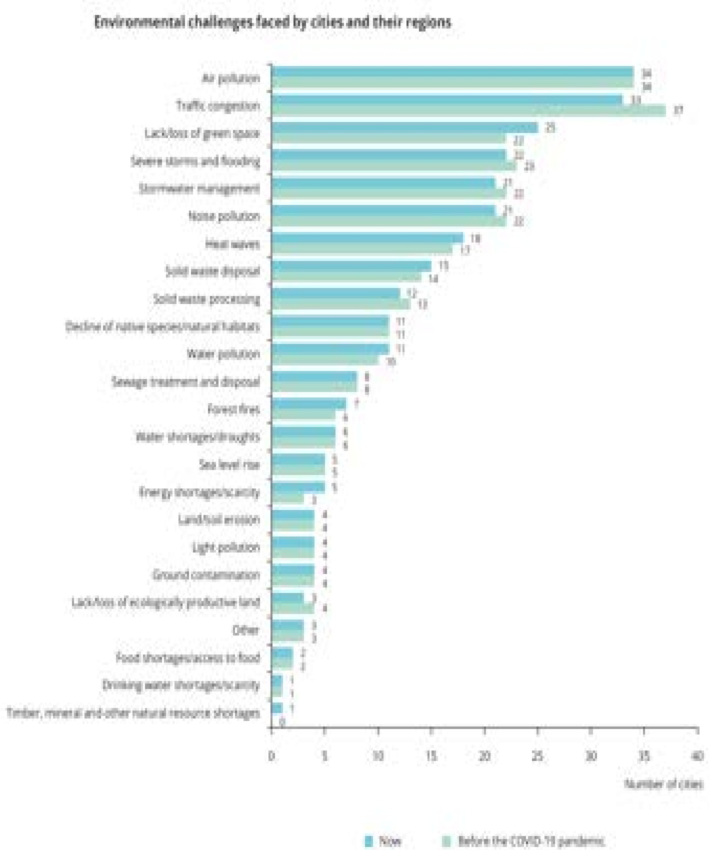
Urban forests as a tool to improve air quality and mitigate heat islands

P. Sicard, ARGANS (France)

Context & Background

LIFE19 ENV/FR/00086

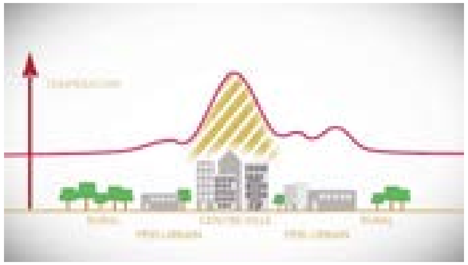
Cities are facing a wide variety of **environmental challenges**: air pollution, climate change, stormwater, loss of bioviversity, noise & light pollution, etc.



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.

