INNOVATIVE GREENERY PROJECT

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(Innovative greenery project – O 5.1.1)

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1. INTRODUCTION

Ostrava, the third largest city in the Czech Republic, is the capital of the Moravian-Silesian Region, lying in the northeast of the country, and it is also an important part of the Central and Eastern European industrial agglomeration with almost 5 million inhabitants living at a distance of 100 km in the Czech, Polish and Slovak parts of the agglomeration.

Since the establishment of the first ironworks in 1828, Ostrava has become an important industrial centre of the country; however, the extent of industrialisation and concentration of heavy industry in the second half of the 20th century exceeded the carrying capacity and caused serious damage to the environment, including enormous air pollution. Despite the restructuring of the sector and numerous effective measures adopted to improve the situation (resulting in a reduction of almost 90% of pollution), air quality is still one of the city's biggest environmental problems, and the city is one of the most polluted in Europe.

The long-term low air quality has led the city and the region to implement various measures to improve the local situation. The CLAIRO project unifies the research activities of the three most important regional universities with the cooperation of public and non-profit institutions, while also involving the public, in order to transfer innovative approaches to the development of the city.

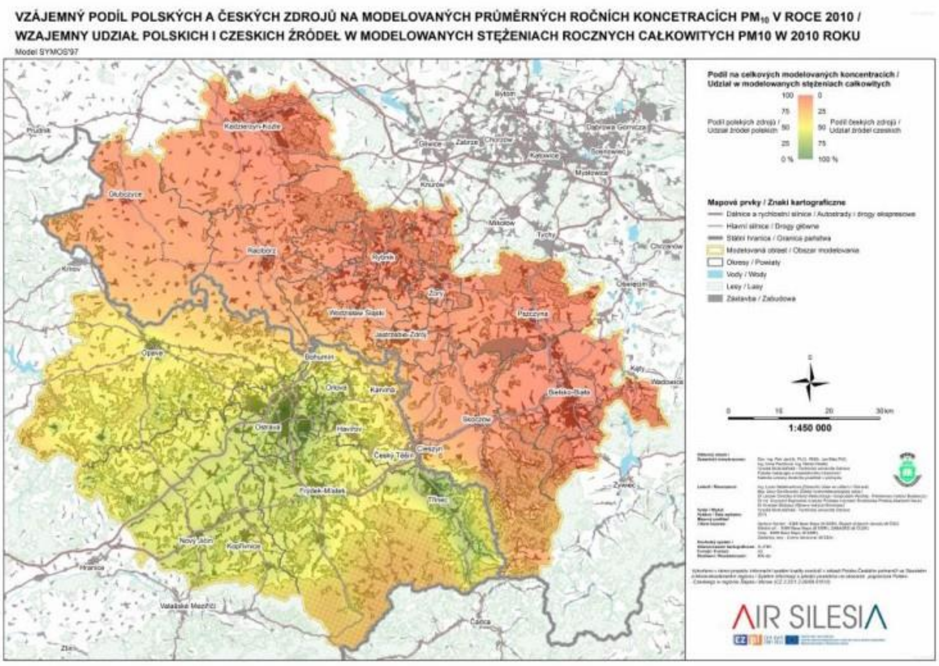
2. BASES

According to the results reported in the ISKO CHMI database for air quality management, until 2014 the valid air pollution limits for suspended particulates PM10 and PM2.5 were exceeded at most monitoring stations in Ostrava. The annual limit value of 40$\mu g/m^3$ was exceeded, the limit of 50 ug/m^3 for the daily concentration of PM10 was exceeded more than 35 times at most Ostrava stations in April. In 2018, the average annual concentration at the Ostrava Radvanice ZU station (ISKO 1650) was 44 ug/m^3 (110% of the limit), ranking the station in 1st place in the list of stations exceeding the valid PM {ut3 }10 limit. For PM2.5, an average annual concentration of 36.8 $\mu g/m^3$ was measured (148 % of the limit). The daily limit at the ISKO 1650 station was exceeded 89x, and 70x at the ISKO 1940 station (Radvanice OZO). (Table yearbook of ISKO CHMI 2019)

The most serious pollutant in the area is benzo(a)pyrene, which can be harmful to health. The annual limit concentration is 1 ng, and it is constantly exceeded at both stations in Radvanice. In 2018, it was 7.7 ng/m^3 at the ISKO 1650 station and 4.7 ng/m^3 at the ISKO 1940 station. This situation is not changing over time, and it poses an increased health risk.

The south-eastern part of Ostrava is one of the worst areas in the Czech Republic due to the accumulation of industrial resources and local heating. In addition, the shape of the valley retains emission in the area during windless periods. Given the seriousness of this problem, air quality is naturally Ostrava's priority number one.

International studies Air Silesia, Air Boarder and Air Region have shown that the main sources of air pollution in Ostrava are stationary sources (metallurgical and energy production), household heating sources and transport. In Ostrava, the fourth most important factor is cross-border pollution from the nearby industrial agglomeration of Katowice (Poland). The situation in Ostrava is worsened by weather conditions - particularly relatively long windless periods, which lead to lengthy inversions in the winter, increasing pollutant concentrations regardless of the reduction in emissions.



The effect of air pollution sources on the Czech-Polish border - model for PM10, source: AIR SILESIA Interreg V-A, VSB TU Ostrava

Studies have shown that there is a clear transmission in the neighbouring country. In the summer pollution flows into Poland, and in winter it flows in the Czech Republic. The amount of exchanged pollution is roughly the same, but in winter it significantly accumulates over time, and this can lead to significant smog episodes.

The monitored area of the project is located in two selected areas in the cadastral communities of Radvanice (715018) and Bartovice (715085) in the Ostrava agglomeration, as the most affected locations in terms of air pollutant concentrations.

The Radvanice area consists of four adjacent arable plots 2601, 2626, 2631 and 2632. This part of the monitored area is more diverse and richer in terms of species diversity. There are scattered solitary trees growing in small forest stands. The existing forest stands extend to the edges of the monitored area. Unlike Bartovice, this area also has herbal growth. The area is significantly more humid, which is reflected in the occurrence of moisture-loving tree species, especially in the surrounding stands, particularly willows and alder trees. There are several technical elements here for air quality monitoring. The total area of Radvanice is 12 175.5 m^2.

The site in Bartovice consists of the western to southwestern edge of the industrial waste landfill on plot 1217. There are currently no technical or vegetation elements in this area. The area is completely empty and barren. Near the monitored area to the east, new woody vegetation elements are already being planted, and a field road leads to the west. The total area of Bartovice is 8 000 m^2.

In addition to the general principles of creating green infrastructure based on the local soil association and the nativity of species in the local region, the green infrastructure should also take into account maximum mitigation of air pollution and the capture of pollutants.

Vegetation primarily removes suspended particulates and other pollutants by capturing them 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. However, most captures particles remain on the surface of the vegetation. The captured particles are subsequently often resuspended into the atmosphere, washed away by precipitation, or deposited on the ground when the leaves fall (Nowak et al., 2006).

Urban vegetation also affects the concentration of suspended particles in the air and indirectly by changing the atmospheric environment in cities. The main mechanism is a reduction of the air flow rate (Froelich, Schmid. 2006). 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 (Raupach et al. 2001). 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 (Löfvenius 1993). Air temperature is the precursor of many pollutants, so reducing it also reduces pollutant concentrations in the air.

Both mechanisms of air pollution reduction are conditioned by the structure of the vegetation growth. Important aspects include the shape and distribution of leaves and needles, as well as the roughness of their surface (Florentina and Io, 2012). 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). In general, the larger the surface area of the vegetation per unit 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 a Willis 2004; Nowak a Heisler, 2010).

An important factor is the annual variability of the structural properties of greenery throughout the year. Experiments have shown a significantly higher capture of pollutants on the surface of evergreen trees throughout the year compared to deciduous trees, which have limited capture ability outside the growing season (Freer-Smith et al., 2005).

Green walls on high-rise buildings, so-called vertical gardens, can also significantly reduce pollutants (Pugh et al., 2012). In the streets of a densely built-up urban environment, we often see a phenomenon in which air flow is slowed down by the side walls of buildings, which leads to a greater concentration of airborne dust in the interspace. Strategic placement of these green walls can effectively capture this pollution. Planting greenery on roofs may have a similarly positive effect (Currie a Bass, 2008).

3. PRINCIPLES OF INNOVATIVE GREENERY PLANTING

3.1 SELECTION OF SPECIES

Plant species were selected on the basis of available scientific materials on the planting of green infrastructure in residential areas. The structure of the planted greenery was designed to monitor the function of air filtration and resistance in industrially stressed areas. Fulfilment of the objectives of the experiment consisted in the design of a continuously connected differentiated tree community. The proposal for the cultivation of a continuous tree community was adopted according to forestry criteria. Criteria of habitat differentiation, tree combinations and planting density were used.

The design of the structure of the plant community focused on habitat-appropriate tree species in mixtures with similar ecological requirements, including layering, the provision of ecological cover and streamlining air filtration. Ecological cover and maximization of pollutant capture will be ensured through the cultivation of woody plants in a continuous canopy.

The parameters of the species composition were determined with regard to the ecological links of individual species and their requirements for the given habitat, which was characterized by soil analysis. The individual species combinations are compatible in terms of growth and demands - the individual layers do not compete in terms of growth and aggressiveness, and the undergrowth tolerates shading. The arrangement of species relative to each other is not important, but for a more regular distribution, they will be planted according to an exact planting scheme. The distribution of taller tree species compared to undergrowth trees and their regular distribution in the area ensures good efficiency of capturing exhalations.

