GREEN INFRASTRUCTURE FOR CITIES

EUROPEAN UNION
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UIA URBAN INNOVATIVE ACTIONS

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CLEAR AIR AND CLIMATE ADAPTATION IN OSTRAVA AND OTHER CITIES
CLAIRO

OSTRAVA!!!

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CONTENTS

SUMMARY

1) Green infastructure contributes to the improvement of air quality in urban environments by removing suspended particles and other pollutants by capturing them on the surface of leaves. Some of the captured pollutants can be passed into intercellular spaces through the stomata, but most of them remain on the leaf surface, from where they can be resuspended into the atmosphere or washed away by precipitation.

2) Important aspects of a quality and efficient green infrastructure in the capture of suspended particulates (PM_x), ground-level ozone (O_3) and nitrogen oxides (NO_x) are the properties of plant organs and their arrangement, as well as the overall structure of the vegetation, its height and canopy density.

In general, the larger the green surface area per unit of area, the higher the air pollution removal. Mature trees with a dense multi-level canopy are significantly more effective than low vegetation that only consists of a herbaceous layer. The addition of coniferous non-deciduous tree species or evergreen shrubs is suitable for the continuity of year-round capture.

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

4) The use of environmentally friendly fertilisers containing biostimulants and phytohormones, which help plants overcome abiotic stresses, can ensure the long-term viability of existing and newly planted greenery even in heavily polluted environments around industrial areas.

Green infrastructure in good health can better photosynthesize and create dense and high-quality canopies. Ultimately it may capture air pollutants more effectively and improve local air quality.

5) To monitor the effect of green infrastructure on the local air quality, sensors should be installed in the surrounding area. Due to their simple installation and operation, they are suitable for additional measurement, which can also detect ‘unusual’ situations, including the time of specific events.

1. INTRODUCTION

A CITY AS A PLACE FOR LIFE

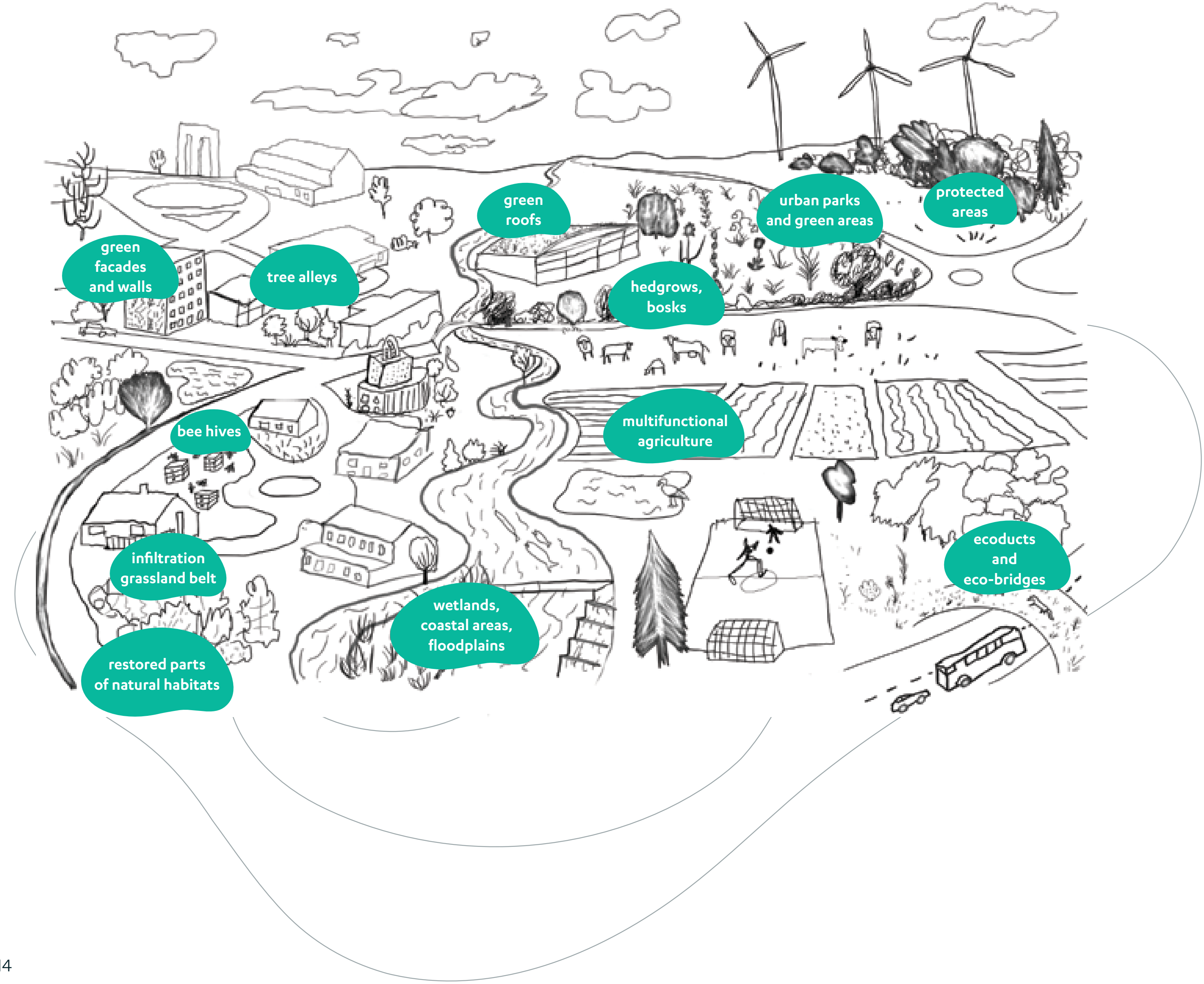
Cities are a place of life and social interaction. Today, over a half of the world's population lives in cities, and it is estimated that by 2030 three-fifths of people will live in cities (Fuller and Gaston 2009; Smith and Guarizo 2009).

The degree of urbanization in the Czech Republic is even higher. Over 73 % inhabitants of the Czech Republic (over 7 million people) live in urban areas (CZSO 2018). Many of these people live in small or medium-sized cities with up to 50,000 inhabitants (over 42 %).

While cities connect us, their rapid and unprecedented growth has brought about serious challenges. Urban development has negatively impacted the environment, led to the loss of natural habitats and biodiversity, and increased the risk to human health associated with overheating, noise and air pollution.

And we can expect the effects of environmental degradation to increase due to climate change. This is why we need to find ways to reduce health risks and maximize opportunities for a high quality of life in expanding urban environments.

GREEN INFRASTRUCTURE IN AN URBAN ENVIRONMENT



GREEN INFRASTRUCTURE COMPONENTS

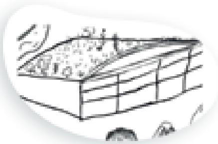
Protected areas, such as Natura 2000 sites and small protected areas.

Healthy, quality ecosystems and areas of high natural value outside protected areas, such as floodplains, wetlands, coastal areas, natural forests, etc.

Natural landscape features, such as small watercourses, forest lands, hedges that can serve as wildlife corridors or stepping stones

Restored parts of natural habitats that have been created for specific species, e.g. to increase the size of the protected area, to increase the area for foraging, reproduction and rest for these species, and to facilitate their migration/distribution.

Artificially created elements, such as ecoducts or eco-bridges, which should make it easier for species to overcome insurmountable landscape barriers.



Multifunctional areas where land use is prioritized in a way that helps maintain or restore healthy, biodiversity-rich ecosystems over other activities that are incompatible with these objectives

Landscape elements that contribute to climate change adaptation or its mitigation, such as wetlands, floodplains and peat swamp forests - for flood prevention, water retention and CO_2 uptake, and that provide space to enable species to respond to changing climatic conditions.

Green infrastructure offers potential adaptation measures for a better life in urban environments. It is generally understood as a network of physical, nature-friendly elements that provides environmental, economic and social benefits for society and promotes human well-being and quality of life. In urban areas, green infrastructure can consist of green areas, such as parks, street trees and green roofs. These natural and semi-natural areas are strategically planned and managed to provide a range of ecosystem services.

SERVICES PROVIDED BY GREEN INFRASTRUCTURE

– Population health: along with improved air quality, pollutant filtration, oxygen generation and noise absorption, green infrastructure helps prevent a number of diseases by encouraging inhabitants to be physically active. Inhabitants of green cities are more active and they use various forms of sustainable transport.