Context & Background

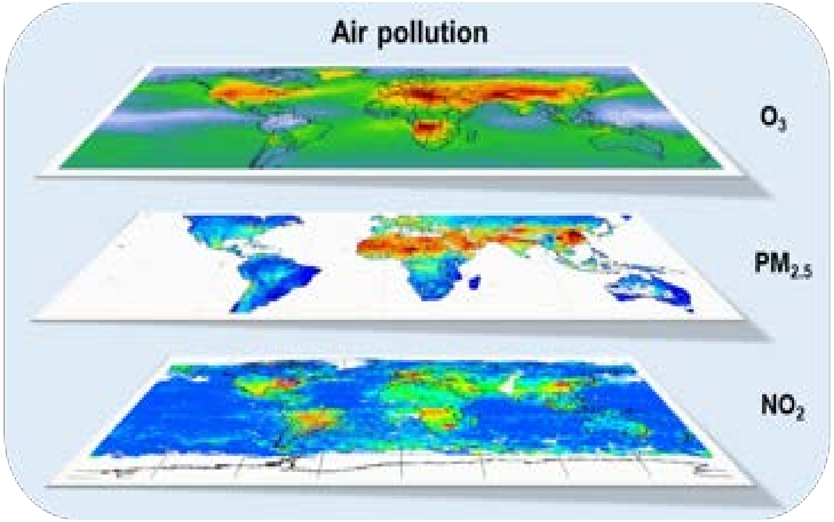
AIRFRESH

LIFE19 ENV/FR/00086

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

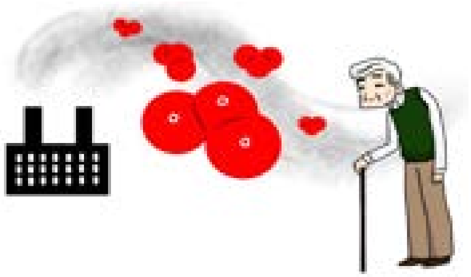
Outdoor air pollution - Major public health issue, leading to **4.14 million** premature deaths worldwide in 2019 (GBD, 2019).

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).



Vehicle electrification in cities

AIRFRESH

LIFE19 ENV/FR/00086

Calatayud et al., 2023

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).

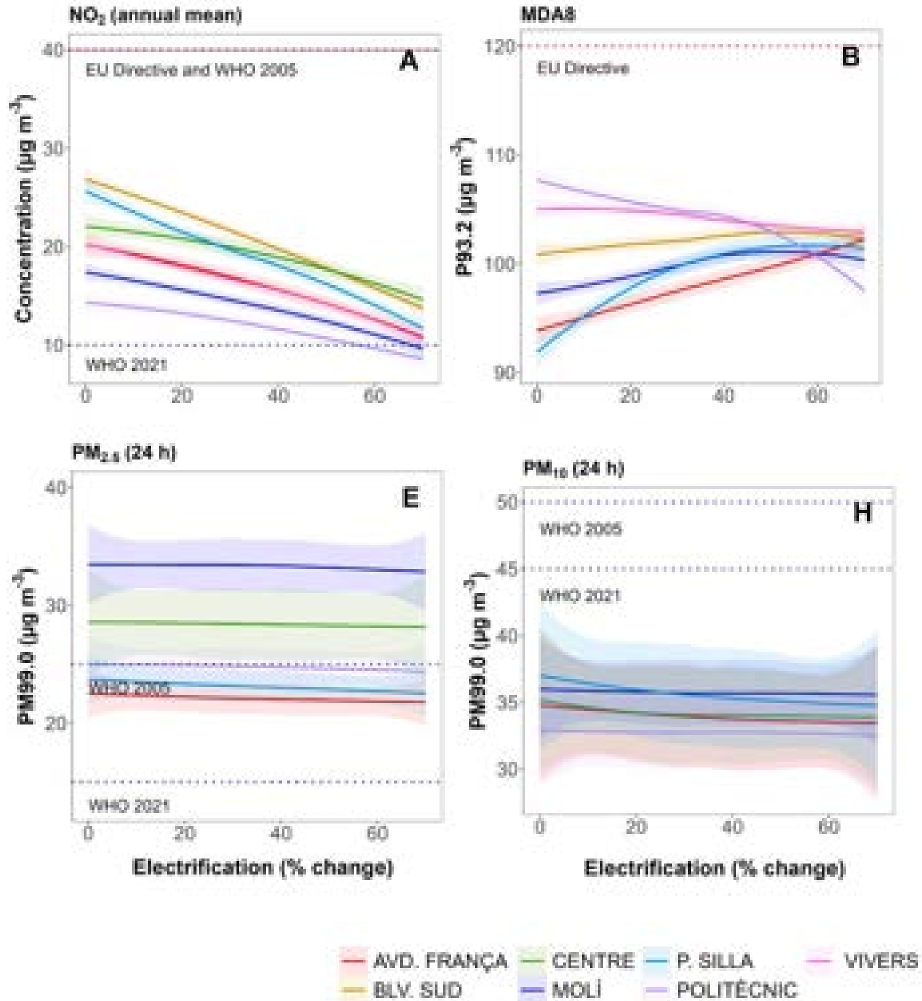
Model was trained with 10 years of AQ & meteo data.

