CLAIRO CONFERENCE: LIVABLE AND CLIMATE RESILIENT EUROPEAN CITIES

How to plant urban greenery for maximum pollutant capture

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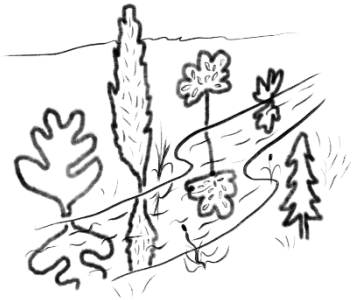
How does urban greenery mitigate air pollution?

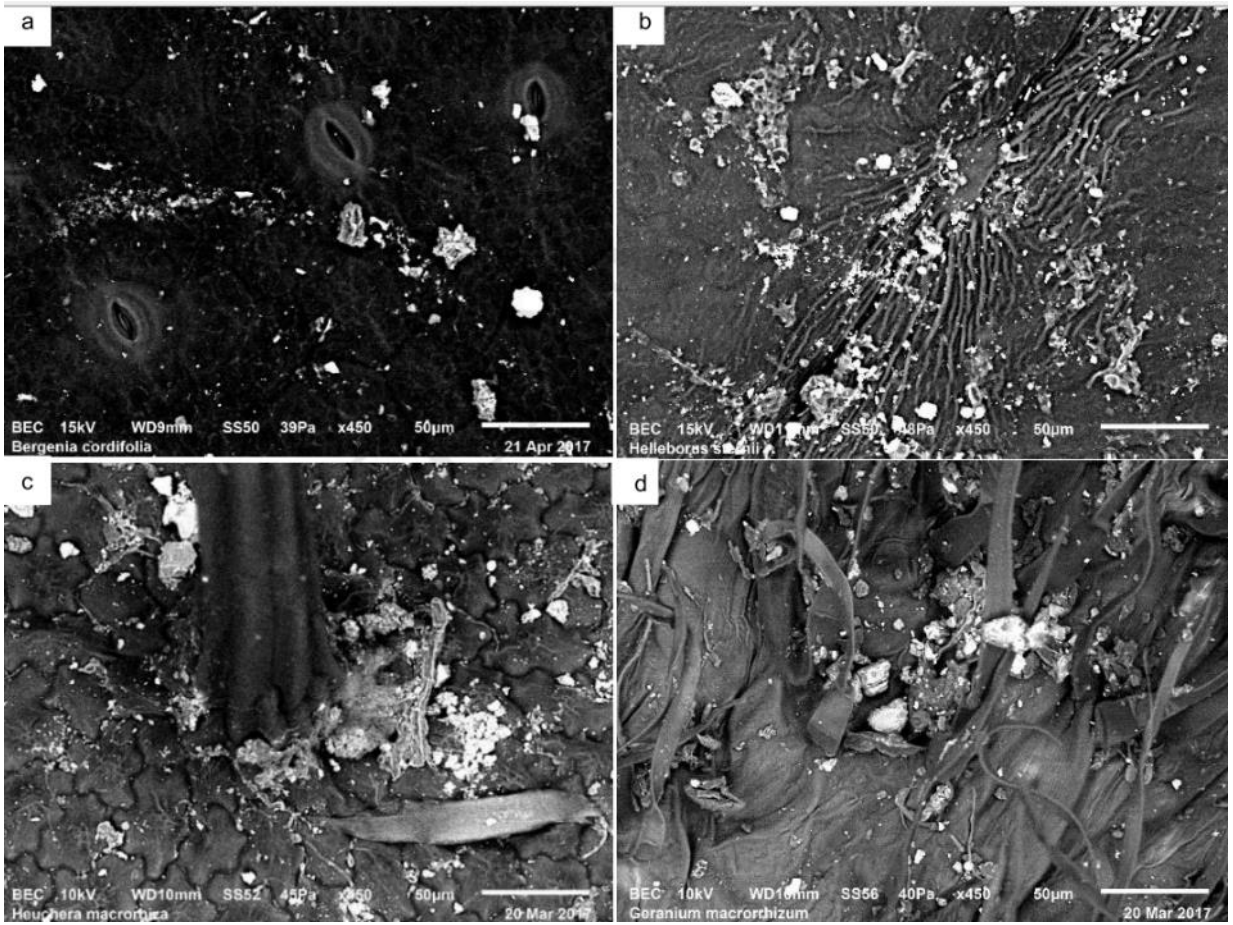
DIRECTLY → removal and deposition of the pollutants → Removal of particulate matter by absorbance or adherence to the leaf surface



Removal of gases through the leaf stomata

INDIRECTLY → Providing shade and increasing transpiration → Reduction of temperature near the surface (maximum in summer) → Reduction of photochemical reactions leading to ozone formation

Capture of suspended particles on the leaf surface

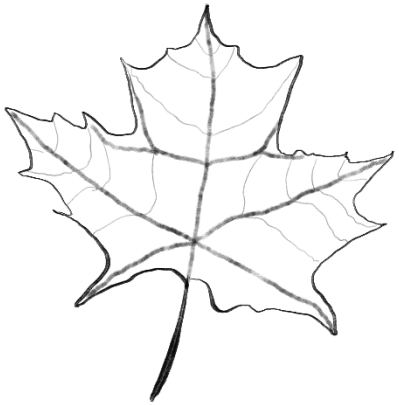


Demonstration of the capture of particles matters (white lumps) on the surface of the leaf blade. Scanned by electron microscopy (Weerakkody, et al. 2018).

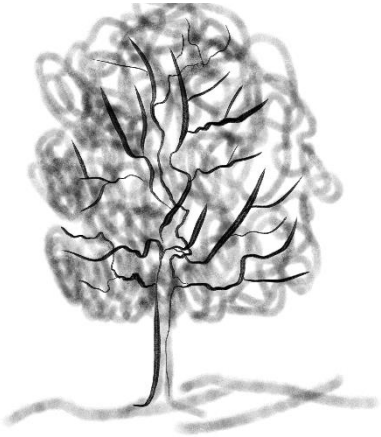
SOURCE: Weerakkody, et al. 2018.