Experimental investigation is a means of verifying the function of greenery in the area of planting before the widespread introduction. The extent of the experiment was adapted to the prevailing growth conditions, including environmental burdens in the intended planting area (Fig 1). For statistically sufficiently probable verification, it is necessary to achieve a continuously connected stand. The experiment was performed as a comparison of the initial state without a sufficiently functional green infrastructure with the change after growth-balanced stages are reached in several species combination and structure variants (Fig 2).

Fig. 1. The tree planting plan at the Ostrava-Radvanice experimental site was situated in the preserved habitat conditions typical for the wider region of the Ostrava Basin, where the proposed vegetation consists of geographically native species.

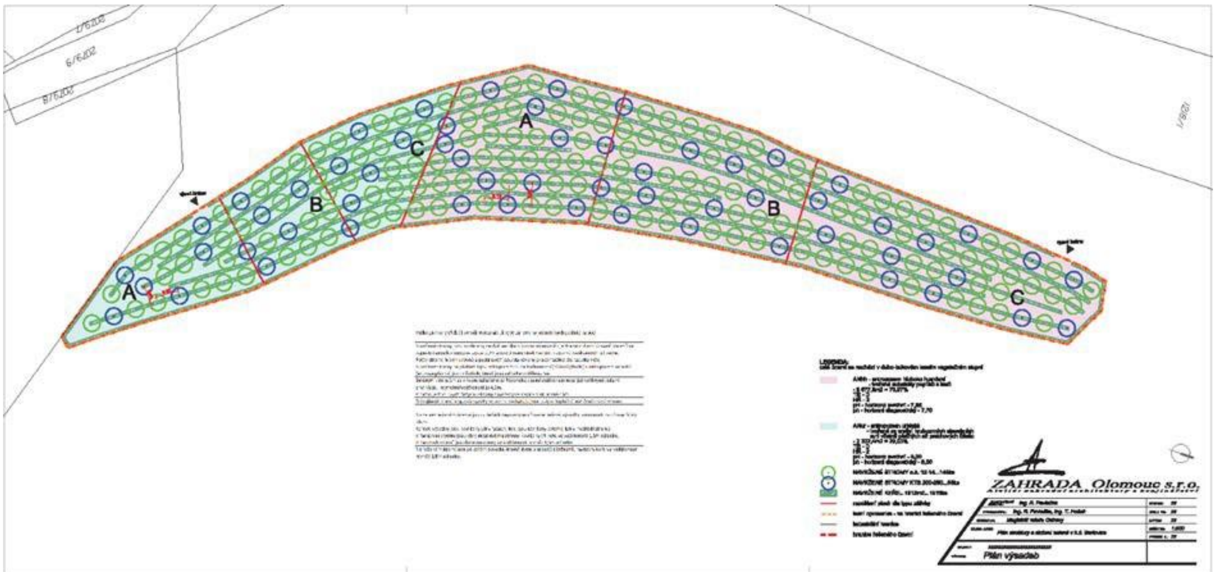


Fig. 2. The tree planting plan at the research site Ostrava - Bartovice is situated on anthropogenic shapes from waste materials, where the proposed vegetation composition is based on a comparison of combinations of non-native resistant species and geographically original pioneer species.

The process of designing the structure of greenery includes the criteria of planting material, allelopathy and replenishment of cultures:

- **Planting material was planted in the form characterized by territorially relevant standards. Plants with a root ball are used for planting.**
- **Unbred plant forms were preferred, with the exception of an experiment comparing unbred and bred plant forms. Domestic plant species were exclusively selected from geographically native unbred populations to preserve the gene pool. Bred forms were only allowed when unbred 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 law or national laws.**
- **Tree layers and a shrub layer. Tree layers are divided into the canopy layer and the understory layer.**
- **Trees up to 4 m in height are preferred for the canopy layer, and up to 2.5 m in height for the understory layer. If any tree species of the required height is not available on the market in a sufficient amount, or if it is necessary to improve the culture after the sudden death of more than 20% of trees, the remaining part of the habitat type will be filled with saplings of all trees of the same species with adjusted spacing (Fig. 3). If a sufficient number of trees are not available, the delivered trees will be evenly planted in each defined polygon of the greenery treatment variant and the remaining areas will be filled with saplings. Replenishment of dead shrubs is not anticipated.**

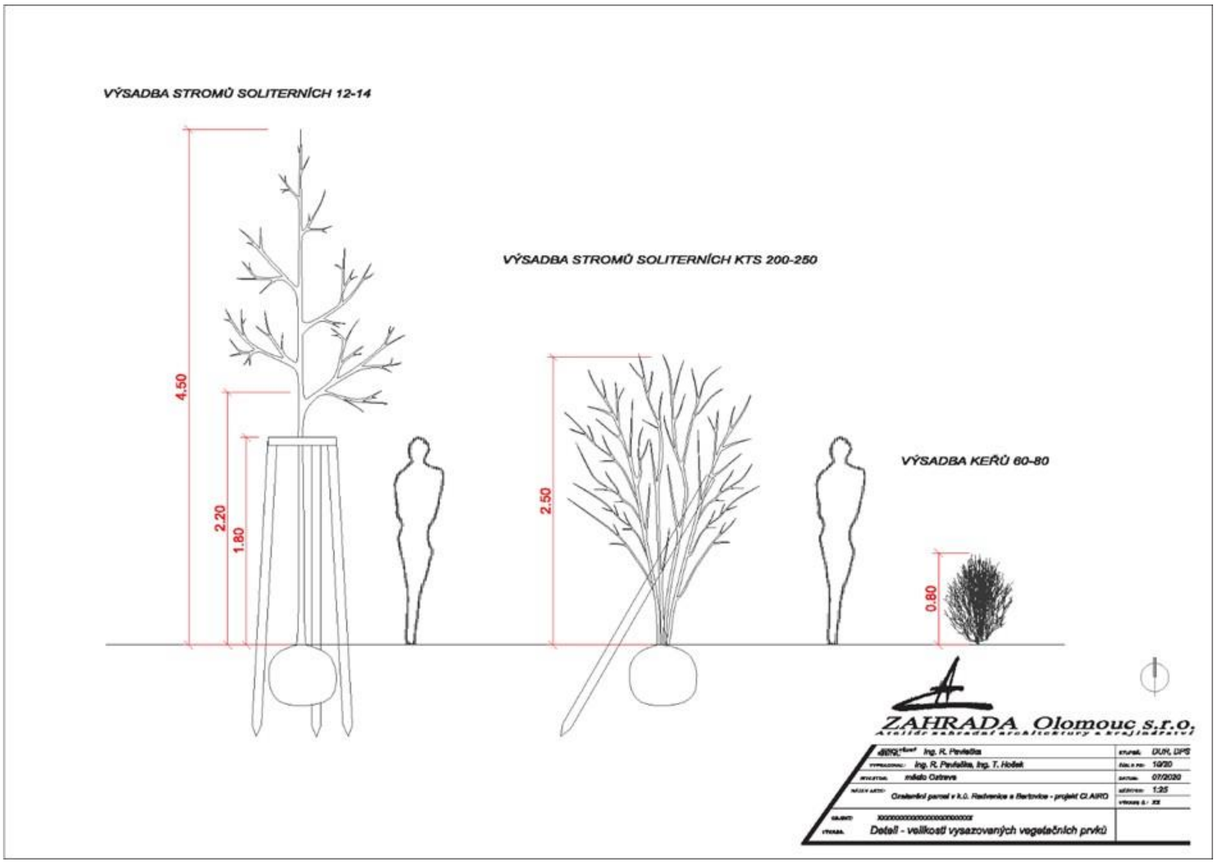


Fig. 3. Preferred heights of planted trees and shrubs for experimental research in anthropogenically disturbed conditions of industrial areas

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. In industrial areas with increased concentrations of tropospheric ozone, it is necessary to pay attention to the sensitivity of the proposed greenery to this pollution when designing the composition of green infrastructure. Assessment of the sensitivity of vegetation to tropospheric ozone is based on the Methodology for assessing visible damage to vegetation caused by the effects of ground-level ozone (Novotný et al., 2009). Coniferous non-deciduous tree species that can catch pollution all year round are preferred.

Species were selected in order to maximize the leaf area where air filtration takes place. Species with a densely branched crown and a large volume of green matter combined with coniferous non-deciduous tree species that can capture pollution all year round were preferred.

3.2 COMPOSITION

The parameters of the species composition were determined with regard to the ecological links of individual species and their requirements for the given habitat, which was characterised by soil analysis.

The individual species combinations are compatible in terms of growth and demands - the individual layers do not compete in terms of growth and aggressiveness, and the undergrowth tolerates shading. The arrangement of species relative to each other is not important, but for a more regular distribution, they will be planted according to an exact planting scheme. The distribution of taller tree species compared to undergrowth trees and their regular distribution in the area ensures good efficiency of capturing exhalations.

The composition of the proposed greenery consisted in the spatial differentiation of the multi-layer tree and shrub communities. The following criteria were used:

1) Two tree layers and a shrub layer in order to maximize the canopy density in the places with the highest pollution. Tree layers are divided into the canopy layer and the understory layer.

2) Trees up to 4 m in height are preferred for the canopy layer, and up to 3 m in height for the understory layer.

3) Minimum spacing between trees taking into account their space requirements in mature state. The planting was planned in a uniformly regular network (ideally hexagonal).

See 3.1 Species selection and Figs. 1, 2 and 3.

The main benefit for the research is that it can compare the investigated quantities on different types of different species.