– Resilience of cities: green infrastructure allows cities to better adapt to climate change and the associated increase in the frequency and intensity of temperature extremes, which affect the health of vulnerable groups. Green infrastructure can also prevent soil erosion, retain water in the landscape and reduce electricity consumption.

– Increased biodiversity: green infrastructure helps maintain and develop the number of animal and plant species in cities.
City dwellers value biodiversity, and it also arouses interest in the environment and public space.

– Quality of life of the population: the amount of greenery is one indicator of quality of life. In green cities, people are more active and satisfied; greenery also helps prevent mental illness.

– Reduced stress: green infrastructure helps improve concentration, memory, and learning ability, it has a calming effect, and it speeds up recovery from illness.

– Attractiveness of the environment: green cities attract groups of people who are often more active, enterprising, more educated and interested in the public space and events.

– Economic growth: green infrastructure creates new jobs and increases the value of housing and land. Green cities are more attractive to investors.

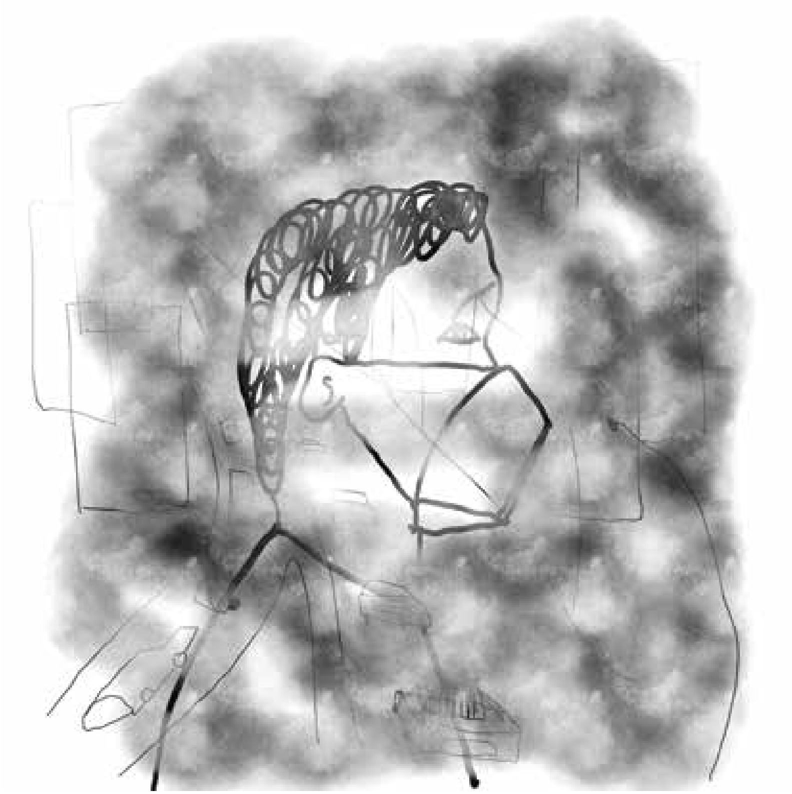
– Strengthening of communities: green cities promote social interaction. Projects such as community gardens and shared plants promote good neighbourly relations. Lower crime rates have been reported in green cities.

CITY AIR QUALITY AND ITS EFFECT ON HUMAN HEALTH

We can imagine air pollution as a dense mixture of chemicals, molecules and solid particles that most of us breathe in daily. Compared to adults, newborns and infants breathe more of this pollution because they inhale more often than adults. Our children are therefore among the most affected groups by air quality during their most vulnerable stages of development (Landrigan et al. 1998).

Common air pollutants include suspended dust particles (PM_x), sulfur dioxide (SO_2), ground-level (tropospheric) ozone (O_3), nitrogen oxides (NO_x) and carbon monoxide (CO). In 2005, 89% of the world's population lived in areas where the World Health Organization's air quality guidelines were exceeded for at least one of these substances (Brauer et al. 2012).

Different air pollutants have different adverse health effects. Coarse particles (PM_{10}) are emitted from domestic heat sources and power plants, while fine particles ($PM_{2.5}$) mostly come from cars, municipal services and the combustion of wood and organic material (Shah and Balkhair 2011). The World Health Organization estimates that suspended particles are responsible for approximately 800,000 premature deaths each year, and the loss of 6.4 million years of healthy life (Brauer et al. 2012).



HEALTH IMPACTS

Acute manifestations - cough, acute respiratory diseases, mucosal irritation, worsening of existing respiratory diseases and cardiovascular diseases, increase in hospitalizations and mortality.

Chronic manifestations - diseases of the respiratory system (inflammation of the bronchi, lungs) and circulatory system, premature deaths, decreased lung function, allergies, asthma.

Potential carcinogenic and mutagenic - cancer, developmental defects.

THE IMPORTANCE OF GREEN INFRASTRUCTURE IN PROTECTING HUMAN HEALTH

One significant benefit of green infrastructure is its positive impact on human health and overall well-being. Green infrastructure provides a place for rest and recreation, as well as an environment for physical activities, which has a positive effect on our physical and mental health (Van den Berg 2015). The green space available near residential areas is directly related to lower obesity rates of the local population (Sakar, 2017) and a lower mortality rate due to cardiovascular diseases (Gascon et al., 2016).

The fundamental importance of green infrastructure from the perspective of human health is its ability to influence local microclimatic conditions and improve air quality. Suspended particles and other pollutants from the air are primarily removed through their capture on the leaf surface (Cavanagh et al. 2006). The amount of sedimented particles also depends on the size or mass of suspended particles and flow rate (Janhäll 2015). When particles settle on leaves, fine particles smaller than 1 μm can be further infiltrated through the stomata into intercellular spaces, where they can be further absorbed. A similar principle of absorption applies to tropospheric ozone molecules. However, larger particles remain on the surface of the vegetation after their capture from where they can be subsequently resuspended in the atmosphere, washed away by precipitation or deposited on the ground when deciduous leaves fall (Nowak et al., 2006).

In addition, green infrastructure also affects the concentration of suspended particulates in the air indirectly by changing meteorological conditions. The main mechanism is a reduction of the air flow rate. Vegetation serves as an effective windbreak, where suspended particles are deposited on the ground and their overall concentration in the air is reduced on the leeward side due to a decrease in flow rate. Green walls on high-rise buildings may also have a significant effect (Pugh et al. 2012).

Vegetation also modifies local temperature conditions. Daily temperatures are locally reduced primarily due to the limited amount of sunlight passing through the canopy and increased evapotranspiration. Air temperature is a precursor to the formation of many pollutants. Locally reduced air temperature therefore partially reduces the concentration of pollutants in the air.

Last but not least, green infrastructure has a positive effect on human health by reducing stress and noise pollution (Al-Dabbous and Kumar, 2014).

HOW DOES GREEN INFRASTRUCTURE IMPROVE AIR QUALITY?

DIRECTLY

– The vegetation cover removes air pollutants.

– By capturing suspended particulates (PM_1, $PM_{2.5}$, PM_{10}) on the surface of leaves.

– The stomata absorb molecules (O_3, NO_2).

INDIRECTLY

– Increased humidity and decreased temperatures reduce photochemical formation of ozone.

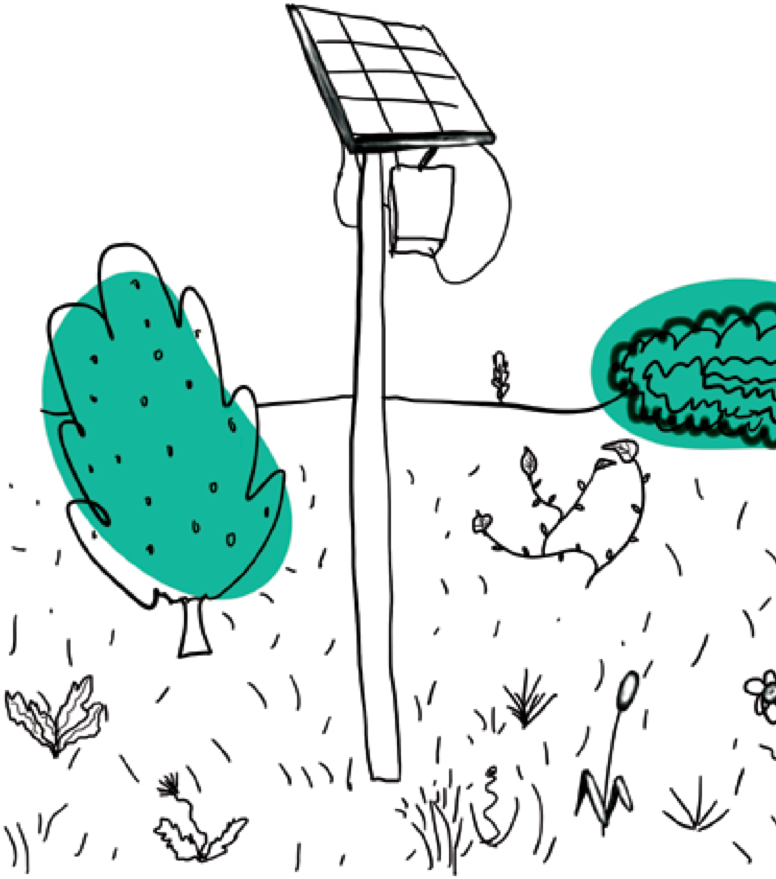
– It obstructs airflow. When wind speed decreases, the deposition of suspended particles occur.