What factors affect the efficiency of air pollution removal?

1. Microscopic
shape and layout of leaves (needles)
roughness of their surface



2. Macroscopic
overall structure of the stand
height, canopy density and spatial arrangement of the branches



SOURCE: Weerakkody, et al. 2018.

Leaf surface, shape and margins

- needles of **coniferous species** appear to be **very effective in removal of particle matters**, providing higher deposition rates than the leaf apparatus of broad-leaved species

- But **broadleaf tree species remove more O_3 than conifers**. Evergreen broadleaf tree species remove more O_3 than deciduous broadleaf tree species.

SOURCE: Sicard et al. 2020

Leaf surface, shape and margins

- complex (lobed, octopus) leaf shapes show a greater potential for capture than simple (elliptical, round) leaf shapes
- rough, hairy or glandular leaf surfaces are more effective for capture than smooth surfaces with a more pronounced cuticle
- **presence of trichomes, epicuticular wax**, or pronounced, profiled veins increases the pollutants capture

trichomes on the leaf surface

stomata on the leaf surface

SOURCE: Botanická fotografie, 2020.

Stand structure and density

- properties of plant organs and their arrangement, but also the overall involvement and density of vegetation, height, crown shape and spatial arrangement of branching
- the larger the green surface area, the higher the pollutant capture
- **> wide, high, multi-layer dense vegetation barriers in the direction of the prevailing airflow**

Different canopy density based on hemispherical photographs

Pollution tolerance

- the choice of species should further reflect the topographic, pedological, hydrological and climatic conditions at the site
- sensitivity of specific species to air pollution in a given place, air pollution from monitoring
- in the case of higher concentrations of tropospheric ozone, deciduous trees are generally more sensitive than coniferous trees
- salinization of soils during road improvements (pine)

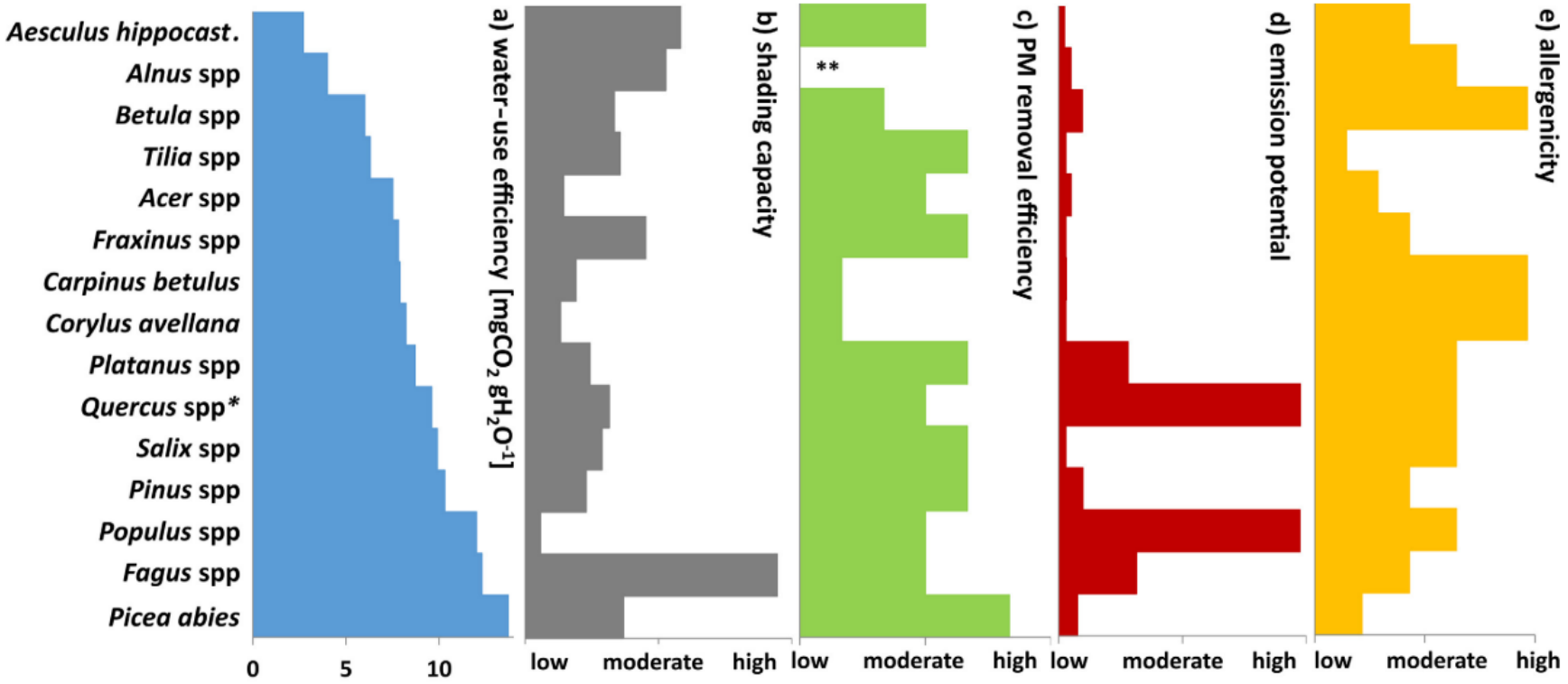
Damage caused by ground-level ozone on elderberry blades (Novotný et al. 2009)

SOURCE: Novotný et al. 2009

Vegetation species

Selected tree species with higher resistance to air pollution and more efficient capture of pollutants

The entire database is available at: https://clairo.ostrava.cz/know-how/



* Only deciduous oaks considered, ** no data available

➢ **Combination of more species both deciduous and coniferous trees and shrubs in assemblages compatible in their ecological demands**

Source: Grote et al. 2016

Composition

- taking into account the surrounding buildings, configuration and height of buildings

