

JOURNAL

PROJECT

CLAIRO – Clear AIR and
Climate Adaptation in
Ostrava and other cities

📍 Ostrava, Czech
Republic

TOPIC

Air quality

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Urban forests for cleaner air - The final journal of the CLAIRO project

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In Ostrava, Czech Republic, as part of the CLAIRO project, two plots of land were afforested in the city's most polluted neighbourhood to improve air quality. However, the project was about much more than planting lots of trees and shrubs in one of the industrial zones of the city. A number of questions arise when an urban authority embarks on such a unique adventure.

- How should urban greenery be designed to support effective pollution removal?
- Which plant species should be selected for plantations targeting at the filtration of air pollutants?
- How can pollution removal be quantified?
- How can future pollution capture be accurately predicted?
- How should a monitoring network be designed so that it is able to track gradual changes in pollution capture over time?
- What can urban authorities do to strengthen planted trees and shrubs so that they can continue capturing air pollutants in the long-term?
- What are the best ways to help other cities that try to adopt similar solutions?

The CLAIRO project was aiming to find appropriate answers to all of these practical questions. The newly planted greenery was meant to function as a testbed, a living vegetation lab encouraging the smart use of nature-based solutions aiming at air quality improvements in urban areas elsewhere in the Czech Republic and Europe.

Executive summary

Air pollution is the largest environmental health threat globally and cities are often hotspots for poor air quality. Urban green infrastructure can bring about positive health outcomes through reducing the public's exposure to air pollution. Plants can help in filtering air pollutants as a significant fraction of the pollution is removed through deposition when pollutants stick to the surface of the leaves.

The CLAIRO project led by the City of Ostrava aimed at systematic reduction of air pollution through comprehensive planning and planting of greenery with a positive impact on air quality. Under the project over 400 new trees and more than 1800 shrubs have been planted and almost 15,000 m² of lawn have been installed in

Ostrava, Czech Republic at the two target areas of the project. The new vegetation was meant to function as a living lab for cities, with which the viability of the practice could be demonstrated.

To support cities and urban practitioners, a specific method has been developed under CLAIRO helping the design of the most effective composition and structure of urban green spaces in order to reduce air pollution.

Continuous air quality monitoring has been performed at the project target sites with an aim to enable the accurate quantification of the impacts of the living vegetation labs on pollutant removal. The consortium relied on the novel and rapidly developing sensor technology during monitoring. The sensor system tested at the target areas of CLAIRO was found to be quite robust and stable, especially in case of particulates. Project findings have indicated, that sensors linked to official monitoring stations can provide high-density complementary data to urban authorities that can help monitoring trends and enable accurate prediction of changes in air quality.

To reveal the full potential of the planted greenery when it will become a mature forest decades later, a comprehensive model predicting future capture has been developed. Through these predictions, the model allows the verification of the effectiveness of the greenery design.

The target areas of the project are located in an industrial area exposed to significant air and soil pollution. Because of the abiotic stress factors proper greenery care was vital to ensure long-term health of the planted trees and shrubs, and through this to improve the ability of plants to remove pollutants. A smart and environmental-friendly plant treatment has been applied regularly under CLAIRO at the new plantations to withstand unfavourable conditions.

The CLAIRO consortium had the ambition to create a robust platform of trained experts and informed cities. The project partnership has managed to reach out to nearly 1100 professionals, and another 1200 people were involved in two public opinion surveys on air quality conducted in 2019 and 2020.

The knowledge accumulated in the CLAIRO project has been translated into a set of useful tools providing substantial support to European cities designed to improving urban air quality with the help of urban green spaces. These tools include a detailed methodological guide, a shorter manual for non-specialists, and an online plant database.

CLAIRO in a nutshell

The CLAIRO project aimed at systematic reduction of air pollution through comprehensive planning and planting of greenery with a positive impact on air quality. Plants can help in filtering air pollutants as a significant fraction of the pollution is removed through deposition when pollutants stick to the surface of the leaves. Due to its relatively large surface area, plant canopy functions as an effective sink for particulate matter.

In the project of the City of Ostrava the new vegetation was meant to function as a living lab for cities in the Upper Silesian metropolitan area and beyond, providing long-term information on air quality improvement. In practice, an area of over 20,000 m² has been planted with greenery in Ostrava in 2021 from mid-March to early May. Over 400 new trees and more than 1800 shrubs was planted and almost 15,000 m² of lawn has been installed in the two target areas of the project located in the Radvanice and Bartovice neighbourhoods of the city.