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 ?

AIRFRESH

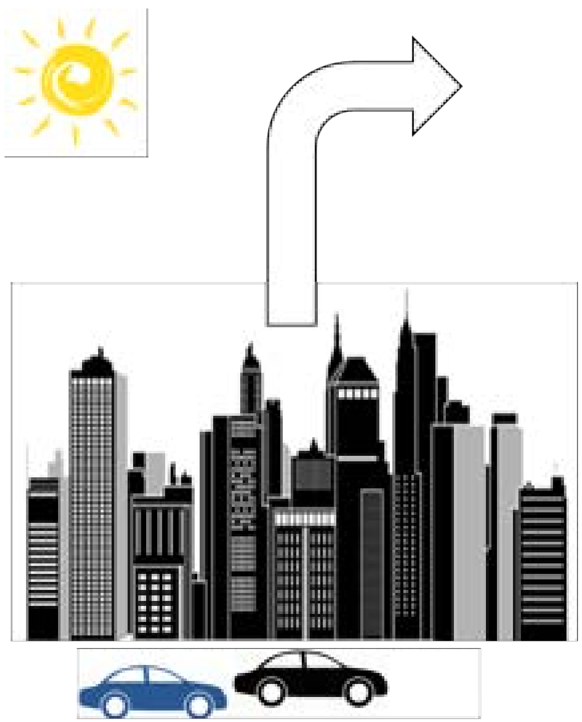
Benefits of urban trees/shrubs

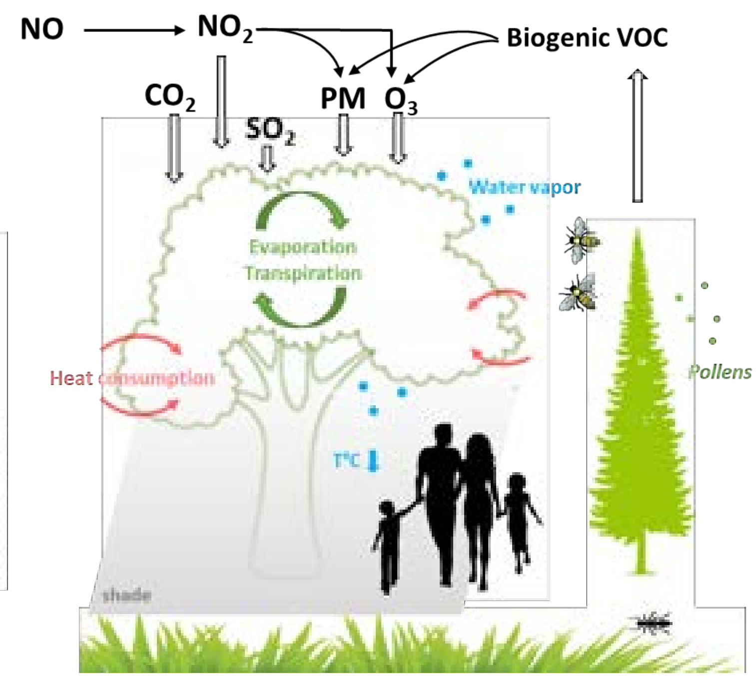
LIFE19 ENV/FR/00086

The urban trees/shrubs can:

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

etc…



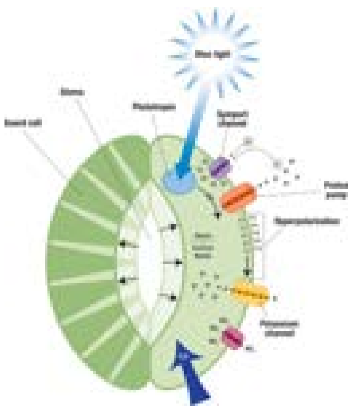


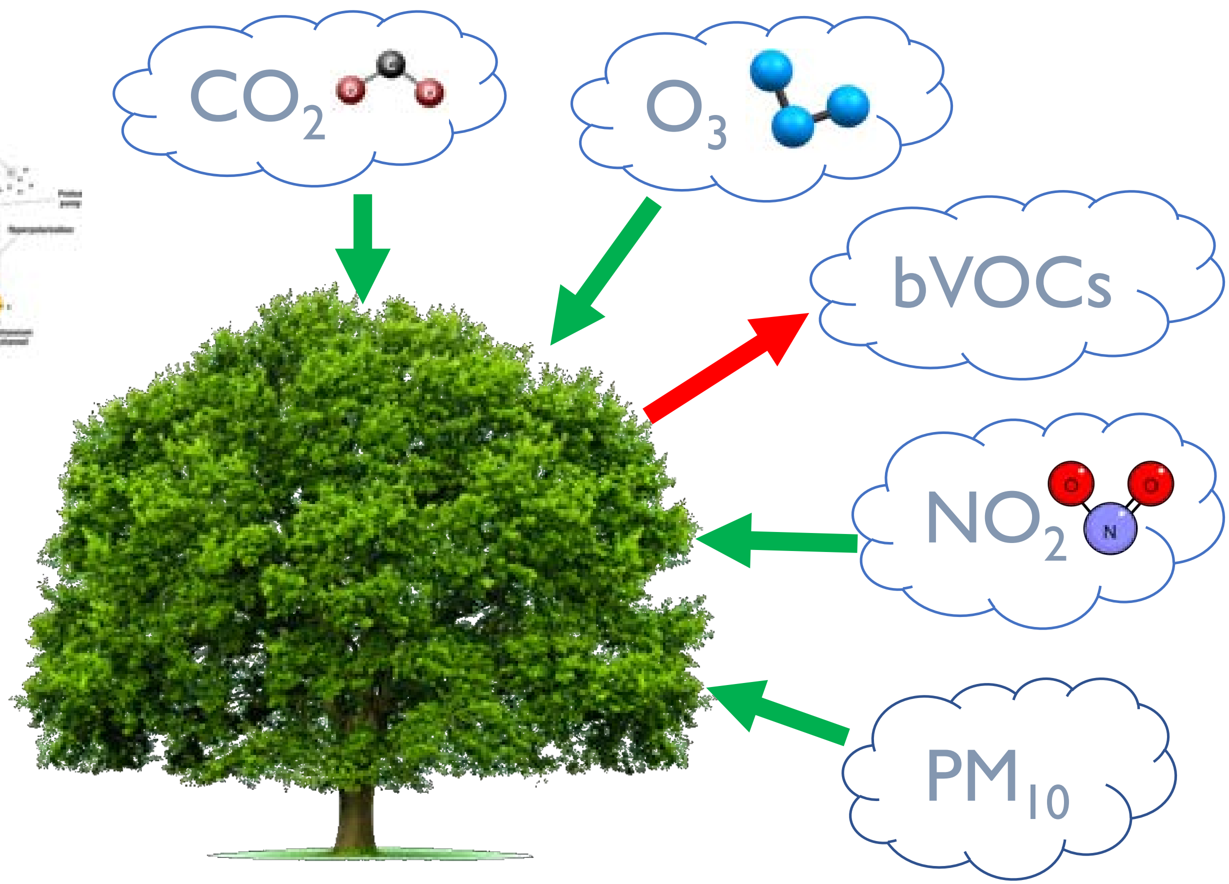
AIRFRESH

Benefits of urban trees/shrubs

LIFE19 ENV/FR/00086

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 ?