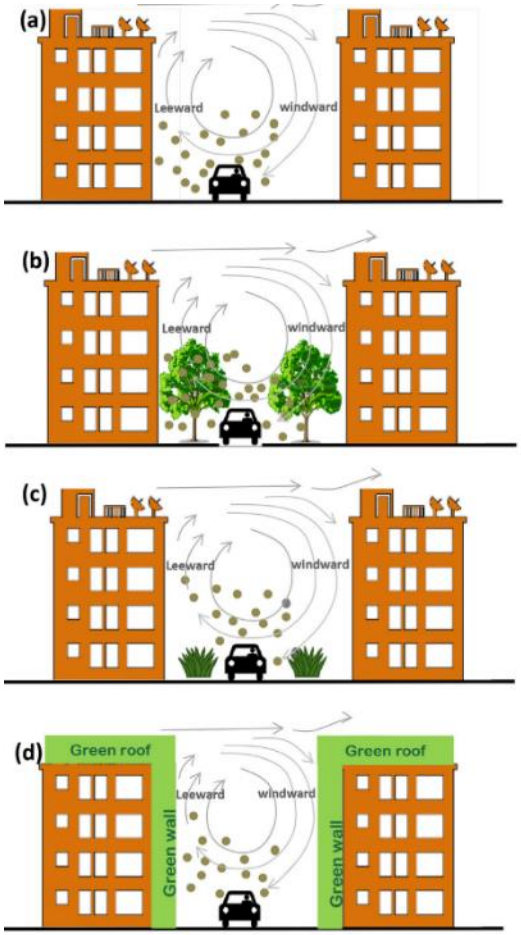
- In open areas - combination of several canopy levels supplemented by shrub layers in the undergrowth

- In street canyons –

  - **Deep canyons - only green walls** are recommended preventing negative effects

  - Mid-depth street canyons - low-level vegetation (**shrubs and low hedges**)

  - In shallow street canyon - **small and open-crowned trees** may be additionally planted on the windward side of the canyon, spaced broadly apart



Pollutant flow and dispersion in a street canyon: (a) street canyon without vegetation, (b) street canyon with trees, (c) street canyon with hedges, and (d) street canyon with green roofs and walls (Abhijith et al. 2017).

SOURCE: Abhijith et al. 2017, Barwise and Kumar 2020

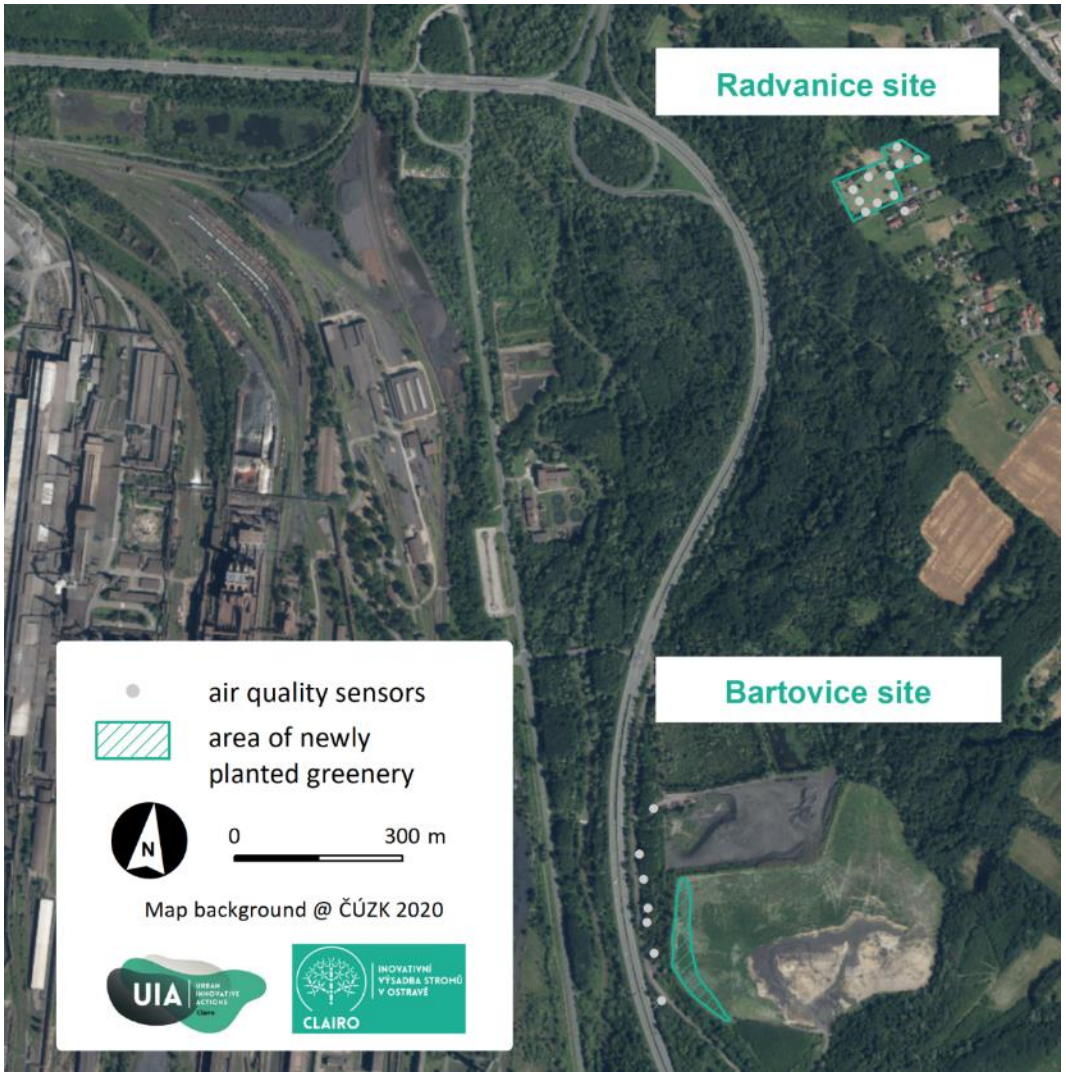
A LIVING LAB

OSTRAVA BARTOVICE, RADVANICE

CASE STUDY
Ostrava – Radvanice, Bartovice

- The proximity of smelter factory Liberty Ostrava, a.s. (about 0.5 km west)

- The average annual concentration of PM_{10} of 44 µg/m^3 (110% of the limit) was measured at the nearby station of the Health Institute in 2018, and the station thus ranked 1st in the list of stations exceeding the valid limit (CHMI 2019).