In CLAIRO, science had a prominent role in the optimization of the vegetation to support pollution removal as well as in the quantification of the impacts of plants on local air quality. Due to the complexity and technical nature of CLAIRO, the City of Ostrava cooperated with three universities, which were responsible for different scientific fields in the project. The Silesian University in Opava was in charge for greenery design and modelling of pollutant capture, the Technical University of Ostrava for the development and operation of a pioneering air quality monitoring network, while Palacky University Olomouc was responsible for the innovative greenery care.

Greenery design, air quality monitoring and modelling of pollutant capture

The plants were not randomly selected for the two target sites, instead the new ecosystems were carefully planned by researchers of the Silesian University in Opava. A specific method was developed under CLAIRO helping the [design of the most effective composition and structure of urban green spaces](#) in order to reduce air pollution.

To be able to accurately quantify the impacts of the living labs on pollutant removal, continuous air quality monitoring have been performed at the project target sites. The consortium relied on the novel and rapidly developing sensor technology in the CLAIRO project as it offers high-resolution data sourced from relatively small areas. Because of the large number of monitoring points, the low cost of the sensor units was an important factor during the selection of the appropriate technology. Access to detailed data was necessary for tracking improvements related to air quality and to make predictions for future capture. In addition, [monitoring of air pollutants in CLAIRO](#) was also essential for the design of new greenery. The Technical University of Ostrava deployed a total of 20 sensor units, which were connected into separate networks at the two target sites.

A number of challenges has been faced by the consortium linked to the development and operation of the monitoring framework, such as the identification of appropriate indicators that allow verification of the achievement of targets set by the project, or the relatively short project lifetime hindering the demonstration of mid-term and long-term impacts of project activities. With the help of the sensor network, enormous amount of air quality data has been collected under CLAIRO. The processing and evaluation of raw data, and their interpretation for formulating key messages was particularly challenging. To address all these challenges, a separate work package of actions was dedicated in the project to monitoring, data evaluation and modelling. Additional information on the use of sensor networks in CLAIRO is available in a specific [web article](#).

The relatively short project duration and the extremely tight schedule for implementation directly affected the monitoring activities. It was evident early on for the consortium that the full potential of the vegetation cannot be demonstrated during the lifetime of the project. The project ended already one year after greenery planting, while decades are actually required for a new plantation to become a mature forest, which can effectively capture air pollutants with the extensive surface of the canopy. As a solution, measurements are performed for five years after project closure, hoping that in the mid-term the positive impact of greenery on air quality will be verified. Still, not even a five-year period after project closure is sufficient to reveal the full potential of the planted greenery, therefore the quantification of air pollutants captured by the vegetation needed to be verified by a model that allows predictions of future capture. Accordingly, as part of the CLAIRO project, a comprehensive [model of capture of air pollutants](#) has been developed by the Silesian University in Opava on the basis of a couple of standard models for the deposition of pollutants.

Plant hormones improve the vitality of trees

At the start of the project, the consortium had to face the significant problem that the plots to be greened were

located in an industrial area, where the new vegetation would be exposed to significant air and soil pollution. Due to these unfavourable conditions, there was a risk that the newly planted vegetation would not survive for long, directly jeopardizing pollution capture. Because of the abiotic stress factors, proper greenery care was vital to ensure long-term health of trees and shrubs, and to improve the ability of plants to remove pollutants. A [smart and environmental-friendly plant treatment](#) has been applied regularly under CLAIRO by the Palacký University Olomouc in Ostrava at the Radvanice and Bartovice target sites of the project. The innovative treatment piloted in Ostrava is based on the use of plant hormones (that are very active growth regulators which are also involved in plant defence) and biostimulants (natural biologically active substances that promote plant growth and help nutrient uptake). The innovative treatment was compared with two other treatment types, a classical one based on the use of commercial inorganic fertilizers and a modern one based on the use of biostimulants only.



Source: U.S. Department of Agriculture, Wikimedia Commons

Reaching out to experts and residents of the Ostrava agglomeration

The CLAIRO consortium had the ambition to create a robust platform of trained experts and informed cities. A large number of external stakeholders have been involved actively in the activities of CLAIRO. Experts on air pollution and urban greenery were trained through workshops and individual consultations so that they can convey the key learning points linked to the CLAIRO methodology to other urban practitioners. Similarly, workshops and consultations were organized to train city representatives so that they can transfer the project's knowledge within their organizations.