The proposed solution is applicable to other areas that have similar soil properties.

The main benefit of the chosen composition is the adequate drought resistance of the species combination and their efficiency in capturing dust particles throughout the year due to the addition of coniferous trees.

One of the many benefits of urban greenery is its ability to remove harmful substances from the air and thus alleviate the health problems that these substances cause at higher concentrations. These substances particularly include ozone, nitrogen oxides (NOx) and dust particles (PMx), which have a negative impact on human health and the environment.

Urban greenery has a great impact on improving air quality, which is also confirmed by the research of Nowak (1994) and Beckett et al. (2000). The effect of vegetation on the capture of suspended particulates depends on the vegetation's properties. Important aspects include the shape and distribution of leaves and needles, as well as the roughness of their surface (Florentina and Io, 2012). It is not only the properties of plant organs that are decisive, it is also the overall structure of the vegetation, such as the height and density of the canopy and the spatial arrangement of the branches (Litschke and Kuttler, 2008). In general, the larger the surface area of the greenery, the greater the capture of harmful substances. As a result, mature trees are more efficient than low herbaceous vegetation (Lovett 1994; Powe and Willis, 2004). Kiss et al. (2015) found that the average value of the capture several pollutants by one tree is between 200-400 g/year. Overall, areas with a higher proportion of trees in urban environments, such as parks and gardens, may have up to four times better air quality than the surrounding area (Nowak and Heisler, 2010). As the properties of vegetation change throughout the year, the capture of particles by vegetation also shows considerable seasonal variability. Experiments have shown than coniferous trees capture a significantly higher amount of particles compared to deciduous trees, whose ability to capture particles decreases significantly after defoliation outside the growing season (Freer-Smith et al., 2005).

The ability of air pollutant capture was evaluated on an example of O3, NOx and PM10 with the current and proposed urban greenery of different species and different placement in the use of model areas in the city of Ostrava. According to the dendrometric survey (height, crown projection area) and the determined species representation and health status, different types of urban greenery have a different leaf area index (LAI). A detailed vegetation inventory was performed and LAI values and stand height were approximated in small detail. This enabled us to model pollutant capture by the current and proposed greenery in both locations (Radvanice, Bartovice) in a detailed 1 x 1 m network.

Current vegetation

A field survey of the current vegetation was conducted at area of interest A - Radvanice August and September 2019. A field survey at site B - Bartovice showed that there is no vegetation in the area that would have a significant effect on the capture of pollutants, and the resulting pollutant capture by the current vegetation was determined to be zero.

The vegetation survey at area of interest A - Radvanice was divided into grassland/herb habitats and trees. The gassland/herb communities consisted of the species Arrhenatherum elatius and Poa trivialis , reaching an average height of 0.3 m above the surface. Tree species were inventoried as solitary trees or shrubs (solitaire) or clusters of multiple tree species (community). Solitary trees were identified by morphological features according to San-Miguel-Ayanz et al. (2016). The taxon was determined for all tree species, the height (h) was measured using a digital altimeter with an ultrasonic rangefinder, as well as the mean crown projection (dk), and the health status was classified on the basis of non-specific symptoms of trunk and crown damage, branching disorders and the occurrence of wood-destroying fungi or rot (Korf 1972; Kandler and Innes 1995). Tree clusters were characterised by the mean stand height, crown diameter and the frequency of non-specific damage (Keller et al., 1997). The projection of the crowns of the tree communities was deducted as the longest axis of the cluster. The characteristics of the current vegetation determined based on a field inventory are summarized in Table 1.

Tab. 1. Overview of tree characteristics based on a field inventory, site A - Radvanice

Identification number	Occurrence	Taxon (dominant)	Crown height	Mean crown projection area (m)	Damage (%)
1	solitary	*Salix caprea*	12	7	26 – 50
2	solitary	*Crataegus monogyna*	6	4	11 – 25
3	solitary	*Juglans regia*	8	7	1 – 10
4	solitary	*Juglans regia*	13	10	1 – 10
5	community	*Juglans regia*	12	13	11 – 25
6	community	*Crataegus monogyna*	10	7	11 – 25
7	solitary	*Juglans regia*	11	10	1 – 10
8	solitary	*Juglans regia*	9	6	1 – 10
9	solitary	*Crataegus monogyna*	8	6	1 – 10
10	solitary	*Acer negundo*	11	7	1 – 10
11	community	*Salix caprea*	14	20	1 – 10
12	community	*Alnus glutinosa*	30	20	26 – 50
13	community	*Fraxinus sp.*	25	14	26 – 50
14	community	*Alnus glutinosa*	22	4	11 – 25
15	community	*Acer negudo*	10	3	1 – 10
17	community	*Populus tremula*	25	11	11 – 25
18	community	*Populus tremula*	25	5	11 – 25
19	community	*Salix Fragilis*	20	6	11 – 25

Individual tree species were positioned on the basis of vectorisation of an aerial orthophoto with a resolution of 0.2 metres, taken in 2018 by the Czech Office for Surveying, Mapping and Cadastre. Their position in site A - Radvanice is shown in Fig. 4.

Fig. 4. Overview map of the current vegetation in area of interest A – Radvanice The basis is an orthophotomap from 2018 distributed by the Czech Office for Surveying, Mapping and Cadastre. The numbers correspond to the identification numbers in Tab. 1.

Proposed vegetation

The characteristics of the proposed vegetation were determined based on the assumed attributes and species composition specified in the underlying documentation of the planting plan. The following attributes were distinguished: the height of the proposed greenery, the species composition and the mean projection of the crown. The health of the new plantings was assumed to be excellent, i.e. with no damage. The height of the vegetation was established at 4.5 meters for solitary trees of vertical canopy layer, 2.5 meters for multi-stemmed trees of the understory layer and 0.80 meters 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 vectorised and the above attributes were assigned to them (Figs. 5 and 6).

Fig. 5. Layout of the proposed vegetation in site A - Radvanice, vectorised based on the planting plan. The basis consists of an aerial orthophoto from 2018.

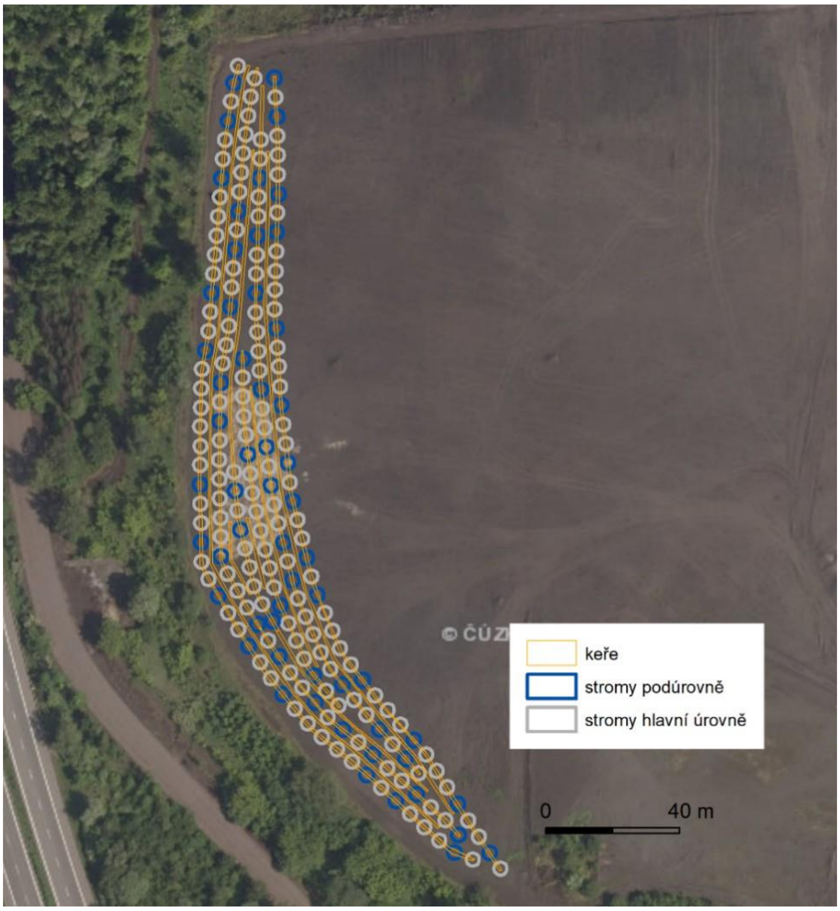


Fig. 6. Layout of the proposed vegetation in site B - Radvanice, vectorised based on the planting plan. The basis consists of an aerial orthophoto from 2018.

Based on these attributes, the input LAI and the height of the stand were determined for the proposed vegetation, as was the case with the current greenery. The LAI was set at 1.5 at shrub planting sites. In places with a herbaceous, shrub and tree layer, 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. The value of the highest point of the vegetation from both states at the given place was used for the stand height (Fig. 7).