SOURCE: ČHMÚ, 2019

AIMS

1) Based on evaluation of air concentration and soil properties propose and plant new greenery to reduce local air pollution

2) To model air pollution removal by existing and newly planted greenery and compare their efficiency

EXISTING VEGETATION

Ostrava – Radvanice

- 1.0 ha
- solitary trees (Juglans regia)
- at the edges, the existing forest stands (Populus tremula)
- represented by the herbaceous floor





Ostrava – Bartovice

- 0.7 ha
- industrial waste landfill
- no vegetation elements





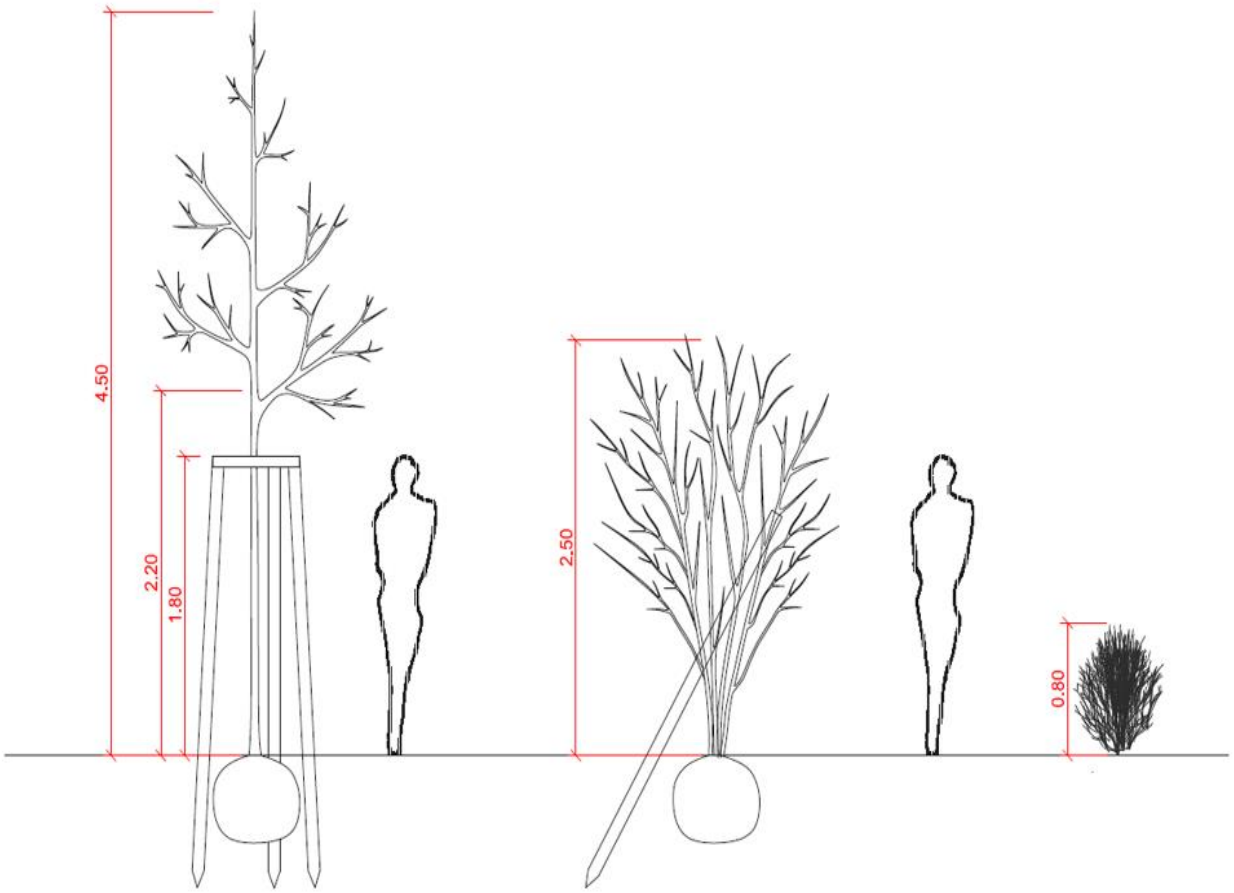
PLANTING OF NEW GREENERY

Planting of greenery - composition

Upper canopy

Lower canopy

Shrubs



Planting of greenery – species selection

Upper canopy

Abies alba, Pynus sylvestris, Larix decidua, Quercus cerris, Tilia platyphyllos

Lower canopy

Betula pendula, Prunus mahaleb, Carpinus betulus, Crataegus monogyna, Sorbus aria