2. PRINCIPLES OF PLANTING GREEN INFRASTRUCTURE

MONITORING POLLUTANT CAPTURE

Air quality monitoring in the Czech Republic is currently ensured by the national monitoring network of the Czech Hydrometeorological Institute, the network of the National Institute of Public Health, and other stations acquired by industrial companies or the cities themselves. Totally, there are about 150 stations. The layout of the stations is sufficient to monitor regional differences in air quality, but it often fails to capture processes and conditions on a local scale. However, when green infrastructure is planted in an urban environment, it is necessary to take into account the air pollution and meteorological conditions in the given place, as the sensitivity of individual plant species to pollutant concentrations varies significantly. It is therefore appropriate to add available and easy-to-operate sensor technology to the existing network, ideally installed right next to the proposed greenery. Long-term continuous monitoring also enables us to monitor and evaluate the effect of pollutant capture by the current and future greenery.

- Sensors are an appropriate addition to the existing network.
- Sensors are suitable for assessing pollutant capture by green infrastructure.
- They are much cheaper than stationary monitoring systems.
- Sensors can discover 'unusual' situations at the site and reveal the time of specific events.
- Sensors should record both air pollution concentrations of individual pollutants (PM_x, NO_x, O_3 etc.) and meteorological conditions, which affect the capture efficiency.
- Sensors are easy to install and require almost no manual operation.
- Sensors do not have to be dependent on an energy source thanks to their connection to a solar panel.
- Each sensor is different, and they must be calibrated.
- Data from sensors can be transmitted in real time to an online system for their quick visualisation and evaluation.
- However, sensors with wireless data transmission via a mobile data network (GPRS) are more expensive.
- Evaluated data from sensors should be taken into account when proposing the composition and arrangement of local green infrastructure.



SPECIES COMPOSITION

An important factor in quality and efficient green infrastructure in terms of capturing pollutants is the species composition. The choice of vegetation species should further reflect the topographic, soil and climatic conditions at the site. Particularly native species should be the preferred choice.

The selection of vegetation species should take into account the sensitivity of specific species to air pollution in the given area, and it should be based on air pollution monitoring. Concentrations of tropospheric ozone, sulfur dioxide and nitrogen oxides are important factors. Deciduous trees are generally more sensitive to tropospheric ozone than coniferous trees (Novotný et al., 2009). Experimental observations have shown relatively high sensitivity of cherry trees (Schaub et al. 2005), birches (Pääkkönen et al. 1998), alders and poplars (Skärby et al. 1998). Sensitive species of coniferous trees include Scots pine.

Another criterion is the capture efficiency itself, which is primarily conditioned by the extent of the leaf area on which air is filtered. Species with a densely branched crown and a large volume of green matter should therefore be preferred. In general, coniferous species capture more suspended particles than deciduous species (Tallis et al. 2011; Tiwary et al. 2009). Defoliation of deciduous species, which significantly reduces the capture of pollutants during the leafless period, is an important aspect. In contrast, coniferous non-deciduous species can capture pollution all year round. Experiments showed higher capture of PM_{10} by black pine, Scots pine, English yew and paper birch. Lower capture is expected by Norway maple, sweet cherry and small-leaved linden (Sæbø et al. 2012).

Moreover, pollutant capture efficiency likely also varies depending on the specific pollutant. In the case of tropospheric ozone, some studies point to higher efficiencies of deciduous species over conifers (Alonso et al., 2011). We can therefore assume that a combination of several deciduous and coniferous species with overall higher species diversity is appropriate for a more efficient capture of a wider range of pollutants. This also increases resistance to seasonal and climate changes.

SELECTED TREE SPECIES WITH HIGH RESISTANCE TO AIR POLLUTANTS AND EFFICIENT POLLUTANT CAPTURE

Latin name	**Apparatus**	**Georelief**	**Climate**	**Sensitivity to acid rain**	**Sensitivity to O_3**	**Capability of capturing dust particles**
Pinus nigra	evergreen	alpine	subtropical	resistant	tolerant	high
Picea abies	evergreen	alpine	boreal	sensitive	resistant	medium
Abies alba	evergreen	upland	mild	tolerant	resistant	medium
Quercus robur	deciduous	lowland	mild	resistant	resistant	medium
Quercus petraea	deciduous	highland	mild	resistant	resistant	high
Malus sylvestris	deciduous	highland	mild	resistant	resistant	medium
Ulmus minor	deciduous	lowland	sub-mediterranean	tolerant	tolerant	high
Cornus sanguinea	deciduous	highland	mild	tolerant	resistant	medium
Populus tremula	deciduous	highland	mild	resistant	resistant	medium
Prunus avium	deciduous	highland	mild	resistant	resistant	medium
Juglans regia	deciduous	upland	subtropical	resistant	tolerant	medium

Malus sylvestris
European crab apple

Picea abies
Norway spruce

Pinus nigra
black pine

Populus tremula
European aspen

Quercus robur
robur English oak

Ulmus minor
field elm

The full plant database can be found at: www.clairo.ostrava.cz.

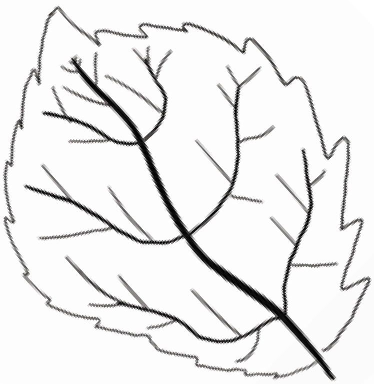
STRUCTURE AND COMPOSITION

Another important aspect of green infrastructure in terms of reducing air pollution is its structure and composition. Important aspects include the shape and arrangement of leaves, as well as the roughness of their surface, type of margin and venation (Florentina and Io, 2012). Suspended particles are more effectively captured on waxy leaves with trichomes or with an otherwise fragmented surface with netted veins. In contrast, leaves with a smooth surface and prominent cuticle are less effective.

It is not only the properties of plant organs and their arrangement that are decisive, it is also the overall structure of the vegetation, such as the height and density of the canopy, the shape of the crown and the spatial arrangement of the branches (Litschke and Kuttler, 2008). For example, spherical crowns are more effective than conical crowns.

In general, the larger the surface area of the vegetation per unit of area, the greater the capture of pollutants; this is why mature trees with a dense multilayer canopy are significantly more effective than low vegetation consisting only of a herbaceous layer (Lovett 1994; Powe and Willis 2004; Nowak and Greenfield 2012). The ideal composition is a combination of several layers with trees and a shrub layer in the undergrowth.

In an effort to maximize canopy, the composition parameters of the species should take into account the ecological links of individual species and their demands on the habitat. The tree species composition should be spatially distributed so as to correspond to the position of the species in a natural community. Individual species combinations should be compatible in terms of growth and demands. Individual layers should not compete with growth and aggression, and species in the undergrowth should tolerate shading.



PROPERTIES OF GREEN INFRASTRUCTURE

1. MICROSCOPIC

– Shape and arrangement of leaves.

– Leaf surface roughness.