Because of the pandemic, most of events, workshops or seminars had to be organized virtually and many of them had to be postponed until later. Initially the organization of 16 physical public seminars had been foreseen for schools, but finally 17 webinars were organized. Despite these difficulties a higher number of external stakeholders were engaged in project activities than expected. CLAIRO managed to reach out about 2300 people. Altogether there were nearly 1100 attendants of 29 different project events. Another 1200 people were involved in two public opinion surveys on air quality conducted in 2019 and 2020.

In addition, the City of Ostrava managed to build a wider regional partnership under CLAIRO. Although originally air pollution measurements were planned to be undertaken in at least three neighbouring towns, eventually six of them volunteered to be pilot cities.

While webinars for experts and cities and the relevant training materials were aimed at stakeholders specialised in urban greenery, the awareness-raising activities based on [in-depth surveys](#) have been targeting the wide public as residents directly influence air quality through their own behaviour and lifestyle. Accordingly, communication activities throughout the project aimed at both awareness raising regarding project outputs and long-term behaviour change. The surveys functioned as particularly effective outreach campaigns supporting awareness raising among residents of the Ostrava agglomeration on clean air and the role of greenery in improving air quality.

Progress since project closure and long-term sustainability

Due to the specific nature of CLAIRO, several crucial activities will continue for years on, even after project closure. Only mature urban forests with their extensive surface will be able to effectively remove air pollutants, while in April 2022, when the project was officially closed, the new plantations at the Radvanice and Bartovice sites were only one year old. Accordingly, it was necessary to ensure the long-term sustainability of some crucial activities. A strategic approach has been adopted by the partnership early on to support the achievement of the key objectives of CLAIRO. It was decided that the monitoring activity, the innovative treatment of the vegetation, and conventional greenery care will carry on for five years after project closure.

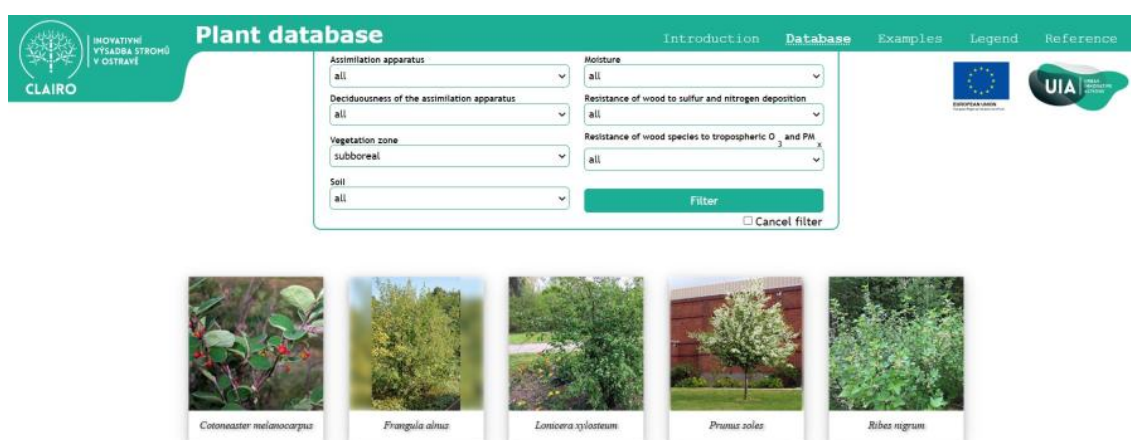
To be able to track the gradual changes in pollution capture as the vegetation is growing over the years, the Technical University of Ostrava continues the measurement of concentrations of air pollutants with the sensor networks until 2027. In the sensor units, concentrations of particulate matter, nitrogen dioxide, ozone and volatile organic compounds are monitored. The data recorded by the sensors every 10 seconds are processed and stored by a geo-database. Compared to the baseline values, significant reductions were recorded at the target sites in the concentration of particulates and nitrogen oxides four years after the first measurements. This positive change in local air quality can be attributed partially to the filtration effect of the planted greenery.