Shrubs

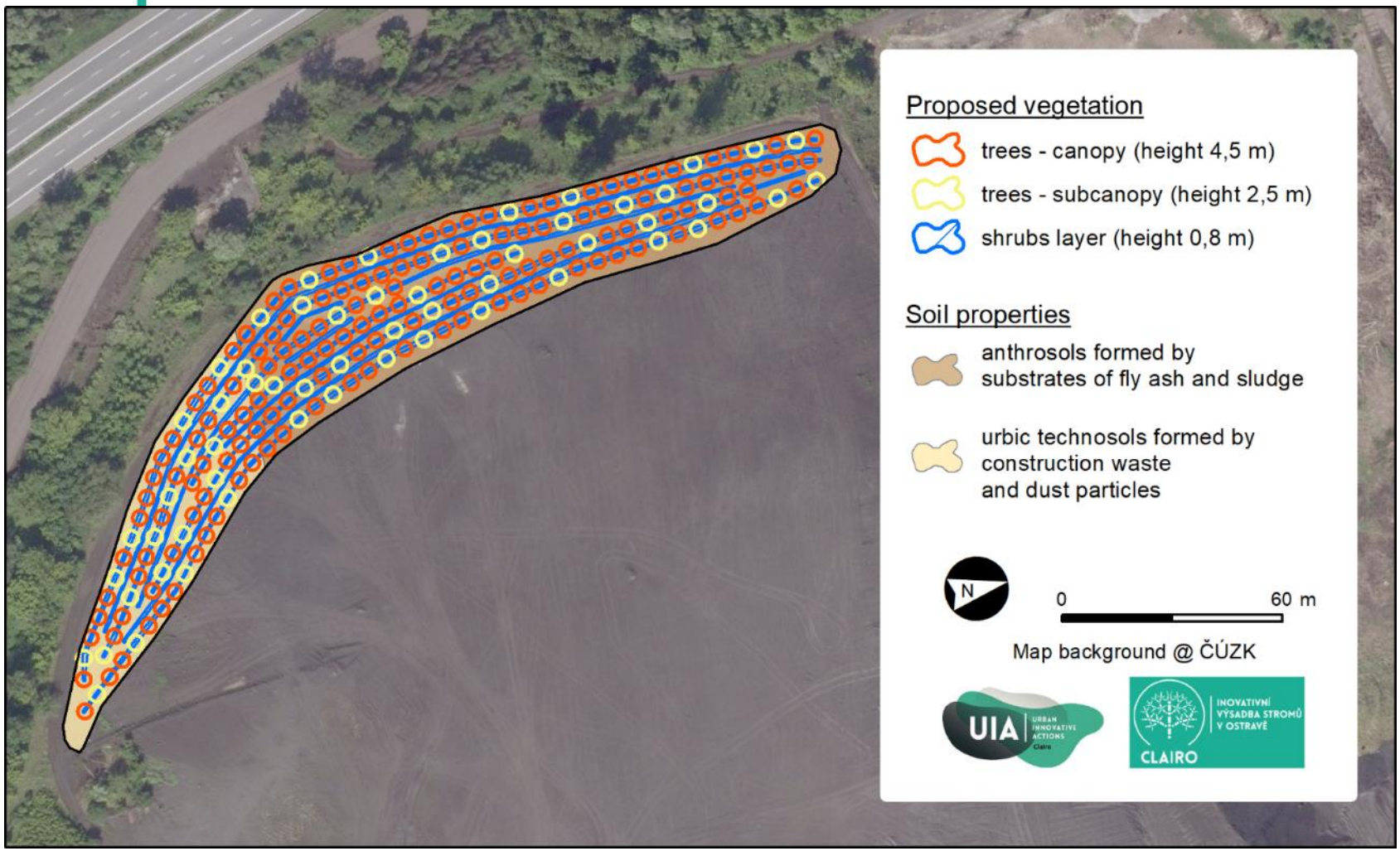
Ribes alpinum, Sambucus racemosa, Ligustrum vulgare, Lonicera xylosteum, Euonymus europaeus, Viburnum lantana, Lonicera xylosteum, Cornus sanguinea

PHOTOGRAPHS: Wikipedia commons, 2020.