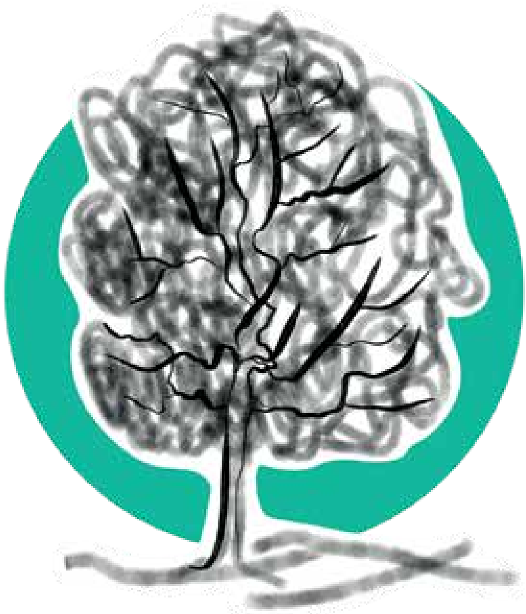
2. MACROSCOPIC

– Overall structure of foliage.

– Canopy height.

– Canopy density.

– Branching pattern.



FERTILISATION AND TREATMENT

It is not only the species, structure and composition of the green infrastructure itself that determine the effectiveness of the capture of air pollutants; For the permanent preservation of the functions of the green infrastructure, further care is also necessary. Trees and shrubs in good health will better photosynthesize and create a denser and better leaf area, which will subsequently have a positive effect on the capture of pollutants from the air.

Urban greenery is generally treated with commercial anorganic fertilisers. However, the use of environmentally friendly products based on ‚smart fertilisers' containing biostimulants and phytohormones, which help plants overcome various forms of abiotic stress, can be an innovative solution for both existing green infrastructure in urban areas as well as for treating new greenery in areas subjec to a combination of different forms of abiotic stress.

We propose the one-time application of TS HG Plant or a similar product containing humic acids, anti-stress substances and seaweed extracts. An active substance, the cytokinin derivative RR-D, can also be applied.

The proposed treatment product contains an optimal mixture of biostimulants with a high content of amino acids, anti-stress substances and seaweed extract, limiting potential negative effects of the external environment, especially during drought or significant temperature fluctuations. This fertiliser can be applied to any plants in any city.

Plant hormones (phytohormones) are small organic molecules that play a vital role in regulating plant growth and development. They occur naturally and act in small concentrations, forming in certain parts of plants, from where they are transported by the bast of the vascular bundle to their destination, eliciting a physiological response. The function of phytohormones is non-specific; one hormone can affect multiple processes. Phytohormones are used as growth regulators in plant production and plant biotechnology; in high concentrations, they act as herbicides for weed control.

Biostimulants are biologically active substances obtained from natural or waste materials. They can support plant growth and/or strengthen the resistance of plants to various stressors. The peculiarity of biostimulants is that they do not contain a high percentage of active substances, so they cannot be considered typical fertilisers or plant protection products. The active ingredients in biostimulants affect the metabolism of the plant and trigger processes in the plant that generally improve its growth and health.

3. CASE STUDY

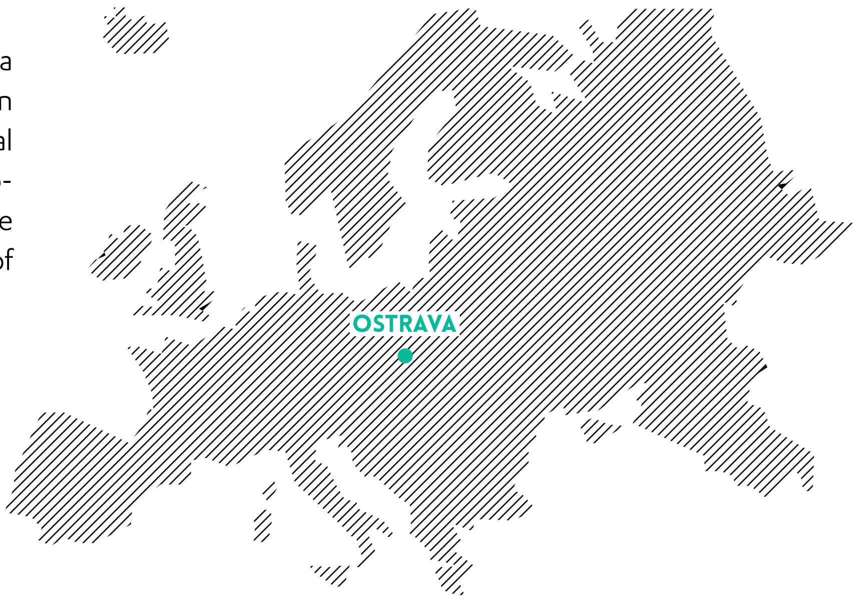
PLANTING OF GREEN INFRASTRUCTURE NEAR AN INDUSTRIAL BUILDING – CASE STUDY IN OSTRAVA BARTOVICE AND RADVANICE

– SITUATION IN THE MORAVIAN-SILESIAN REGION

The Moravian-Silesian Region has long been an area with poor air quality in a pan-European context. According to the results provided in the ISKO CHMI database (CHMI 2019) for air quality management, in 2018 the annual limit value of suspended particles PM_{10} and $PM_{2.5}$ was exceeded at most monitoring stations in Ostrava.

The main sources of air pollution in Ostrava are stationary sources (metallurgical and energy production), household heating sources and transportation. In Ostrava, the fourth most important factor is cross-border air-pollution transport from the nearby industrial agglomeration of Katowice (Poland). The situation in Ostrava is exacerbated by topographically induced micro-climatic conditions - namely relatively long windless periods, which lead to lengthy inversions in the winter, increasing pollutant concentrations regardless of the decline in emissions.

The southeastern part of Ostrava is a particularly polluted area in association with the accumulation of large industrial resources and local heating. Additionally, the shape of the valley along the Ostravice River also limits dispersion of emissions when there is no wind.



BARTOVICE AND RADVANICE SITES

The monitored area used for the case study is in two selected locations in the cadastral areas of the city districts of Radvanice and Bartovice. These neighbourhoods are characterized by significant emissions from the nearby industrial area in Ostrava Kunčice.

In 2018, the nearby monitoring station of the National Institute of Public Health measured an average annual PM_{10} concentration of 44μg/m^3 (110 % of the limit), placing the station in 1st place among the Czech stations where the limit value was exceeded. For $PM_{2.5}$, an average annual concentration of 36.8 μg/m^3 was measured (148 % of the limit). The daily limit was therefore exceeded 89x at that station (CHMI 2019).

Overview map of the areas of interest in the case study and the surrounding area. In the western part we can see an industrial building in Ostrava Kunčice.

RADVANICE SITE

Radvanice is spread over an area of 1.04 ha, and it includes a combination of permanent grassland and scattered, solitary trees and shrubs, or their small clusters. The existing forest stands extend to the edges of the monitored area. The area has significantly more moisture, which is reflected in the occurrence of water loving tree species, especially in the surrounding stands, particularly willows and alder trees.

Current vegetation at the Radvanice site before the planting of the proposed greenery (as of 2019).

BARTOVICE SITE

The site in Bartovice consists of the western to southwestern edge of the industrial waste landfill. Before planting greenery, there were no technical or vegetation elements in this area. The area was completely empty and barren. Near the monitored area to the west, mostly pioneer tree species can be found. The total area of Bartovice is 0.73 ha.

AIR POLLUTION MEASUREMENT AND INFORMATION SYSTEM

A total of 19 sensor units and one reference system are installed in the areas of interest for the purposes of monitoring the air pollutant concentrations. The sensors were installed before the greenery was planted so that the effectiveness of pollution capture by the newly planted green infrastructure could be evaluated. Continuous measurements for at least another 8 years are anticipated, so that the development over time can be evaluated with the development of the greenery and connectivity of the growth.

A sensor box is installed at each measuring point - this is a device consisting of a 300 x 400 x 220 mm measuring part and a 620 x 670 mm solar panel. Each sensor is alternately independent of the energy source; they contain a battery and are connected to a solar panel and 220 V mains. The sensors are installed on metal poles up to a height of about 4 metres.

The purpose of the measurement and the nature of the methodology used must be taken into account when applying the measurement results, and it is necessary to realize that monitoring does not serve to control the limits, but rather for comparison and information about the spatial distribution of pollutant concentrations.

Results to date indicate very good compliance with reference stations for PM_x, which is the most serious pollutant, and less compliance for NO_x and O_3.