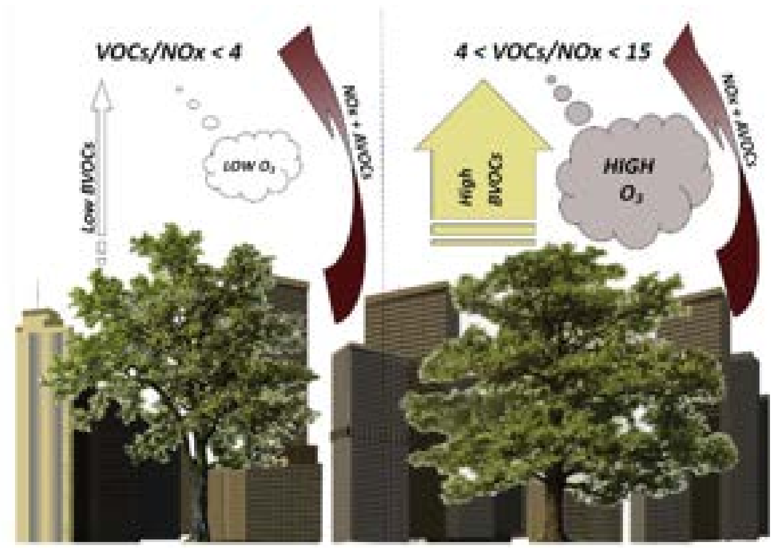
LIFE19 ENV/FR/00086

AIRFRESH

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

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

ELSEVIER

Original article

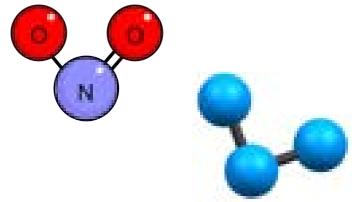
FlorTree: A unifying modelling framework for estimating the species-specific pollution removal by individual trees and shrubs

Jacopo Manzini, Yasutomo Hoshika, Elisa Carrari, Pierre Sicard, Makoto Watanabe, Ryoji Tanaka, Ovidiu Badea, Francesco Paolo Nicese, Francesco Ferrini, Elena Paoletti

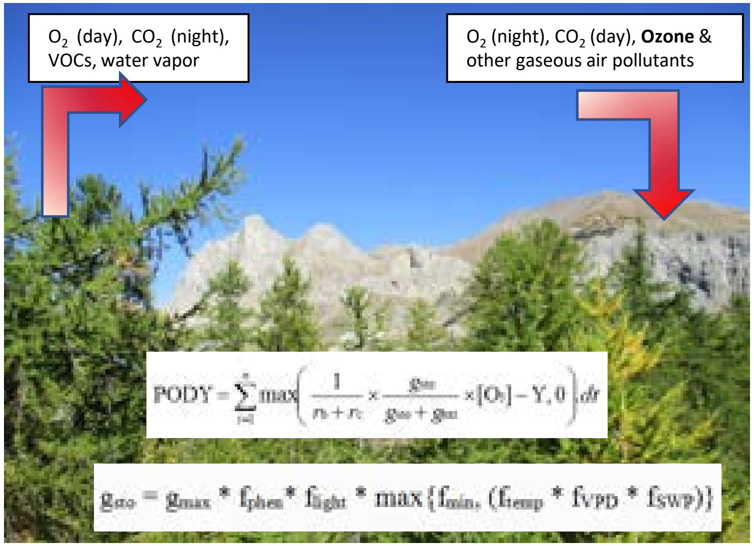
For **220 species (trees and shrubs)**:

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

Quantification & mapping of benefits



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

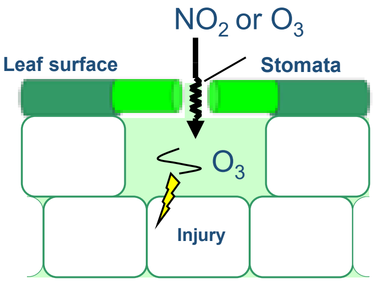


Deposition $Q = V_d \times C \times LAI \times T$

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

Removal capacity of urban tree species

AIRFRESH

LIFE19 ENV/FR/00086

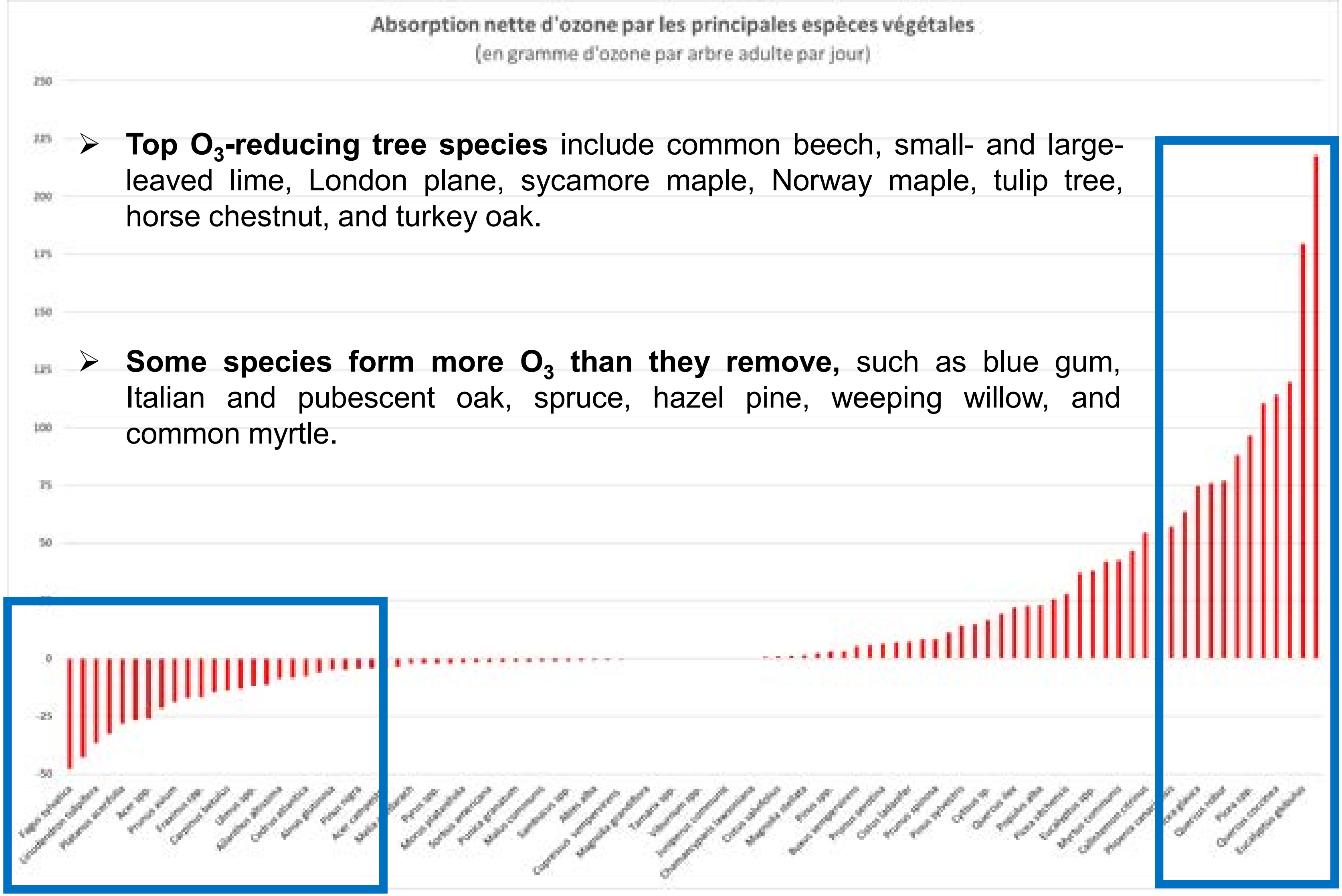
Genus	Species	Net O3 uptake	NO2 uptake	PM10 deposition	CO2 seq,
		g tree-1day-1	g tree-1day-1	g tree-1day-1	t tree-1year-1
Abies	alba	3,82	4,55	2,04	0,0421
Acacia	dealbata	1,16	0,93	0,1	0,0393
Acer	campestre	2,92	2,21	0,37	0,0623
Acer	japonicum	0,4	0,33	0,06	0,0092
Acer	monspessulanun	1,26	1,14	0,2	0,0623
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

AIRFRESH

Ozone-reducing urban plants: Choose carefully

LIFE19 ENV/FR/00086



- **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.