Planting greenery proposal - Radvanice

Planting greenery - Radvanice

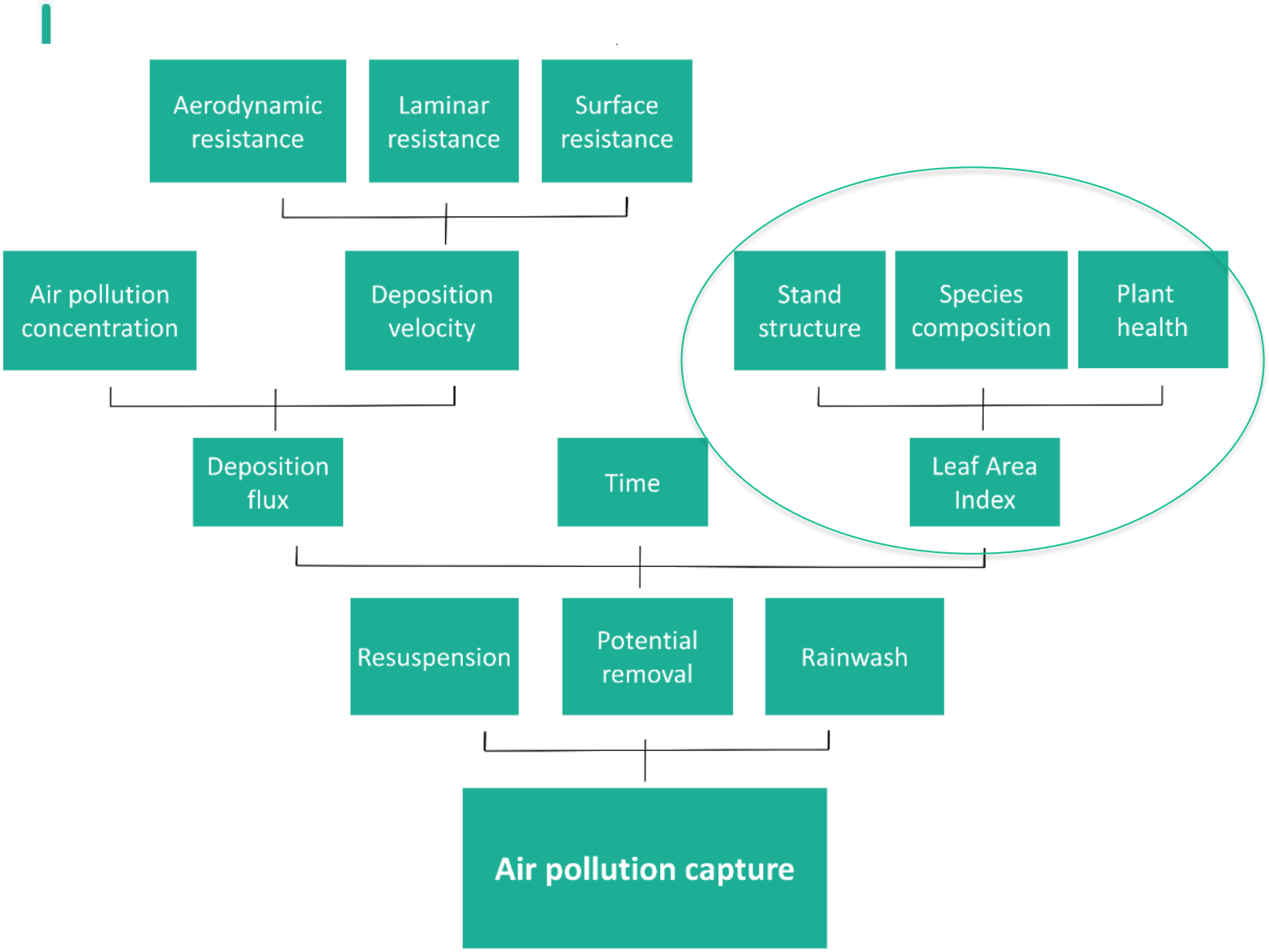
Planting greenery proposal - Bartovice



Planting greenery- Bartovice

MODELLING AIR POLLUTION CAPTURE

Modelling air pollution capture



Field inventory and hemispherical photography

1) species composition
2) canopy height
3) canopy density
4) average diameter of crowns
5) diameter at breast height
6) health condition

LEAF AREA INDEX

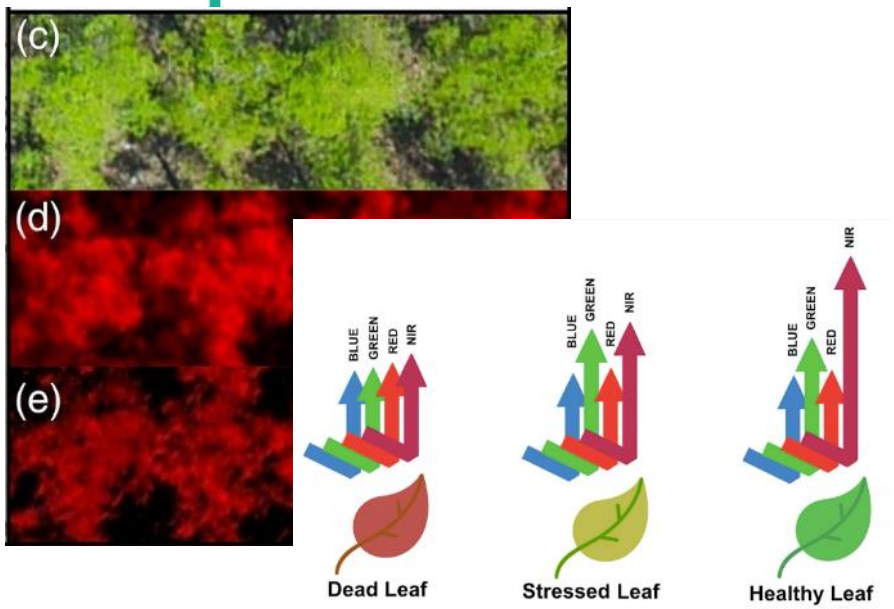
Source: Nowak 1994; Zapletal 2001; Zapletal et al. 2011; Janhäll 2015

Remote sensing approach

- Multispectral camera onboad Unmanned aerial vehicles

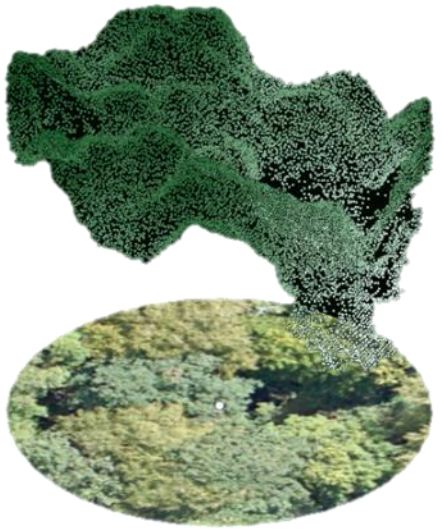
Remote sensing approach

1) Spectral reflectance



1) spectral vegetation indices (NDVI, EVI …)
2) vegetation classification

2) Photogrammetry



1) canopy height
2) canopy density

LEAF AREA INDEX

Modeling capture of PM_{10}, O_3 a NO_x

$$Q = LAI \times F \times T$$

- Q is amount of matter captured by vegetation (g)
- F deposition flux (g m^2 s^{-1})
- LAI is leaf area index (m^2 m^{-2})
- T is time (s)

$$F = V_d(z) \times c(z)$$

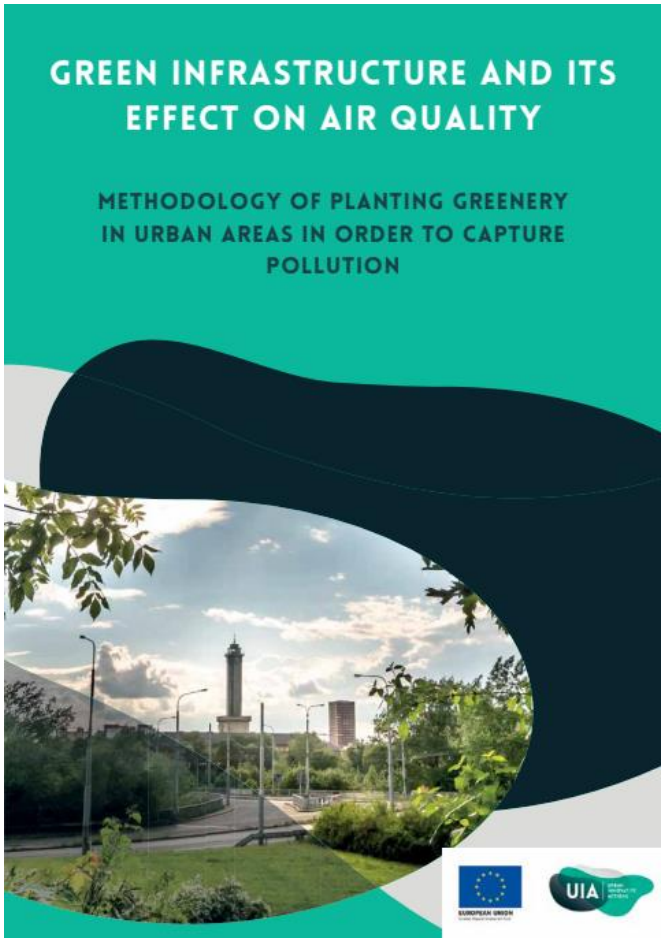
- V_d is deposition velocity (m s^{-1})
- $c(z)$ is concentration of mearused air pollution matter (g m^{-3})

The deposition flux of gases and particles (F) on the surface of receptors is determined on the one hand by their **concentrations in the air** and turbulent transfer processes in the boundary layer of the atmosphere, on the other hand by their chemical and physical properties and surface ability to capture or absorb these gases and particles.