The sensor units are connected to one common network and they provide online data wirelessly. Data are transferred to the existing intelligent information system, which allows:

– collection of short-term concentrations from sensors
– storage of transferred data in a specially structured database
– automatic data inspection
– validation based on reference measurements
– manual evaluation of data validity
– concentration maps for individual pollutants
– model calculation based on measured meteorological indicators (wind speed and direction)
– animated sequences for various intervals (hour, day, month)
– automatic marking of the place and time of a „non-standard" concentration in concentration tables
– data export for individual IIS network points into tables
– data and map storage in a well-arranged archived

SENSOR PARAMETERS

– variable power supply (mains, battery or solar panel), all ariants listed
– weather resistant; the whole system is robustly designed
– communication with the server via a radio network
– applicability ranges of sensors for air pollution measurement

NO_2 sensors

– Type of measurement: electrochemical sensor
– Minimum range: 0–250 ppb
– Detection limit: ≤20 ppb
– Frequency of the provision of measured data: ≤1 min

NO_3 sensors

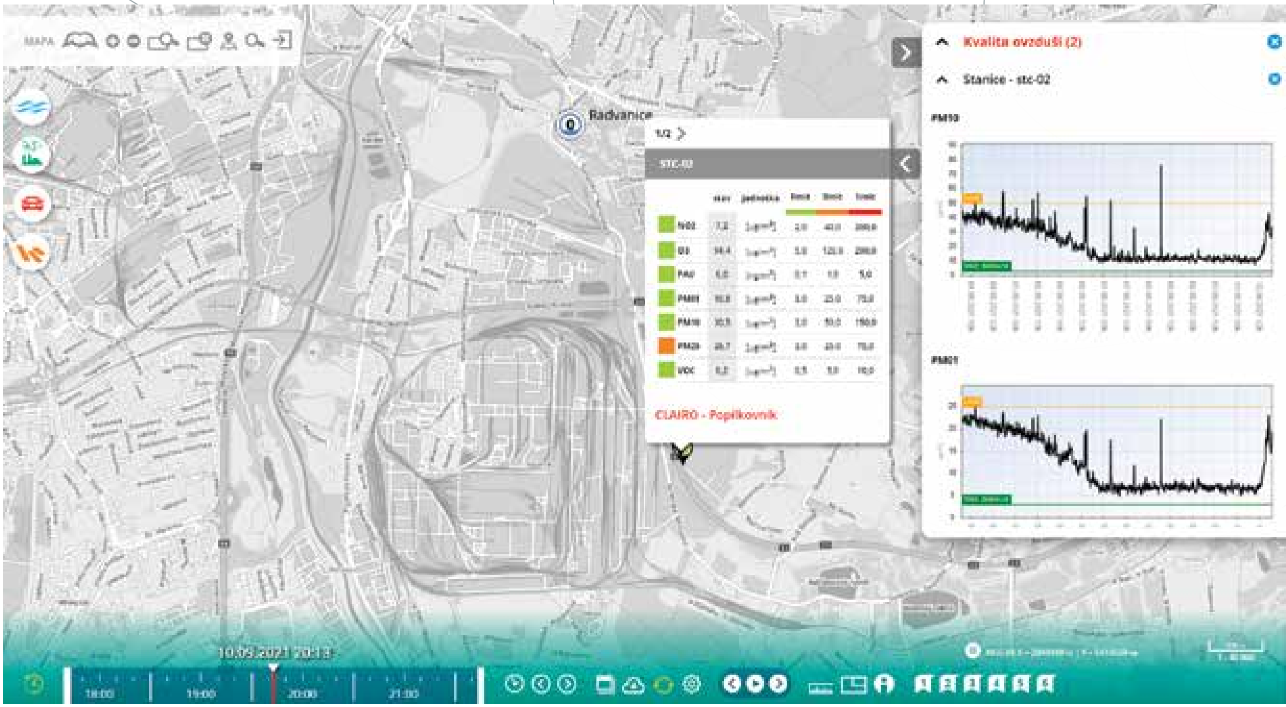
– Type of measurement: electrochemical sensor
– Minimum range: 0–5000 ppb
– Detection limit: ≤40 ppb
– Frequency of the provision of measured data: ≤1 min

PM_x sensors

– Type of measurement: optical
– Size range of measured particles: 0.38 – 10 µm
– Minimum amount of size channels: 8
– Minimum range of mass concentration measurement: 0 – 500 µg/m³
– Detection limit: ≤1 µg/m³

VOC sensors

– Type of measurement: photoionization detector (PID)
– Measured substances: VOC sum
– Minimum range: 0–16 ppm
– Detection limit (for isobutylene): ≤10 ppb



Preview of the information system map portal application.

Data can be viewed at the web map portal: **www.floreon.eu** or **www.airsens.eu**

PLANTING GREENERY IN THE PROPOSED STRUCTURE

The main purpose of the case study is to compare the initial air pollution without a sufficiently functional green infrastructure with the change after growth-balanced stages are reached in several species combination and structure variants.

The tree planting plan at the Radvanice site is situated in the preserved habitat conditions typical of the wider Ostrava Basin region, where the proposed tree composition consists of geographically native species.

In contrast, the proposed greenery at the Bartovice site is situated on heavily anthropogenically affected soils from waste materials, where the proposed tree composition is based on a comparison of a combination of non-native resistant species and pioneer species.

The process of designing green infrastructure includes criteria for planting material, allelopathy and culture replenishment. The following principles were taken into account:

- Planting material was planted in the form characterised by territorially relevant standards. Plants with a root ball are used for planting.
- Native, uncultivated plant forms were preferred, with the exception of an experiment comparing cultivated and uncultivated plant forms. Native plant species were exclusively selected from geographically native uncultivated populations to preserve the gene pool. Cultivated forms were only allowed when uncultivated forms of the proposed non-native species were unavailable.
- Plants grown in habitat-appropriate conditions were preferred. The transfer of reproductive material was only permitted in accordance with international or national law.
- Tree layers and a shrub layer. Tree layers are divided into the upper canopy layer and the understory layer.
- Species with increased resistance to air pollution were preferred. The resistance of trees was simplified to classify the degree of tolerance to the deposition of sulfur and nitrogen, tropospheric ozone and solid dust particles.

Creation of an initial plant list

Viability and resilience

Will the proposed vegetation thrive
in local environmental conditions?

<u>What to consider:</u>

- The current air pollution (according to local monitoring).
- Climate and soil conditions.
- Soil salinity.
- Other environmental risks (drought, toxicity of the environment).

Taking into account local development and urban composition

Morphology and ecophysiology

What are the local conditions and overall context in terms of surrounding development? Is the greenery planted in an open
space or a street canyon?

- In general: Sun-loving species for open areas, shade-loving species for street canyons.

Revision of the list

Source of pollution

- Species with lower volatile organic compound (VOC) and pollen emissions.

Species diversity

- Multiple species.

Native species

- Elimination of non-native, invasive species or species incompatible with local legislation.

Competition

- Species combinations should be compatible in terms of growth and demands.

Prioritization of plants depending on their ability to capture pollutants

Air pollutant capture potential

How can we maximize the efficiency of pollutant capture by the proposed vegetation?

<u>What to consider:</u>

- The type of vegetation (evergreen, coniferous species over deciduous species).
- The structure of the vegetation (height, densely branched crown, multiple layers).
- Size and complexity of the leaf apparatus.
- Leaf surface (rough, sticky).

Diagram of the procedure for creating a plan for planting green infrastructure with regard to improving local air quality.
Edited based on Barwise and Kumar (2020).