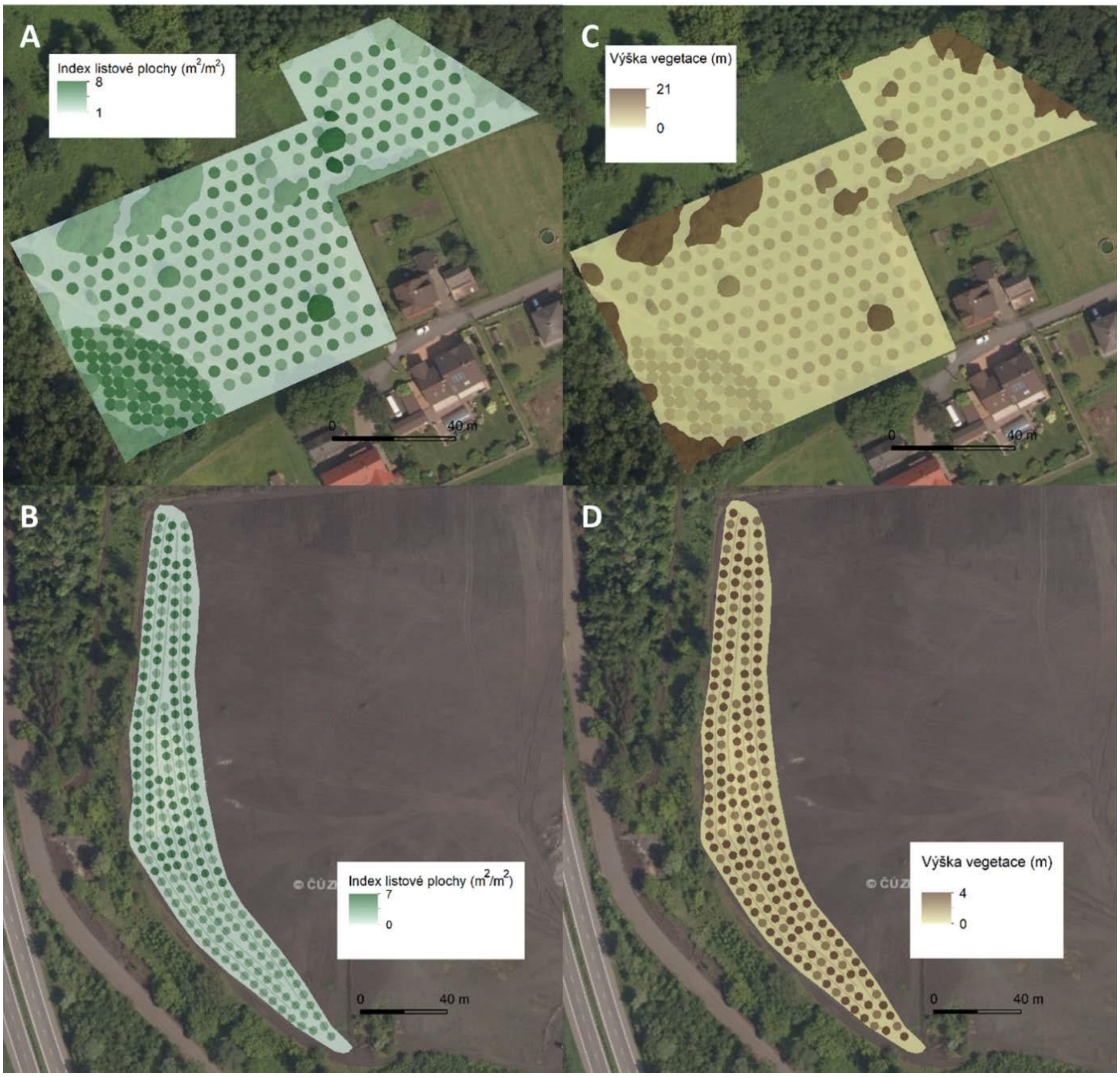


Fig. 7. Input parameters LAI (Leaf Area Index m^2m^{-2}), (A,B) and stand height (m), (C, D) for the proposed vegetation (inclusive).

Capture of ozone, nitrogen oxides and PM10 particles by vegetation

The quantification of pollutant capture (Q) by the current and proposed vegetation at the given site (Radvanice, Bartovice) during a certain period of time (September - October 2019) was calculated according to (Janhäll, 2015):

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

where Q is the amount of gases and particles captured by vegetation in a certain area and time period (gm^{-2}), F is the deposition flux of gases and particles ($g\ m^2\ s^{-1}$), LAI is the leaf area index ($m^2\ m^{-2}$) and T is the time period (s).

The deposition flux (F) of gases and particles was determined from the measured concentrations of these components and from the corresponding deposition rates:

$F = vd(z)c(z)$,

where F is the deposition flux of gases and particles per unit of area (g m^2 s^{-1}), vd is the deposition rate of the component (m s^{-1}) and c(z) is the concentration of the component at height z above the ground (gm^{-3}). The concentration of the individual components was measured by sensors. The deposition rates of gases and particles were modelled using a multiple resistance model (Zapletal, 2006) from meteorological data and greenery characteristics.

Tab. 2 shows the total leaf area (m^2) and the total capture of O_3, NO_x and PM_{10} (kg) by the current vegetation, the proposed vegetation and the proposed and current vegetation inclusive, in the two areas of interest, namely Radvanice, Bartovice, in September and October 2019. Figs. 8 to 10 show the capture of O_3 (g), NO_x and PM_{10} by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site A - Radvanice. Figs. 11 to 13 show the capture of O_3 (g), NO_x and PM_{10} by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site B - Bartovice.

Tab. 2. The total leaf area (m^2) and the total capture of O_3, NO_x and PM_{10} (kg) by the current vegetation, the proposed vegetation and the proposed and current vegetation inclusive, in the two areas of interest, namely Radvanice, Bartovice, in September and October 2019.

Current vegetation	Site A - Radvanice		Site B - Bartovice	
	Leaf area (m^2)	Capture (kg)	Leaf area (m^2)	Capture (kg)
O_3	14869	11,9	0	0
NO_x	14869	0,7	0	0
PM_{10}	14869	1,0	0	0

Proposed vegetation	RADVANICE SITE		BARTOVICE SITE	
	Leaf area	Capture (kg)	Leaf area	Capture (kg)
O_3	12044	14,7	12243	17,8
NO_x	12044	0,8	12243	0,8
PM_{10}	12044	1,8	12243	1,3

Proposed and current vegetation	Site A - Radvanice		Site B - Bartovice	
	Leaf area (m^2)	Capture (kg)	Leaf area	Capture (kg)
O_3	26913	26,6	12243	17,8
NO_x	26913	1,5	12243	0,8
PM_{10}	26913	2,8	12243	1,3

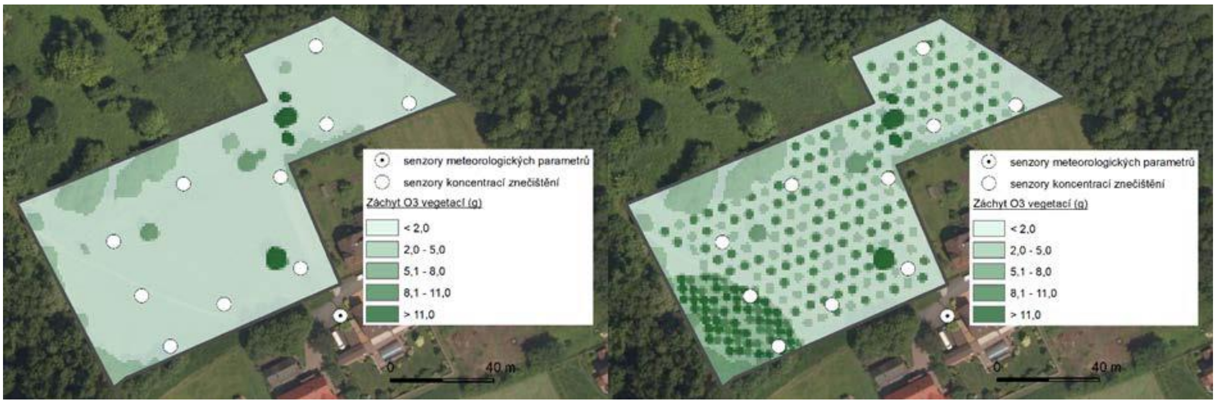


Fig. 8. Capture of O_3 (g) by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site A - Radvanice

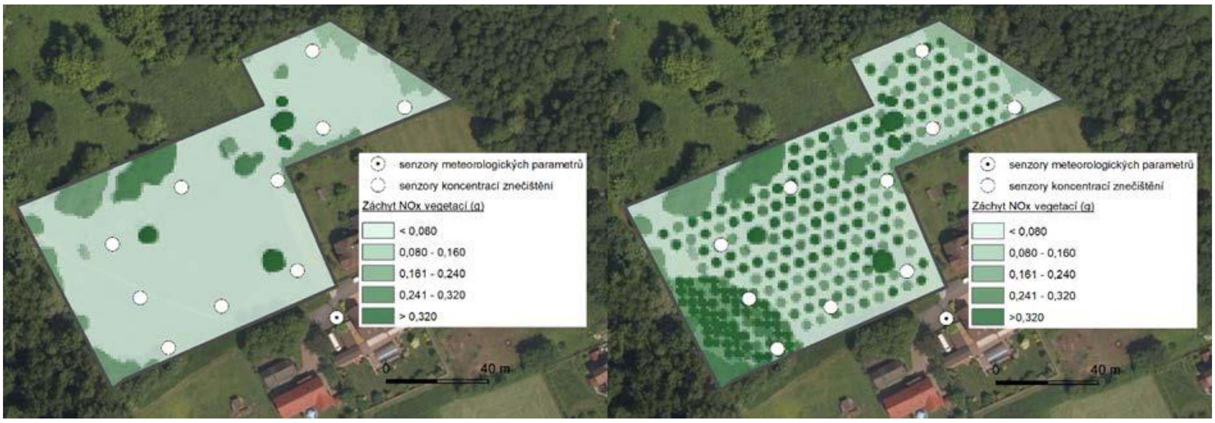


Fig. 9. Capture of NO_x (g) by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site A - Radvanice