Source: Nowak 1994; Zapletal 2001; Zapletal et al. 2011; Janhäll 2015

Modeling capture of PM_{10}, O_3 a NO_x

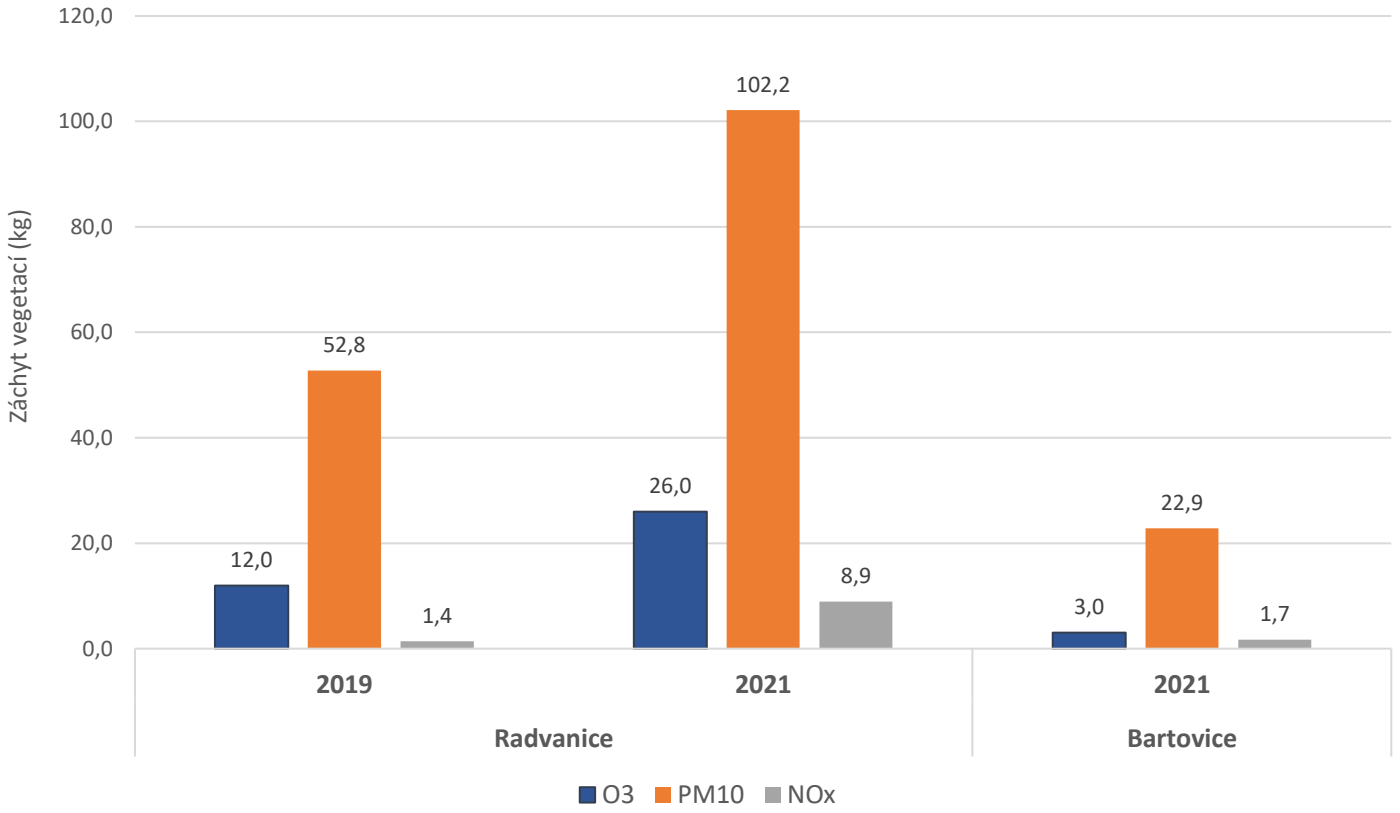
https://clairo.ostrava.cz/documents/



Source: Nowak 1994; Zapletal 2001; Zapletal et al. 2011; Janhäll 2015

RESULTS

Air pollution removal – modelled results



Comparison of O_3, PM_{10} and NOx (kg) vegetation in the localities of Radvanice (1 ha) and Bartovice (0.7 ha). Modeled for a period of two months (at the end of the growing season) in 2019 (before planting) and 2021 (after planting).

Air pollution removal – modelled results

			Study area (m^2)	Total leaf area (m^2)	Removal rate (g/m^2)	Total removal (kg)
Radvanice	2019	O_3	10418,1	14869	0,8	11,97
		PM_{10}		14869	3,5	52,75
		NO_x		14869	0,1	1,42
	2021	O_3		32240	**0,8**	25,96
		PM_{10}		32240	**3,1**	102,15
		NO_x		32240	**0,2**	8,9
Bartovice	2019	O_3	7255,8	-	-	-
		PM_{10}		-	-	-
		NO_x		-	-	-
	2021	O_3		7165	**0,4**	3,03
		PM_{10}		7165	**3,2**	22,85
		NO_x		7165	**0,2**	1,68

Values of the total area and green matter, removal rate and and total amount of captured particles PM_{10} and gases O_3 and NO_x in the area of the modeled areas. Removal is considered for the period September and October 2019 (before planting) and 2021 (after planting).