Trees in the upper canopy layer

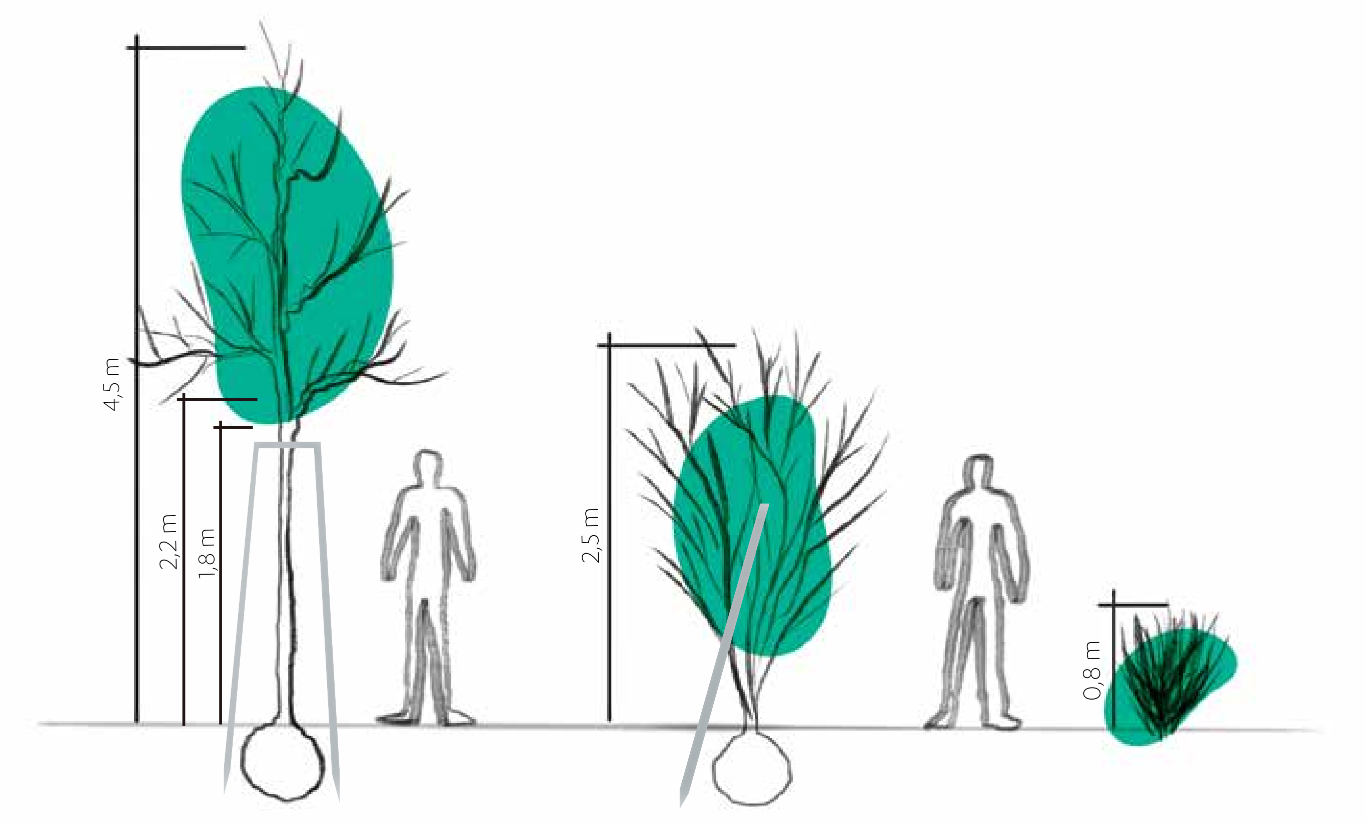
Abies alba, Pynus sylvestris, Larix decidua, Quercus cerris, Tilia platyphyllos

Trees in the understory layer

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

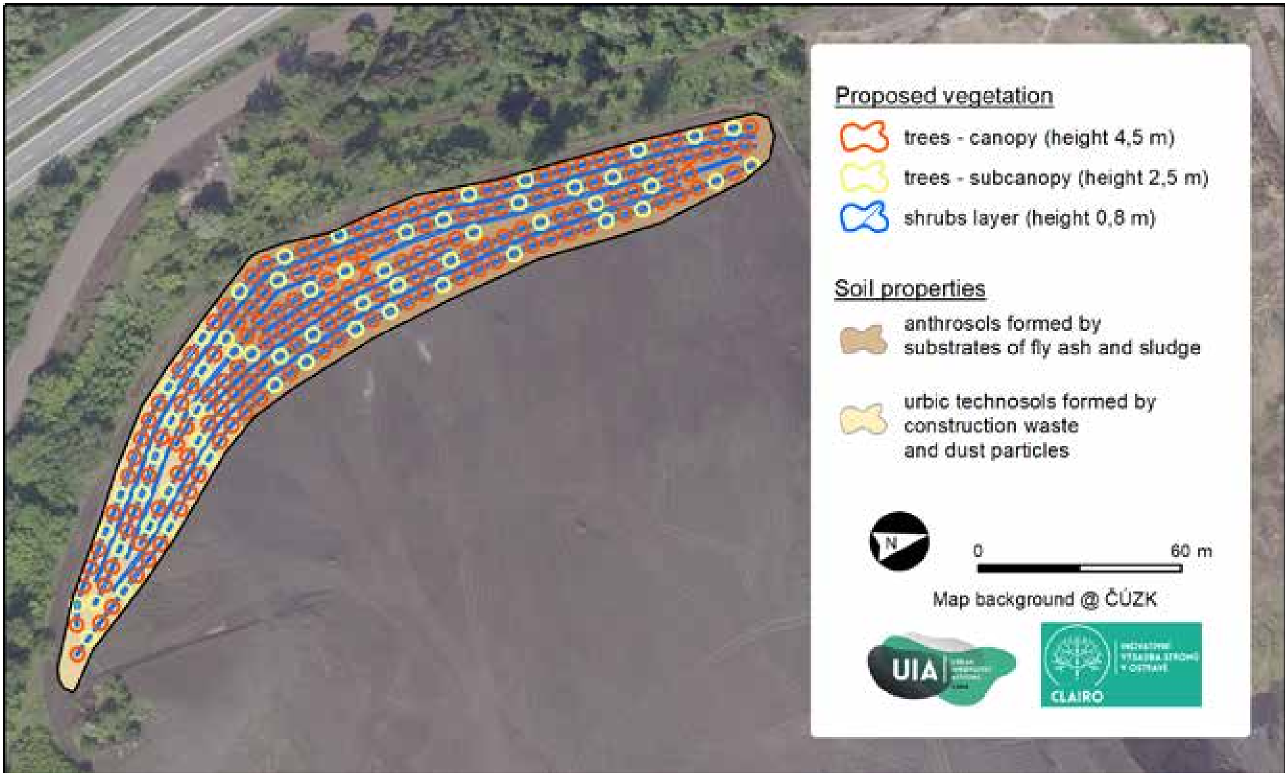
Shrubs

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



Size and species composition of proposed greenery. The proposed trees are divided into two vertical vegetation layers - the canopy layer with a canopy height of 2.2 m, and the understory layer with multi-stemmed trees branched from the ground.

Greenery planting plan in Radvanice. The proposed trees are placed in rows 6 m apart. The same spacing between trees was kept in each row. In places with a stagnosols soil types, mulched shrub plantings were proposed over the entire area in rows 1.5 m apart. The following species were used: *Quercus petraea, Acer pseudoplatanus, Tilia platyphyllos, Populus nigra, Salix daphnoides, Ulmus laevis* (upper canopy layer), *Acer campestre, Crataegus monogyna, Prunus padus, Lonicera xylosteum, Prunus avium* (understory layer), *Viburnum opulus, Alnus viridis, Frangula alnus, Rosa majalis, Salix purpurea* (shrubs).



Greenery planting plan in Bartovice. The tree layout was designed in rows that are 6 m apart in the central part of the monitored area. The distance between individual rows is reduced to 4.5 m at the edges. In each row, the trees are 6 m apart. A total of 203 trees were proposed. The following species were used: *Pinus sylvestris, Larix decidua, Quercus cerris, Tilia platyphyllos* (upper canopy layer), *Betula pendula, Malus sylvestris, Carpinus betulus, Crataegus monogyna, Sorbus torminalis* (understory layer), *Ribes alpinum, Sambucus racemosa, Ligustrum vulgare, Lonicera xylosteum* (shrubs).