List of suitable trees species for municipalities

AIRFRESH

LIFE19 ENV/FR/00086

<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

AIRFRESH

List of suitable trees species for municipalities

LIFE19 ENV/FR/00086

Espèce	Nom commun	Capacité d'élimination 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!

Espèce	Nom commun	Biodiversité: Nourriture pour oiseaux	Pollinisateur	Caractéristiques de l'arbre: 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

AIRFRESH

List of suitable trees species for municipalities

LIFE19 ENV/FR/00086

		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"

AIRFRESH

LIFE19 ENV/FR/00086

Greening strategies

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

LIFE19 ENV/FR/00086

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.

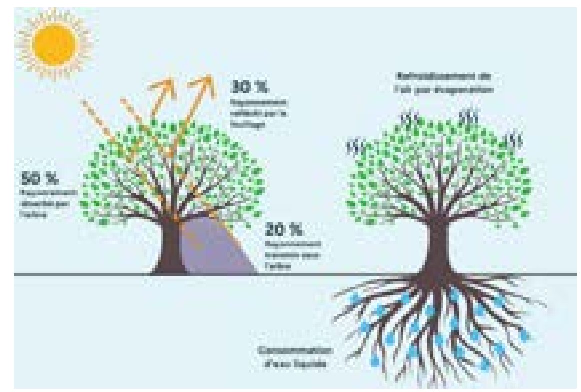
Vegetation at the tree base: each tree base can support up to 20 plant species & capture vehicle emissions.

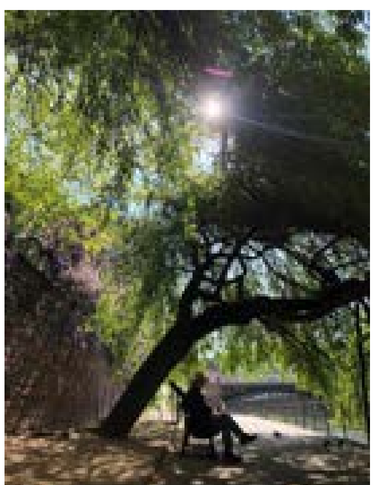
AIRFRESH

LIFE19 ENV/FR/00086

Recommendations

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.

LIFE19 ENV/FR/00086

Recommendations

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.

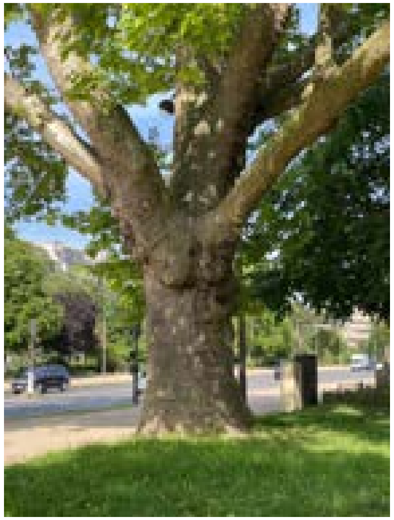
Green roofs: during a sunny day of 26°C, dark roof ~ 80°C, white roof ~ 45°C & green roof ~ 29°C.

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

AIRFRESH

Conclusions

LIFE19 ENV/FR/00086



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.

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

LIFE19 ENV/FR/00086

AIRFRESH

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

LIFE19 ENV/FR/00086

➡ Importance of peri-urban forest in densely populated cities