Apart from air quality monitoring, the innovative treatment of the new plantations with biostimulants and plant hormones will also continue for five years following the closure of the project until the plants are established and do not need care anymore. The treatment undertaken by the Palacky University Olomouc on the one hand ensures the long-term health of trees and shrubs, and at the same time allows the researchers to evaluate the impacts of the innovative preparation on the physiological state of the plants for a longer period. Plants are treated twice each year in the vegetation period, in May and in September. The preparations are applied in a liquid format on the soil and the plants.

The vitality of plants is also monitored in this five-year period. Following the treatments, a number of parameters are measured linked to the chlorophyll content of the leaves, the exchange of oxygen and carbon dioxide, and the rate of transpiration.

In addition, the City of Ostrava has signed a contract for greenery care for five years after planting with the company that planted the trees and shrubs in the CLAIRO target areas.

Since the project closure, several steps were taken to scale up the results of CLAIRO up across Ostrava. First of all, the main findings of CLAIRO are integrated into the urban planning processes of the city. Currently a 'Blue-green infrastructure methodology' is being prepared by the urban authority which will be part of a more comprehensive guide for the preparation of the investment projects. The methodology is also planned to be linked to the climate adaptation strategy of the city. These basic policy documents will provide guidance on green space design in case of new investments. The strategic document on blue-green infrastructure of the City of Ostrava will refer to key project outputs, the [CLAIRO Methodology on 'Green infrastructure and its impact on air quality'](#) showcasing the basic principles for planting greenery for pollutant capture, as well as the [online Plant Database](#) of CLAIRO that is listing species suitable for cutting back pollution exposure.



Online Plant Database of CLAIRO (Source: CLAIRO project homepage)

Project results are being scaled up in Ostrava also on a more practical level. It is planned that the innovative plant treatment piloted in CLAIRO will be applied in 8 different green space projects across several city districts in Ostrava, including the rehabilitation of parks and street greening interventions.

Aside from these specific projects, the company responsible for green space management in Ostrava intends to apply the biostimulant and plant hormone-based treatment developed by Palacky University as part of its general practice related to greenery care.

The project partnership also managed to get the message about the applicability of the CLAIRO approach to other cities beyond Ostrava. As a result of intensive consultations among interested cities and the Moravian-Silesian Region, the City of Trinec and the City of Orlova decided to use the smart plant treatment of Palacky University and the city councils are currently updating their strategic policy documents accordingly. The town of Ruzomberok in Slovakia was also interested in the CLAIRO project results. The innovative outcomes related to greenery have already been incorporated into the Air Quality Improvement Plan of the municipality.

Building on the experiences linked to sensor-based monitoring under CLAIRO, one consortium member, the Moravian-Silesian Region initiated a new project, KAPOOO, that is funded by the European Environment Agency (EEA) and Norway Grants. The project aims to propose the most effective measures to reduce emissions in the Moravian-Silesian Region based on the development of a comprehensive action plan. High-resolution measurements are performed with the help of the sensor technology tested in CLAIRO to identify the most problematic pollution sources and to support the assessment of already implemented and planned air quality measures.

CLAIRO has also given way to another initiative in Ostrava. The City of Ostrava has recently submitted an application to the new Thematic Partnership on Greening cities under the Urban Agenda for the EU. The Czech city intends to start a knowledge-sharing pool and to put forward a methodology for assessing the impacts of blue-green measures, partly building on the results of CLAIRO.

Generated knowledge

Lessons learned

CLAIRO provided some relevant learning points related to diverse aspects of the project, such as greenery design, the applicability of the sensor technology, tools supporting awareness raising, and the attitude of citizens of the Moravian-Silesian Region towards air quality and the use of nature-based solutions in urban environment.