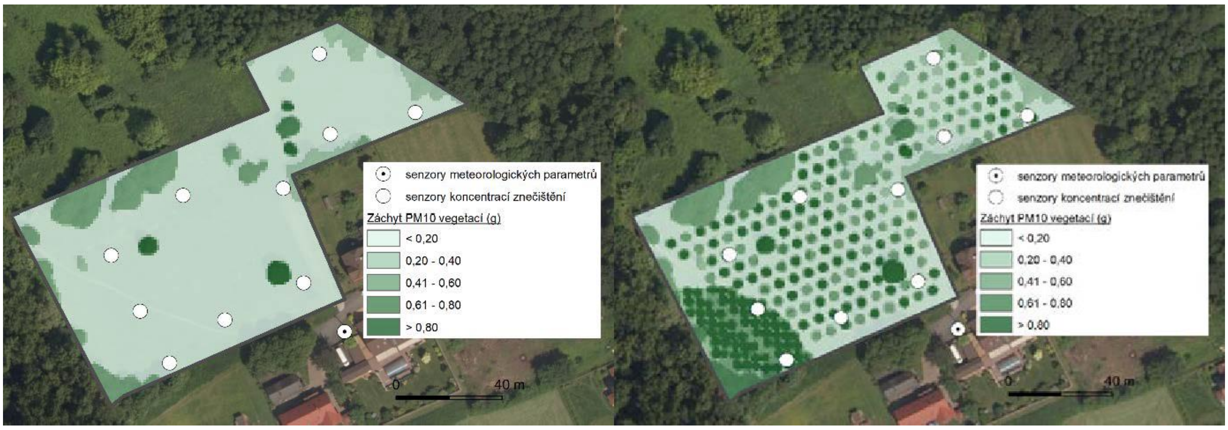


Fig. 10. Capture of PM_{10} (g) by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site A - Radvanice

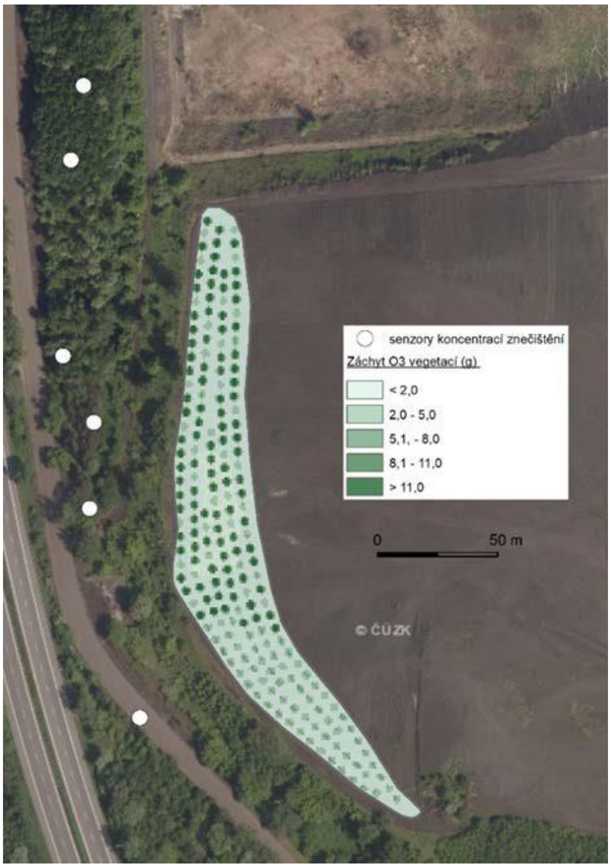


Fig. 11. Capture of O3 (g) by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site B - Bartovice

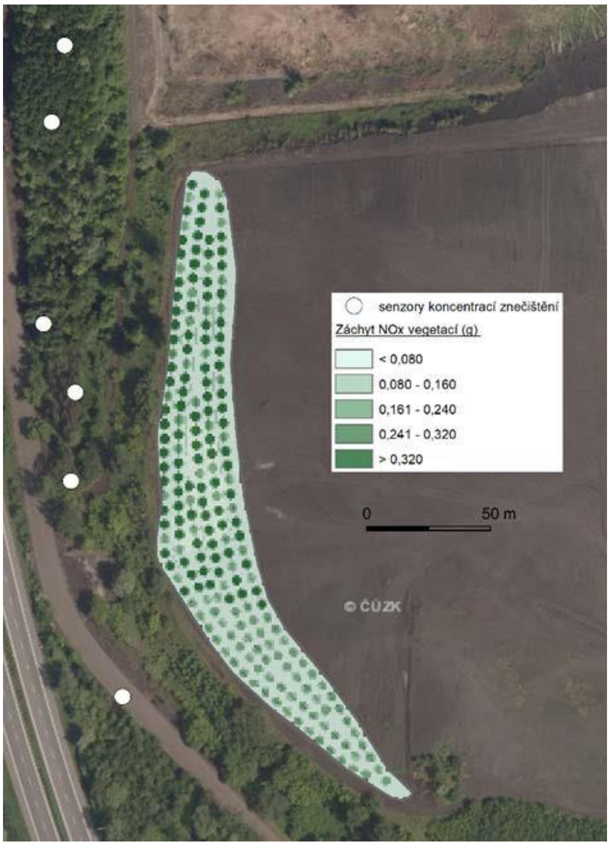


Fig. 12. Capture of NOx (g) by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site B - Bartovice

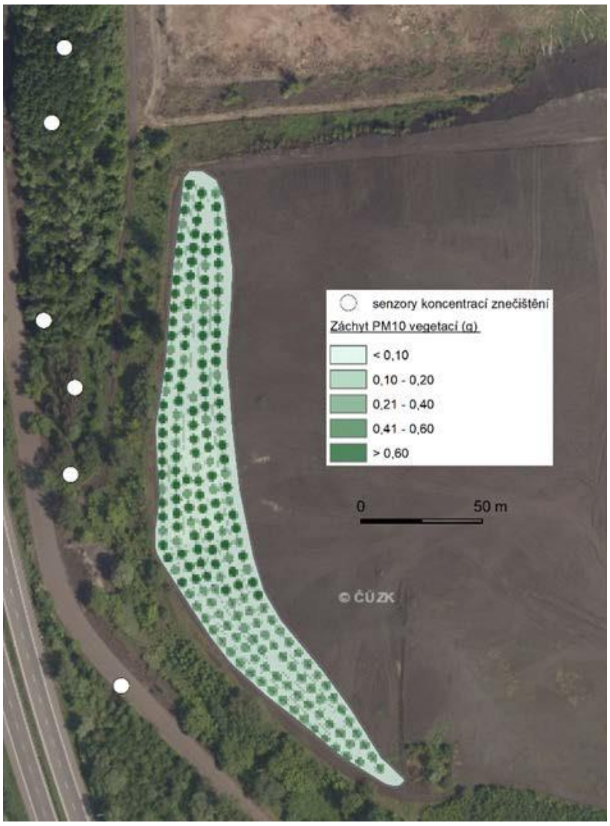


Fig. 13. Capture of PM10 (g) by the current and proposed vegetation (including the current vegetation) in a 1 x 1 m network at site B - Bartovice

3.3 INNOVATIVE GREENERY TREATMENT

One of the world's greatest environmental challenges is to reduce the negative environmental impact of intensive agriculture. Intensive chemical treatment affects key ecophysiological properties of plants, symbiosis with mycorrhizal fungi and endophytic microorganisms. 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 not only for new systems of sustainable crop production, but also for the treatment of new greenery in an urban environment, i.e. in locations often exposed to a combination of different forms of abiotic stress.

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 effect of the hormone must always be preceded by binding to a specific receptor. The function of phytohormones is non-specific; one hormone can affect multiple processes. In a relationship, hormones can act in a synergistic or antagonistic way. Phytohormones are used as growth regulators in plant production and plant biotechnology; in high concentrations they act as herbicides for weed control. The main groups of phytohormones are: auxins, cytokinins, gibberellins, abscisic acid, ethylene, brassinosteroids, jasmonates, strigolactones. 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. Interestingly, the exact mechanism of the action of most biostimulants is unknown, which opens up a number of possibilities for scientific research. Biostimulants may contain phytohormones, but this term is most commonly associated with protein hydrolysates, seaweed extracts, vermicomposts, and humic acids.

The combination of phytohormones and biostimulants proposed for this project is a unique result of up to 20 years of research conducted in the Laboratory of Growth Regulators, Faculty of Science, Palacký University, and the Institute of Experimental Botany of the Czech Academy of Sciences; it is the subject of several international patents licensed to Czech and foreign companies operating in the field of foliar fertilisers.

The 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, and tested on forest cultures.This preparation will be used as a basis for the application of our active substance, a patented cytokinin derivative.

There are 2 different types of soil conditions at both sites. This fact means that each of the sites will be divided into six sub-sections (3 sections for each soil type) so that the individual sub-sections can be treated with three types of fertiliser (classic fertiliser A, commercial fertiliser based on modern biostimulants B, and innovative fertiliser C) .

Variant A will be treated on the same dates as the remaining variants, but only with fertilizer containing a common commercial inorganic fertilizer chosen by the planting company based on its experience.

Option B, i.e. treatment with a commercial biostimulant, will take place twice a year (June and August-September in the first year, April and August-September in the following years). The product TS Sentinel (https://www.trisol.farm/pripravky_profi/sentinel.html), TS VIN (https://www.trisol.farm/pripravky_profi/vin.html) or a similar product from another company containing an optimal combination 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, and tested on forest cultures, was chosen for the CLAIRO project. The dose of 2.5 ml/plant must be diluted with about 2L of water before application.