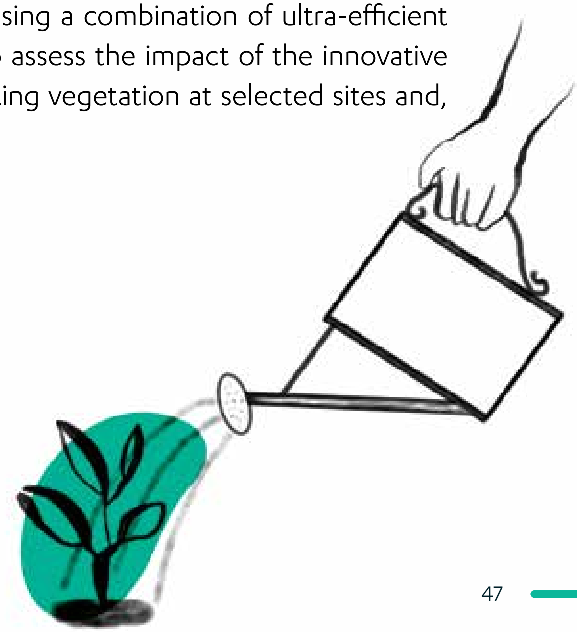
STRENGTHENING THE RESISTANCE OF PLANTS

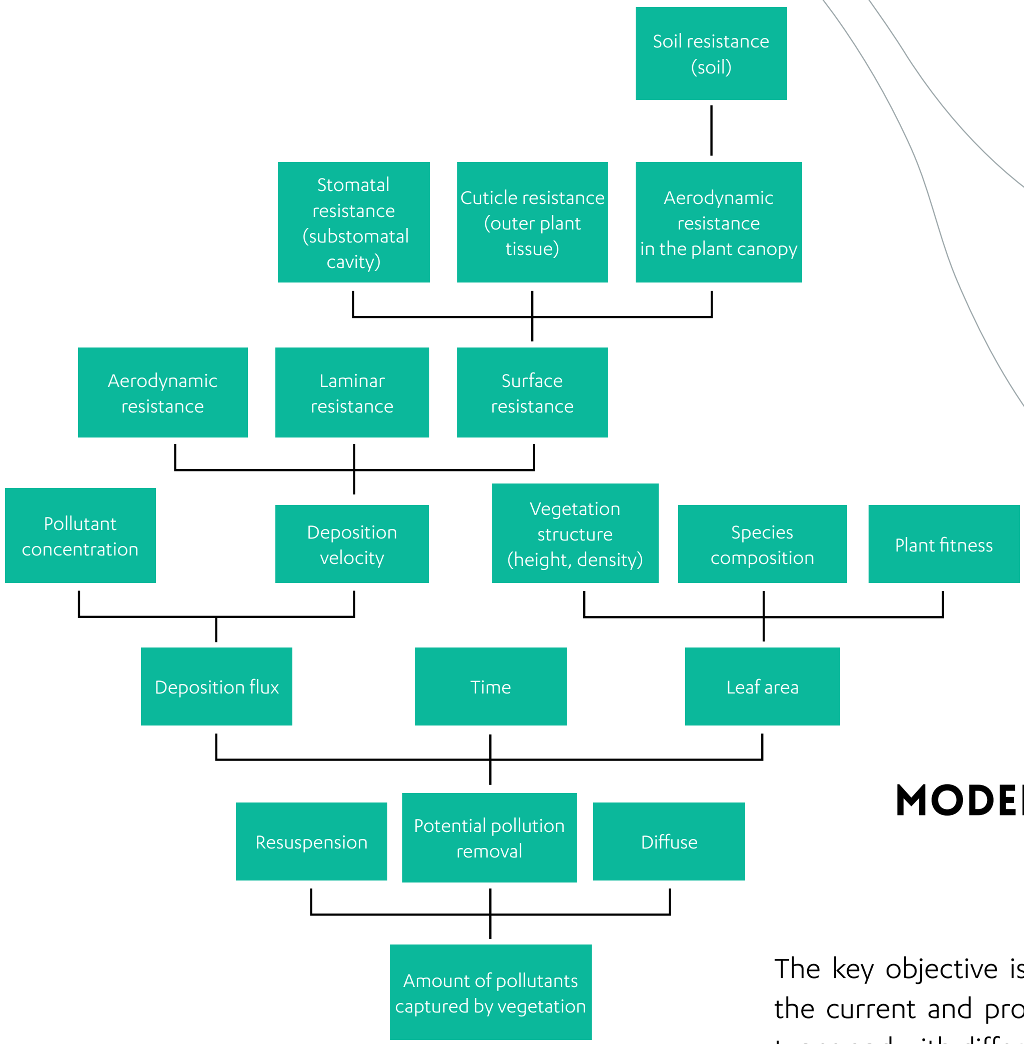
At the site of the proposed green infrastructure, several types of fertilisers are applied and their impact on the quality of the greenery is monitored, which ultimately reflects the ability to capture pollutants from the air.

The soil is specifically treated with three types of fertilisers: (1) a common commercial inorganic fertiliser, (2) a commercial biostimulant with a high content of amino acids, anti-stress substances and seaweed extract limiting potential negative environmental influences (TS entinel, TS VIN), and (3) an innovative smart fertiliser with the active substance cytokinin derivative RR-D.

All other standard crop treatments (watering, weeding, etc.) are the same for all three variants - at the same time in the same amount, etc., so that the effect of the applied fertilisers is distorted as little as possible by other factors.

The main prerequisite for the application of innovative treatment is the improvement of the basic physiological parameters of the new greenery. These are monitored by a number of highly sensitive and unique methods (gasometry, detection of selected fluorescence parameters, content of photosynthetic pigments, measurement of endogenous phytohormone levels using a combination of ultra-efficient liquid chromatography and tandem mass spectrometry) in order to assess the impact of the innovative treatment on the physiological condition of new plantings and existing vegetation at selected sites and, if necessary, to propose further optimisation of this treatment.





Simplified diagram of the model of pollutant capture by green infrastructure. Adapted based on Zapletal et al. (2011) and Janhäll (2015).

MODELLING POLLUTANT CAPTURE

The key objective is to evaluate the capacity of the current and proposed greenery of different types and with different layouts to capture air pollutants O_3, NO_x and PM_{10}. The quantification of the capture of a pollutant at a given site during a certain period of time (e.g. vegetation period, calendar year) is based on deposition models (Zapletal 2001; Zapletal et al. 2011; Nowak 1994; Janhäll 2015).

Model inputs include meteorological characteristics (temperature, wind speed, global radiation, humidity) measured in the given place or its surrounding area, concentrations of pollutants and structural properties of greenery. All information from previous project phases is used.

The inventory of existing greenery is assessed on the basis of a dendrometric survey (height, mean crown projection), species composition and health status. The spatial distribution of individual plants and their structural properties is transferred to a GIS environment on the basis of aerial orthophotos, which enables modeling capture in a two-dimensional space in a detailed 1 x 1 m grid, taking into account the spatial variability of the air pollution field.

The proposed greenery is based on the planting plan and it takes into account both the proposed species composition and the considered structure and composition of the stand. The following attributes were distinguished: height of the proposed vegetation, species composition and mean crown projection area. The health of the newly planted vegetation was assumed to be excellent, i.e. with no damage. The height of the vegetation was determined to be 4.5 metres for solitary trees in the vertical canopy layer, 2.5 metres for multi-stemmed trees in the understory layer, and 0.80 metres for shrubs. The mean crown projection area was established at 4 m.

The spatial arrangement of the vegetation was defined on the basis of planting plan drawings, which were georeferenced into a GIS environment using the boundary points of cadastral parcels. Each tree was vectorized and the above attributes were assigned to them.

Based on these structural parameters of the current and proposed greenery, the leaf area index (LAI) was determined as the input for the deposition model (Nowak et al. 2008). In places with herbaceous, shrub and tree layers, all LAI values were added up. The value of the highest point of the vegetation at the given place was used for the stand height. Finally, LAI values for the proposed and current vegetation, inclusive, were determined by the sum of the LAI in both states.

After the proposed greenery is planted, we can expect a significant increase in the capture of pollutants on the basis of modelled outputs, with over double the amount of capture at the Radvanice site.

