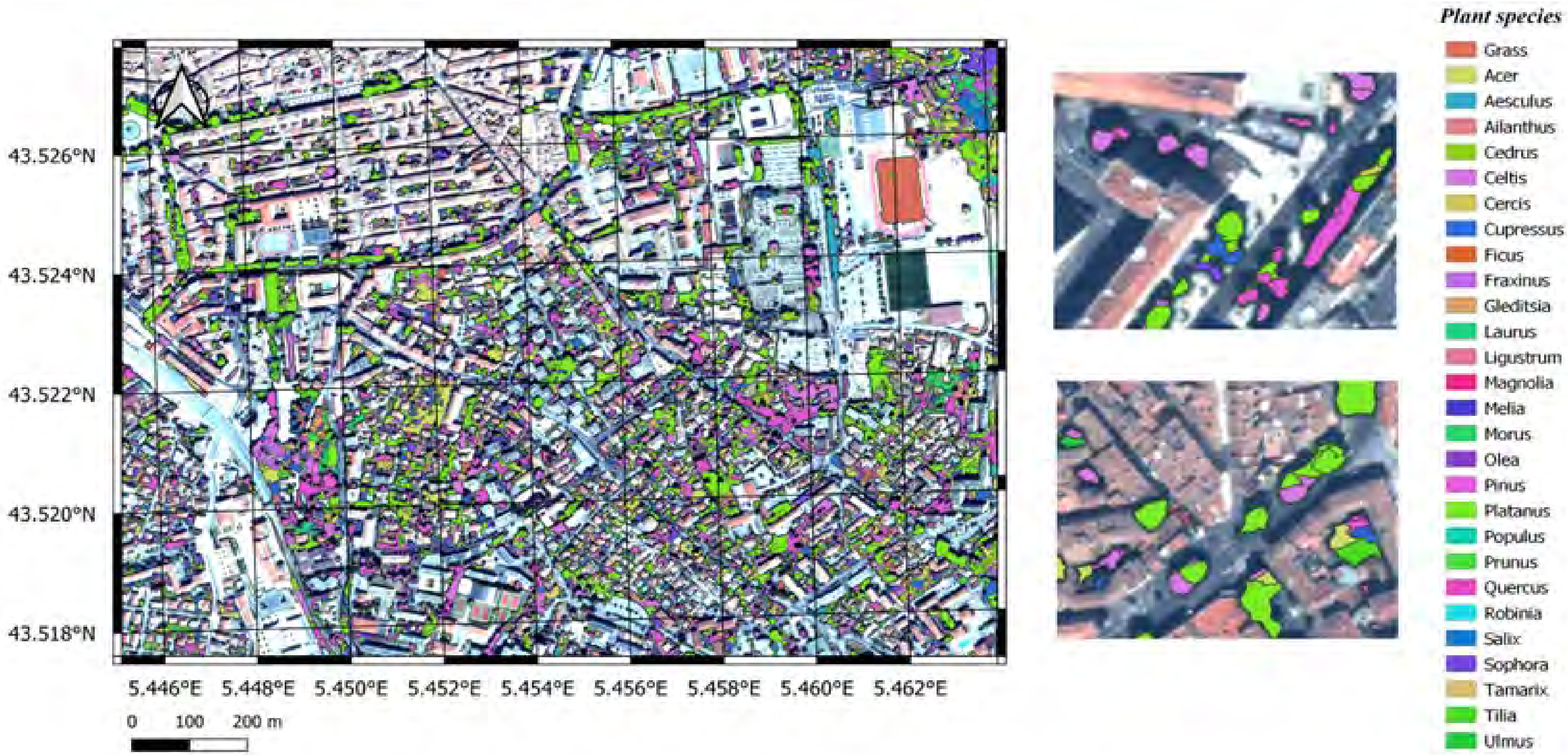
**The ability of urban greenery to reduce air pollutants varies depends on fragmentation, green cover and plant species**

## Mapping of canopy cover in Aix-en-Provence & Florence




=> **Aix & Florence**: 22 & 20 dominant species identified & classified (accuracy: 84% & 83%).

=> **Efficient tool** to support appropriate nature planning and air quality assessment in cities.

# Example of Greening Strategies

## Planting & maintenance

➡ Importance of peri-urban forest in densely populated cities





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