During the initial planting, we suggest a single application of TS HG Plant or a similar product containing humic acids, anti-stress substances and seaweed extracts (https://www.trisol.farm/pipravky_profi/hg-plant.html{ut3 }) at a dose of 2 g per seedling (ideally for all three variants, or at least for variants B and C).

Product B will be used as a base for the application of our active substance, the cytokinin derivative RR-D (in a concentration of 10-5 mol/L), i.e. variant C. The application will take place on the same dates as variant B. Both variants (B and C) will be completely prepared by Palacký University in Olomouc and delivered to the implementing company at least one week before each application.

All other standard crop treatments (watering, weeding, etc.) should be the same for all three variants - on the same dates, in the same amounts, etc., and they should be carried out regularly by the planting company to ensure evaluation and comparison of individual treatment variants.

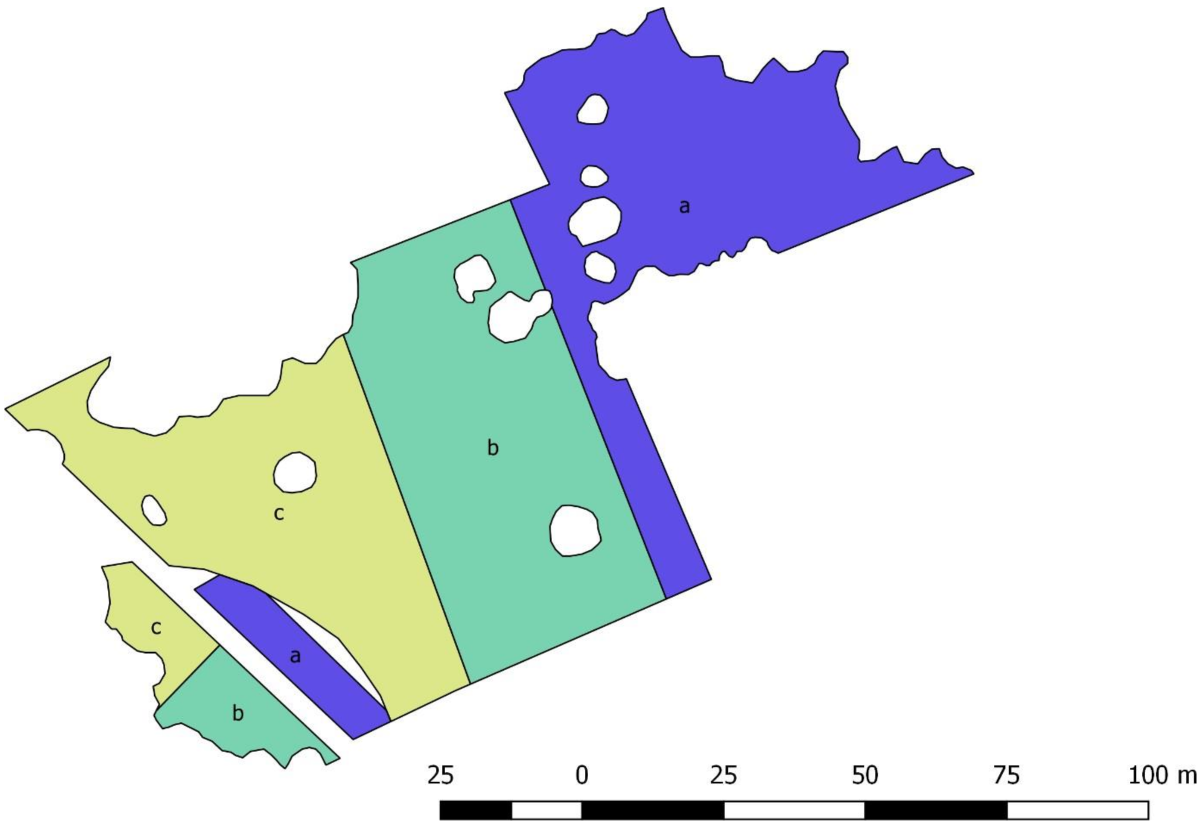
This is far from the first application; however, their use in the CLAIRO project is unique in some respects, especially the levels and combinations of different types of abiotic stress at the selected sites.

The main prerequisite for the application of innovative treatment is the improvement of the basic physiological parameters of the new greenery.

The prognosis assumes that trees and shrubs in better 'health' will better photosynthesize and will have more and better leaf areas, which will certainly have a positive effect on pollutant capture; it is certainly an important part that will significantly affect the result.

The fertiliser can be applied to any plants in any place.

Within a series of workshops that are part of the CLAIRO project, city representatives will be presented with all the essential information on how to use innovative treatments for new greenery in the urban environment.



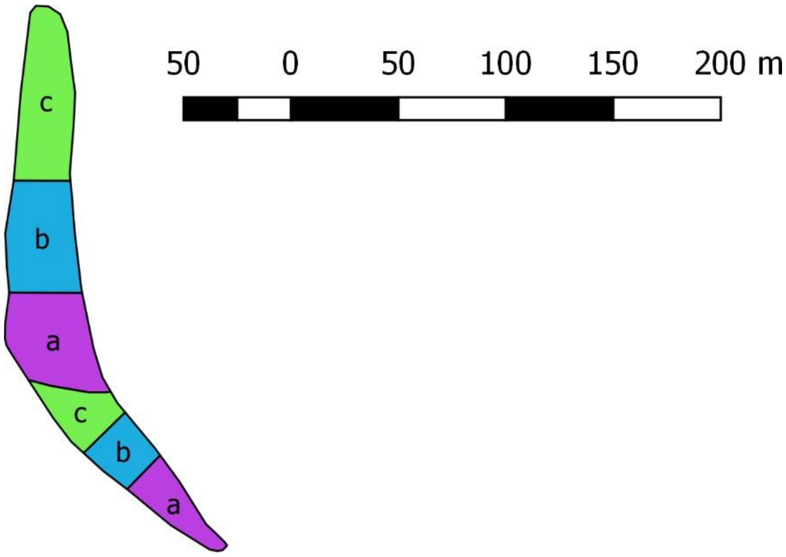


Fig. 14. Proposal of the scope of individual chemical treatment variants for the proposed greenery at the Bartovice and Radvanice sites

3.4 MONITORING POLLUTANT CAPTURE

Air monitoring at the site with planned greenery planting has been ongoing since 1 September 2019. In the monitored period until 30 September 2020, the following characteristics can be listed. These statistics are based on primary - unvalidated values.

sen./ substa nce	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
yield																									
PM_{10}	98,9	99,3	99,2	98,8	99,1	99,4	98,8	99,3	98,6	99,1	99,1	98,9	99,3	99,4	99,4	99,3	99,4	99,1	99,4	23,8	92,6	91,8	93,9	93,6	93,3
NO_2	96,7	96,7	96,7	96,8	96,7	96,9	96,8	96,9	96,7	96,7	96,7	96,7	96,7	97,0	96,7	96,8	96,9	96,7	74,5	78,4	81,2	80,1	77,3	76,5	79,9
O_3	98,0	97,9	98,0	98,0	98,0	97,9	97,4	98,0	98,0	98,0	98,0	98,0	98,0	98,0	98,0	98,0	98,0	98,0	64,2	93,9	93,6	93,3	29,2	29,8	29,8
average concentration in the measured period (ug/m^3)																									
PM_{10}	34,0	35,3	35,9	36,3	32,8	34,6	37,5	33,4	38,5	38,5	37,7	36,8	33,9	35,5	27,8	36,3	33,3	33,0	30,7	43,6	30,1	36,9	30,3	32,6	34,0
NO_2	14,6	12,9	13,5	15,0	13,6	13,9	16,2	15,7	13,4	13,3	12,7	14,7	14,9	14,4	13,6	13,9	14,3	16,4	16,2	33,8	32,9	25,5	24,8	25,2	37,6
O_3	45,8	49,8	48,2	48,3	44,6	47,0	45,0	48,8	42,5	43,4	47,7	49,0	50,3	49,4	45,8	52,7	50,7	49,5	42,0	30,3	32,6	34,0	26,0	27,4	28,8
maximum concentration in the measured period (ug/m^3)																									
PM_{10}	227,8	218,8	216,7	204,9	225,2	264,8	199,0	219,3	240,7	241,5	198,6	219,0	219,0	209,0	215,0	212,3	207,2	231,5	240,5	138,0	211,0	220,4	203,4	244,9	241,5
NO_2	138,4	157,6	150,0	146,0	115,5	139,4	104,9	160,5	140,3	112,6	143,0	143,9	101,0	107,6	105,9	134,6	123,9	132,9	106,9	108,7	103,7	145,2	142,5	130,3	147,2
O_3	195,1	191,1	181,9	222,6	210,9	174,4	185,6	213,3	180,3	217,2	173,5	164,4	179,5	189,6	177,2	183,6	238,9	222,9	202,5	107,0	108,7	101,8	101,9	103,8	105,8

The measurement yield from all sensors is very good, with the worst yield by NO2 sensors, but it is still sufficient with 5-minute average data.