Modelling PM_{10} removal – Radvanice

PM_{10} (g) capture in the state before planting (left) and after planting of the proposed vegetation (right) in the 1 x 1 m network at the Radvanice locality. Modeled for a period of two months (at the end of the growing season).

Modelling PM_{10} removal – Barotivce

PM_{10} (g) capture in the state after planting the proposed vegetation in the 1 x 1 m network at the Bartovice locality. Modeled for a period of two months (at the end of the growing season). In the case of pre-planting conditions, due to the absence of any existing greenery, it does not assume significant pollution.

CONCLUSION

Conclusion

1. **Urban greenery contributes to the improvement of the air quality** in the urban environment by capturing suspended particles and other pollutants on the surface of leaves and needles.

2. **Especially trees have a large role in improving urban air quality**, among other mechanisms, through dry deposition.

3. Important aspects of quality and efficient green infrastructure are both the **properties of plant organs** and their arrangement, as well as the **overall structure of the stand**, its height and canopy density.

4. The **high, dense-canopy and multi-layer** stands combining **broadleaves** and **coniferous tree species** enable the highest capture. Denser canopies and **canopy stripes** experience more total deposition than homogeneous canopies.

Conclusion

4. When planting green infrastructure in industrial areas with increased concentrations of air pollutants, it is necessary to give priority to species with **increased resistance to air and soil pollution**. Especially at high concentrations of ground-level ozone, it is necessary to select species resistant to this type of pollution.

5. After the planting of the proposed vegetation, based on the modeled outputs, a significant **increase in the capture of pollutants can be expected, more than double the current state**, and thus an overall improvement in the state of the air in the given locality

6. The presented methodology enables the quantification of the capture of particles, ground-level ozone and nitrogen oxides by urban greenery on a local scale, taking into account the actual structural properties of local vegetation

THANKS FOR YOUR ATTENTION

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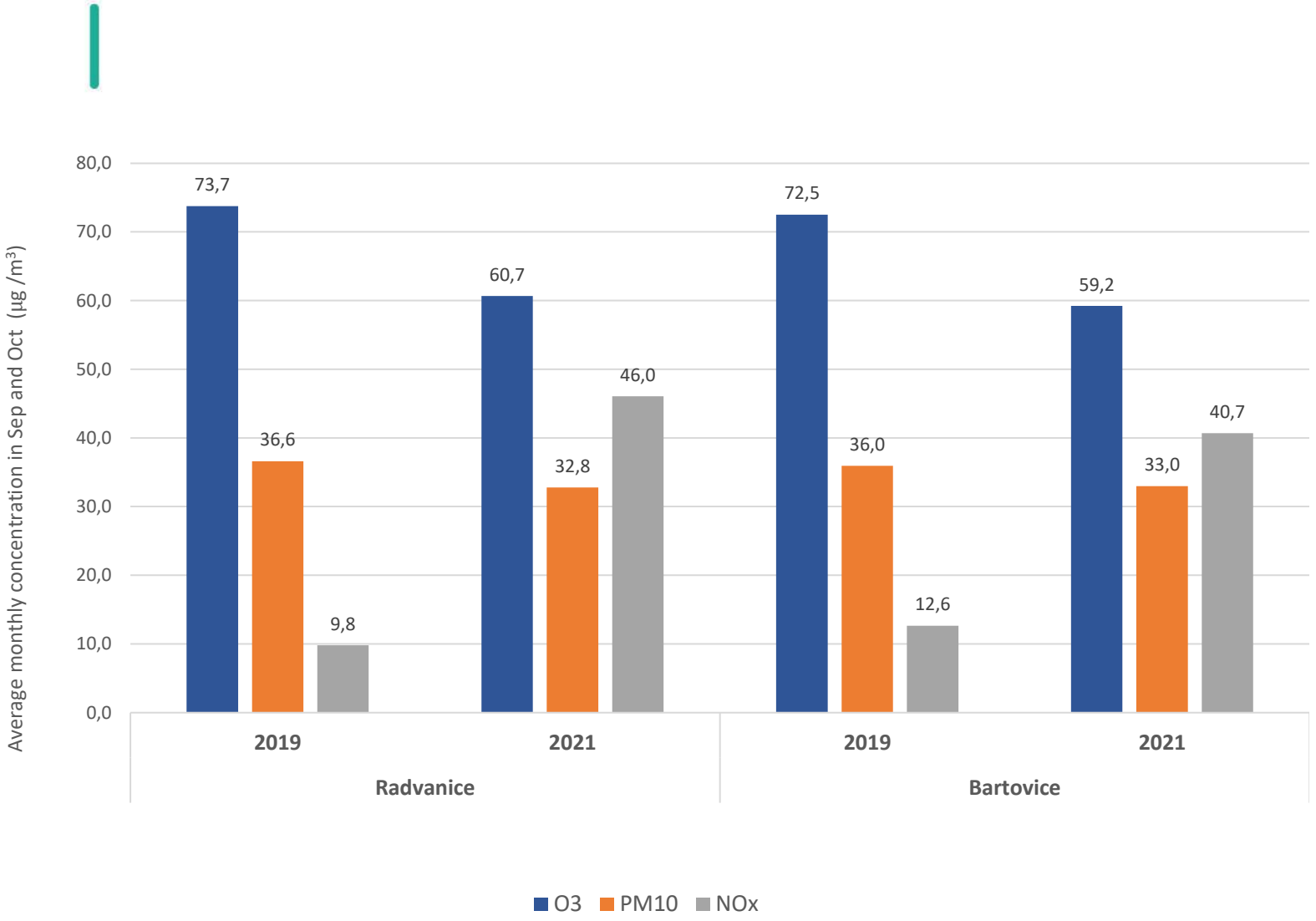
Average monthly concentration in Sep and Oct (µg /m³)
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
73,7
36,6
9,8
60,7
32,8
46,0
72,5
36,0
12,6
59,2
33,0
40,7
2019
2021
2019
2021
Radvanice
Bartovice
O3
PM10
NOx