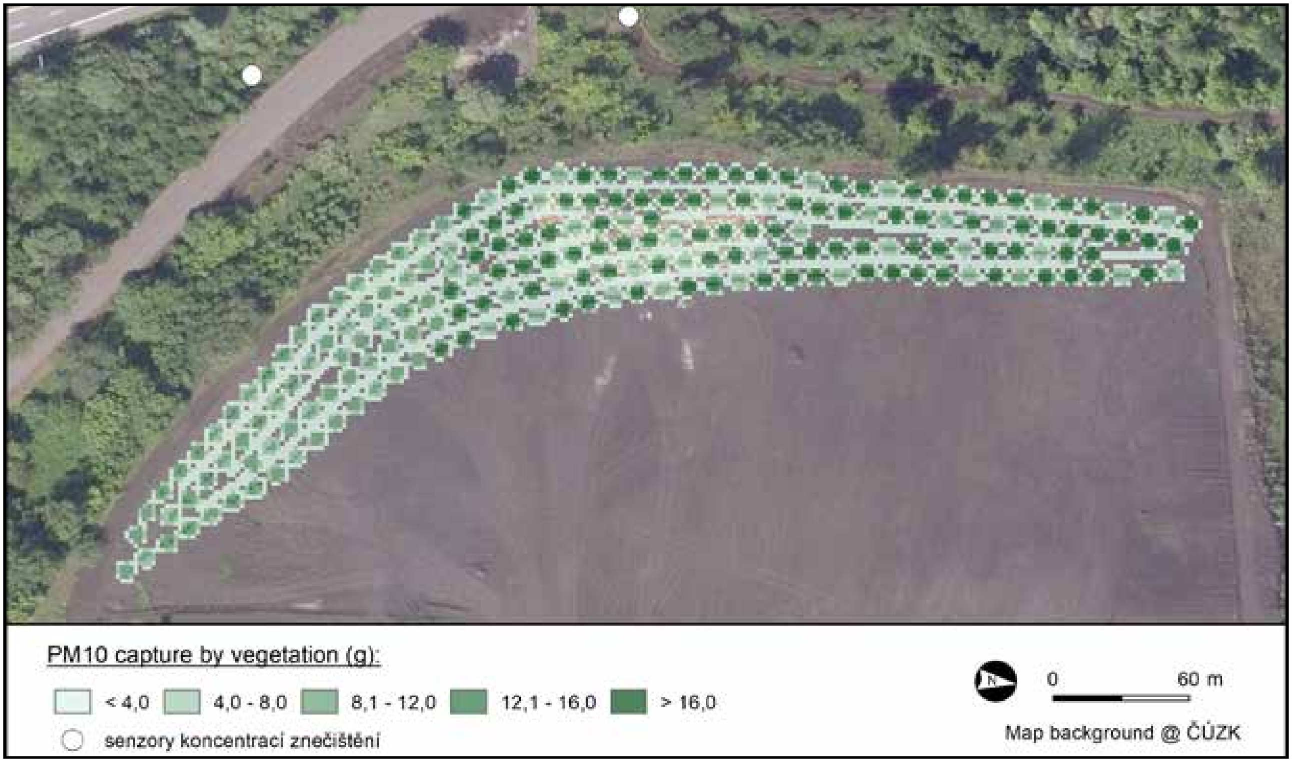
At the Bartovice site, no significant capture is currently expected before the planting due to the absence of any current greenery. A significant increase in capture is expected after the greenery is planted.

Capture of O_3 (g) before the planting (on the left) and after the planting of the proposed vegetation (on the right) in a 1 x 1 m grid at the Radvanice site. Modelled for a two-month period (at the end of the growing season).

Capture of PM_{10} (g) before the planting (on the left) and after the planting of the proposed vegetation (on the right) in a 1 x 1 m grid at the Radvanice site. Modelled for a two-month period (at the end of the growing season).

Capture of NO_x (g) before the planting (on the left) and after the planting of the proposed vegetation (on the right) in a 1 x 1 m grid at the Radvanice site. Modelled for a two-month period (at the end of the growing season).

Capture of O_3 (g) after the planting of the proposed vegetation in a 1 x 1 m grid at the Bartovice site. Modelled for a two-month period (at the end of the growing season). No significant capture is expected before the planting due to the absence of any current greenery.

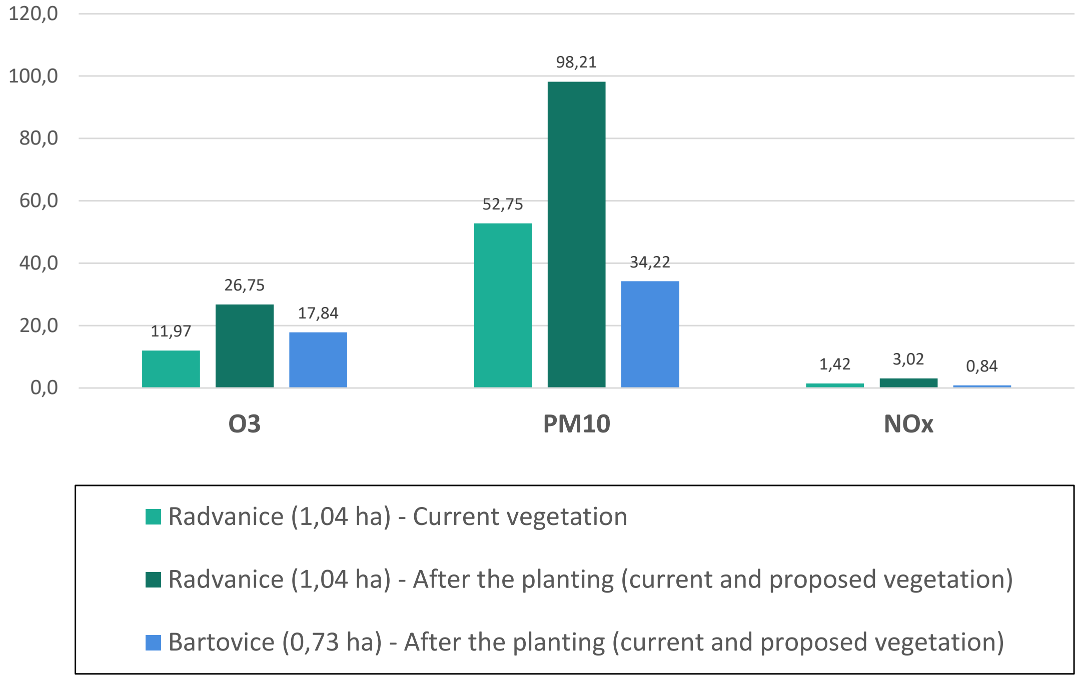


Capture of PM_{10} (g) after the planting of the proposed vegetation in a 1 x 1 m grid at the Bartovice site. Modelled for a two-month period (at the end of the growing season). No significant capture is expected before the planting due to the absence of any current greenery.

Capture of NO_x (g) after the planting of the proposed vegetation in a 1 x 1 m grid at the Bartovice site. Modelled for a two-month period (at the end of the growing season). No significant capture is expected before the planting due to the absence of any current greenery.

MODELLED O_3, PM_{10} A NO_X CAPTURE

Total capture (kg) for September and October 2019



Modelled capture at the Radvanice and Bartovice sites. At the Radvanice site, the capture by the current and the proposed (including the current) green infrastructure for a period of two months (at the end of the growing season) is distinguished. The condition after the planting of the proposed vegetation is considered for the Bartovice site.

Overall, we can expect a significant improvement in local air quality at both sites.

TRANSFER OF KNOW-HOW AND PUBLIC SURVEYS

The methods and experience gained during the project are also passed on to other partner cities (e.g. Opava, Třinec, Karviná) in the Moravian-Silesian Region. Both the professional and the general public in the Czech Republic and around the world is notified of the findings.

Know-how on the importance of green infrastructure in cities and its planting with regard to improving air quality and adapting to climate change is transferred through workshops for city representatives, academics and students in primary and secondary schools and universities.

Further transfer of knowledge and experience is made possible by opinion polls, which serve to educate people as well as present findings. They also provide an insight into local society and how important the issues of air pollution and the role of greenery are to the population. The findings are processed in the form of a study dealing with the public's attitude to air quality and urban greenery and their willingness to change their behaviour in favour of air protection. They also include the views and comments of experts.

The surveys were conducted in the Moravian-Silesian Region in 2019 and 2020, and they were carried out by exclusive quantitative research using standardized face to-face, in-home interviews. The subsample consisted of a total of 1207 respondents.

THE MOST IMPORTANT FINDING IS THAT:

Almost 30 % of inhabitants in the region believe that the air quality has worsened in the last 10 years, which does not correspond with actual air quality measurements.

The topic of air quality is important to four fifths of inhabitants of the agglomeration. Almost one half of inhabitants are somewhat or definitely unsatisfied with the air quality.

An overwhelming majority of respondents declare their willingness to personally contribute to improving the air and environment in their region. Most often by supporting the planting of greenery (90 %) and not burning household waste (including leaves, grass, paper), but also by using sustainable forms of transport.

The topics of clean air and greenery in cities are especially important to university-educated and younger inhabitants, which is an important message for cities facing an outflow of population mostly from this group. Although we are facing this outflow in our region, we should also take advantage of the fact that there are universities in these cities (Ostrava, Opava, Karviná), as it is young and educated people who produce leaders in thought and politics.

CONCLUSION

Green infrastructure improves the environment with its filtering, cooling, protective and social functions. It contributes to the improvement of air quality in urban environments by removing suspended particles and other pollutants. Green infrastructure, planted and treated with regard to its sensitivity to pollution and its ability to capture pollutants from the air, can be a suitable adaptation measure and solution for improving air quality in places with heavy air pollution.

The present manual, including a case study of greenery planting in Ostrava Bartovice and Radvanice, provides the basic principles of establishing green infrastructure in industrial areas to mitigate the impacts of environmental change through nature-friendly management.

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IMAGES

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