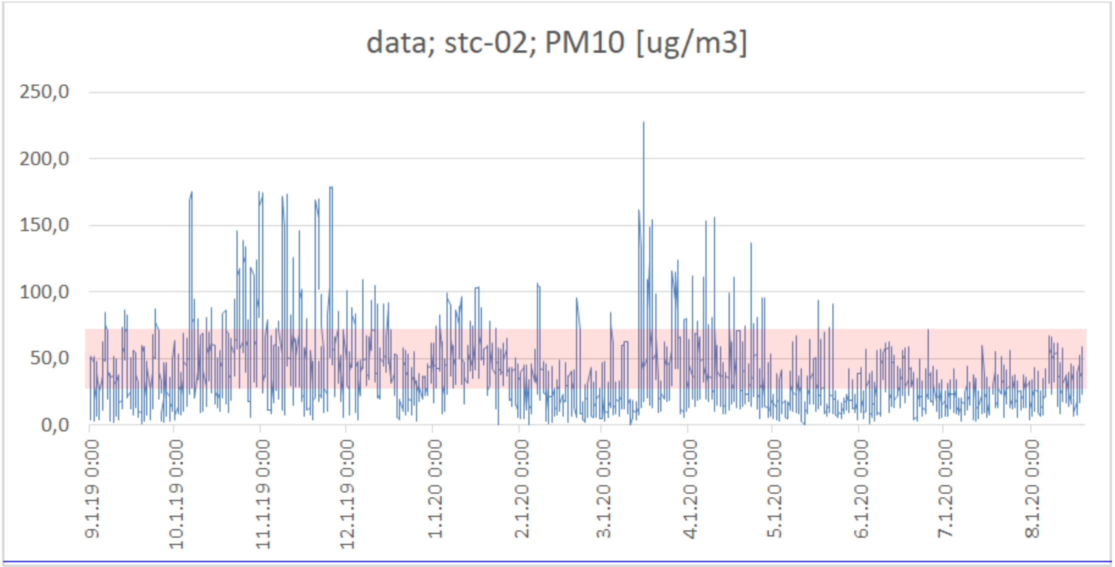
Average PM_{10} concentrations do not exceed the limit, with the exception of 1 sensor, which may be due to a nearby ash pond. Given that Přední Street is located in the most exposed area of Ostrava, this value is also very optimistic. PM_{10} concentrations measured by all sensors at the planting site are very similar, which corresponds to the proximity of their mutual location (approx. 15 m).

NO2 and O3 concentrations are also very favourable, under 50 % of the limit.

Sensors 19–25 were located in Opava and Třinec, and we can see a difference from the site in Radvanice. They are more significantly affected by traffic; NO2 concentrations are about 2 times higher than in the meadow by Přední Street.

The maximum concentrations indicate that there is a short-term exceedance of the PM_{10} limit of 50 ug/m^3 by up to four times. However, the frequency of such concentrations is low and they mostly occur during the heating season. To provide a general idea, a chart of the curve of hourly concentrations on Přední Street is shown below. The limit value is shown in the chart as a red field.

The chart shows that the daily limit of 50 ug/m^3 for PM_{10} was exceeded in November and December 2019 and at the turn of March 2020.



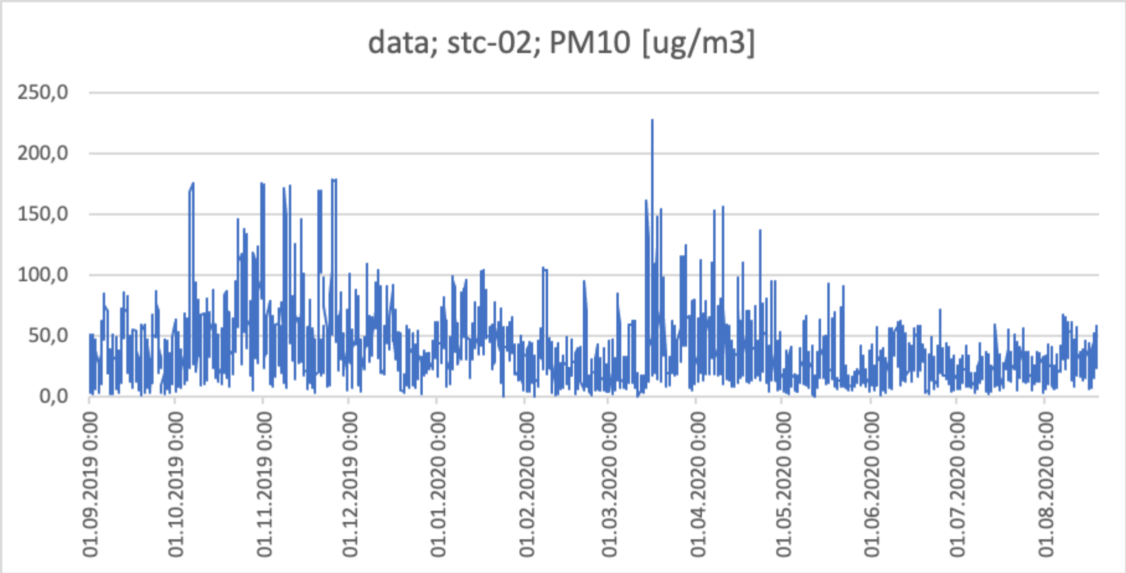


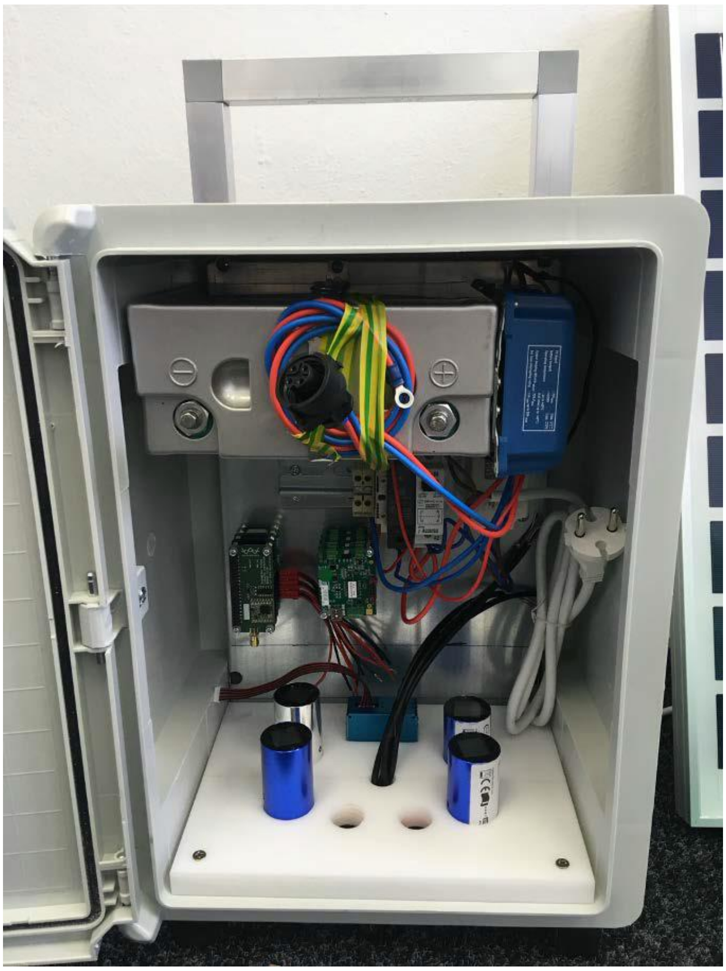
Fig. 15. Chart of hourly PM_{10} concentrations for the whole period

The devices were selected according to the project specifications and with regard to the applicable limits of air pollutants.

Device specification

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.

The box is alternately independent of the energy source; they contain a battery and are connected to a solar panel and 220 V mains. The device is designed for installation up to a height of 3 - 8 m, and power must be ensured at least through a solar panel (there must be access to the sun).



Sensors provide very fast measurements in a matter of minutes, which are transmitted via the LORA radio network to the database at VSB.

Common sensor parameters

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

Measurement

- Type of measurement: electrochemical sensor
- Minimum range: 0–250 ppb
- Detection limit: ≤20 ppb
- Frequency of the provision of measured data: ≤1 min O3 sensors

- Type of measurement: electrochemical sensor
- Minimum range: 0–5000 ppb
- Detection limit: ≤40 ppb
- Frequency of the provision of measured data: ≤1 min PMx 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/m^3
- Detection limit: ≤1 µg/m^3

VOC sensors

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

The sensor units are connected to one common network and they provide online data wirelessly.

Data are transferred to the existing intelligent information system (IIS), which allows:

- communication with measuring systems in the network
- online visualisation of measured values

- online display of measured data in graphical and tabular form
- value database management, corrections and modifications - all with registration
- generating maps for GIS in layers
- creation and archiving of animations from map materials

The above parameters were part of the Public Procurement, which took place in accordance with the "Public Procurement Act…".

Given the issues with the LORA network, GPRS transmission was later added to the sensor units.

Třinec, Opava, Frýdek - Místek, Karviná, Havířov and Rychvald were selected for pilot measurements of air pollution. Their involvement is gradual, and an analytical measurement report will be given to each of the them upon completion. Measurements were so far carried out in Třinec and Opava. Monitoring in other cities is not used to control limits. However, if we use the measurement of nitrogen oxides and ozone to identify the impact of traffic, the measurement is very appropriate, and it will allow assessment of the impact of traffic.

The project assesses the impact of greenery on reducing air pollutants. We have known of the ability of greenery to reduce the amount of dust in the air for a long time, but the project addresses the selection of suitable greenery, the method of its planting and special treatment with phytohormones. Simply put, it is about streamlining the process of removing dust and other substances by planting greenery that is resistant to a 'stressful' environment. The effect of greenery is continuously verified by sensor technology, linked to reference analytical equipment. There are 19 sensor units and 1 reference system in the test locations near Liberty Ostrava. Each cooperating city will be measured by the same technology with 3 sensor units. Monitoring is performed gradually before the greenery is planted and after it is planted. The sensors will measure for over 8 years. The effect of greenery on concentrations of suspended particles PMx, nitrogen oxides and ground-level ozone is monitored. The purpose of the measurement and the nature of the methodology used must be taken into account when applying the measurement results, and it's necessary to realize that monitoring does not serve to control the limits, but rather for comparison. The conformity of measurement by sensors and reference analysers is excellent for PMx, which are the most serious pollutant, and not as high for NO2 and O3. However, if we use the measurement of nitrogen oxides and ozone to identify the impact of traffic, the measurement is very appropriate and it will allow assessment of the impact of traffic.

Despite this, we can make several conclusions:

- Sensors are suitable for supplemental measurement, they are easy to install and operate.
- Data transmissions are a weak spot, increasing costs in the case of a transition to GPRS.
- Sensors can discover 'unusual' situations at the site and reveal the time of specific events.
- Each sensor is different and they must be controlled.
- The sensitivity of the sensors did not decline during the measurement, so we can assume that
- they will remain stable for 1 year and longer; with dropping prices, this is an excellent conclusion.
- The results must always be interpreted by an expert; only 'unvalidated' data are available online.
- Sensors are suitable for identifying a local problem.

Data processing

The concentrations of the measured substances will be transferred online for further processing to the database of the Intelligent Identification System - IIS, which was created at VSB within the IIS project. This system can receive any transmitted data, store them in a structured database and work with them according to specified algorithms.

Data are always stored in a primarily transmitted format. In the case of calibration inspections, IIS allows the measured values to be validated by a correction factor. This is recorded in the system. Validation is generally not performed for reference methods that use the calibrated devices. PMx determined by an equivalent method, the correction factor of which may vary slightly depending on the period and place, may be an exception. VSB regularly checks dust metres gravimetrically with its analysers.

The IIS system was developed to simplify the identification of air pollution sources on a local scale. The system is entered via the airsens.eu portal.

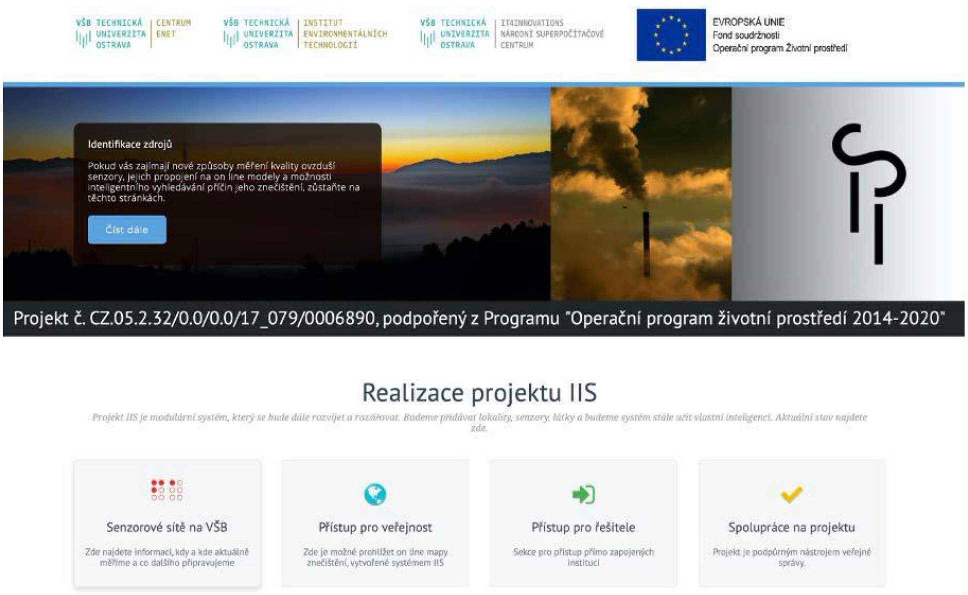
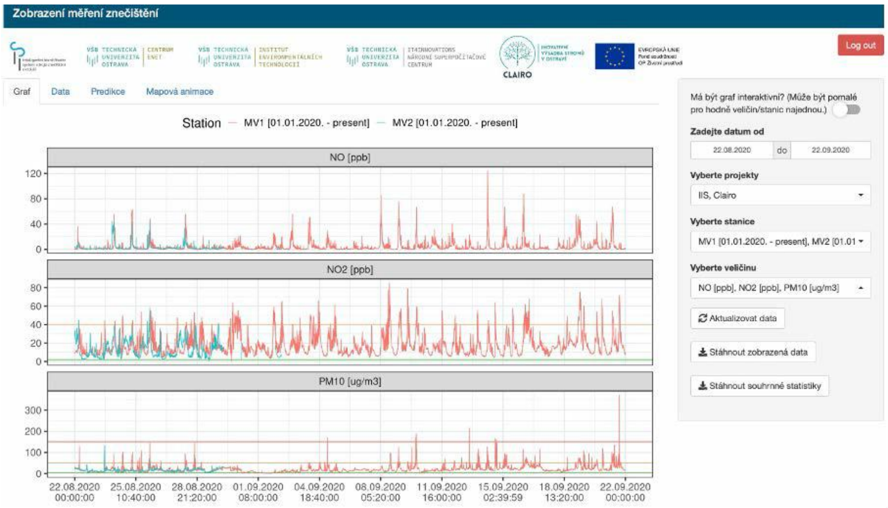


Fig. 16: Entry into the IIS system via the airsense.eu portal

The IIS system allows choosing substances, sites and periods, and it performs basic statistical evaluations. It checks the valid measurements, calculates the averages and finds the maxima of the measured concentrations. It displays the measured concentrations in a chart. These data are used to check data consistency, or for comparison with other measurements.



	Stanice	Veličina	Vzorkování [min]	Všechna pozorování	Validní pozorování	Minimum	Ar. průměr	Geom. průměr	Maximum
1	MV1 [01.01.2020. - present]	NO [ppb]	5	8929	8758	0	4.5	0	124.2
2	MV1 [01.01.2020. - present]	NO2 [ppb]	5	8929	8926	0	17.7	0	85.2
3	MV1 [01.01.2020. - present]	PM10 [ug/m3]	5	8929	8926	1	21.3	16.8	372.3
4	MV2 [01.01.2020. - present]	NO [ppb]	5	8929	2531	0.2	2.8	1.7	45.2
5	MV2 [01.01.2020. - present]	NO2 [ppb]	5	8929	2530	0.4	12.7	9.7	57.8
6	MV2 [01.01.2020. - present]	PM10 [ug/m3]	5	8929	2409	3.3	15.5	14.1	132.9

Showing 1 to 6 of 6 entries

Previous 1 Next

Fig. 17: Basic statistical data from measurements

Thanks to short-term concentrations, we can find the time and place of 'unusual or unwanted' air pollution concentrations. The IIS system uses specified rules to indicate where and when the set concentration level was exceeded (increased). The system allows automatic animation of measured concentrations.

Fig. 18: Map section with concentration interpolation (PM_{10})

All statistical characteristics for the selected period are displayed in the same way. You can find the places with the highest average concentration, with the highest maxima, places that exceed the limit most frequently, etc.

The result of this process is an evaluation of when and where the set rules are violated (limit, regulatory limit, monitoring limit, rate of increase in concentrations, correlation with other attributes, etc.).

4. CONCLUSION

The innovative greenery planting project provides the basic principles for establishing green infrastructure in industrial areas to mitigate the effects of environmental change through nature-friendly management. Green infrastructure improves the environment with its filtering, cooling, protective and social functions. Because green infrastructure is required to deliver several benefits at the same time in industrial areas, its cultivation is successful in applying monitoring approaches and sustainable use of ecosystems.

The sustainable cultivation of green infrastructure in industrial areas consists of a description of the current growth conditions, the design of a green structure and differentiation of care. The description of the current condition consists of the characteristics of growth conditions and the condition of vegetation. The characteristics of growth conditions include a survey of the geological subsoil, relief and soil properties. The spatial relationships between the subsoil type, the relief type and the soil type are used to derive the local soil association in the occurring climatic conditions. The soil association forms the basis for both the design of the green infrastructure and the assessment of the impact of climate change. The characteristics of the condition of vegetation include an inventory of the species composition of plant communities, including an assessment of their health status.

The design of the green structure is conditioned by the differentiation of target state functions. While differentiation will have the greatest impact on the long-term care of green infrastructure, the proposal includes data common to all its forms. The common data are the classification of the current type of vegetation (habitat) and potential type of vegetation (forest type), characteristics of growth conditions and growth demands of tree species. Habitat classification is taken from the system of transnational biodiversity assessment. Classification of the potential vegetation is differentiated along the dominant biomes, of which the most widespread in industrially developed areas are forest biomes consisting of forest types. The weighted average between the tree representation of the habitat and the forest type expresses the degree of ecological stability (SES) as a criterion for assessing the intensity of redevelopment of the current condition of greenery and for assessing the intensity of adaptation measures to climate change. The characteristics of growth conditions are used to select the tree species composition by comparison with the classification of growth requirements and biogeography in the overview database. The comparison between growth demands and tree distribution lies in the intersections between the classifications of environmental indicators from individual properties of growth conditions (eco-elements) and the ecovalence of tree species. The intersection between growth demands and biogeography is necessary in assessing the geographical origin of the proposed composition in compliance with nature conservation regulations. The tree species composition should be spatially distributed so as to correspond to the position of the species in a natural community.

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