- First of all, it was clearly demonstrated by the CLAIRO partnership that with careful greenery design, and proper greenery care even at extreme sites exposed to contamination and air pollution, it is possible to maintain a healthy urban ecosystem for a longer time. The key to success in Ostrava was the selection of resistant plant species, greater species diversity and strong ecological relationships among different species.
- CLAIRO offered a unique opportunity in the field of air quality monitoring. Under the project, huge amount of data was gathered and processed for a relatively long period that was exceeding 18 months. Such extensive datasets that were recorded for more than 1.5 years have not yet been available elsewhere. The researchers at the Technical University of Ostrava have seized this opportunity to test the measurement validity of air quality sensors and their behaviour during long-term measurements exceeding one year. The results were found to be surprisingly reassuring as the sensors had a service life longer than expected. All of the sensors deployed at the two target sites were functioning properly after one and a half year of use.
- While experts and city representatives were targeted by seminars (or eventually rather by webinars) and training materials, the wide public was engaged by in-depth surveys. Since residents can directly influence air quality through their own behaviour and lifestyle, the surveys were undertaken not only to enable mapping of the population's attitude towards the project's main objectives, but also to raise the awareness of citizens in general. The high number of respondents indicates that the surveys functioned as particularly effective outreach campaigns supporting awareness raising among residents of the Ostrava agglomeration on clean air and the role of greenery in improving air quality.
- The [results of the survey](#) has indicated that a remarkably high proportion of the population of the Moravian-Silesian Region considered the topic of air quality to be important. In addition, over three quarters of the survey respondents supported the application of nature-based solutions in urban areas. The responses indicated clearly that the approach offered by CLAIRO is relevant for the majority of city dwellers. This result can be a positive message for other cities across Europe that play with the idea of improving urban air quality with the help of greening.

- Survey results also revealed that over 25% of the inhabitants of Ostrava agglomeration consider changing their residence due to air pollution. These responses suggest to decision-makers that inaction in the field of air quality on part of the city administration can have serious consequences.

Recommendations to other urban authorities who wish to implement similar innovative initiatives

Based on the experience gained during the implementation of CLAIRO a series of specific recommendations can be formulated for cities and urban practitioners related to vegetation-based pollution capture, greenery care, or outreach to the general public:

- In case an urban authority decides to establish an urban forest to support the deposition of pollutants then special attention must be paid to the design of the greenery structure and composition. Higher species diversity will lead to greater ecosystem health and resilience to environmental stresses, and a multi-level tree cover can maximize the capture of air pollutants.
- When the goal is to use greenery to promote deposition of pollutants, foliage density needs to be taken into account during planning. Vegetation barriers that aim at the filtration of pollutants should be sufficiently dense to promote deposition with an extensive surface area, while at the same time it should not be overly dense, to support the penetration of the airflow.
- Hedges can be really effective in protecting schoolgrounds, kindergarten yards, and playgrounds from air pollution exposure, through displacing emissions of air pollutants and supporting their dilution.
- For urban authorities, it is worth considering the application of plant hormone based innovative treatment in case of both existing or new green infrastructure, to strengthen the vegetation when it is exposed to abiotic stress factors, such as drought, excessive water, high salinity, heavy metal contamination of the soil, or air pollution.
- Low-cost air quality sensors can provide local authorities with high-resolution data that can enable close monitoring of trends in pollutant concentrations, forecasting changes in air quality, or the identification of pollution hotspots. This high-density data sourced from sensors can support urban practitioners on neighbourhood or street-level city planning.
- Surveys can be particularly effective tools for outreach towards urban residents. They can support awareness raising linked to various topics associated with sustainability. Interviews performed as part of surveys can be designed in a way that respondents obtain basic information about the themes in focus.



View of Ostrava (Source: Oleksandr Dede, Wikimedia Commons)

Conclusions

The main legacy of CLAIRO in terms of knowledge generated

The Silesian University in Opava has designed a specific method for the establishment of greenery supporting the

removal of air pollutants. Project results indicated that a combination of both deciduous and coniferous plants with an overall higher species diversity is suitable for a more efficient control of a wider range of pollutants and that the filtration of pollutants improves with increasing vertical layering of forests. In line with the design phase, at first a longer initial plant list is created with suitable candidate species, then during the assessment of local environmental conditions less appropriate species are removed from the base list. Later factors influencing species diversity and ecological links are studied and finally plants are prioritized based on their ability to capture pollutants.

A comprehensive model was developed by the Silesian University in Opava in the CLAIRO project that on the one hand enables accurate quantification of the effects of greenery on air quality, and on the other hand allows the prediction of future pollution capture. Eventually, through predictions the model enables the verification of the effectiveness of the greenery design. Accurate predictions are crucial, since decades are required for a new plantation to become a mature forest that can effectively filter air pollutants, while the project only lasted for a few years. Accuracy has been ensured by species-specific simulation of pollutant removal.

Even before greenery planting, the model indicated that the planned vegetation would be quite effective, as at one of the target sites -Radvanice- the new greenery was expected to capture twice the particulates per leaf area as the original vegetation. The CLAIRO project results were quite promising, as the measured concentration values supported the initial predictions. The Technical University of Ostrava has compared the monitoring results to the predictions of pollutant capture and it was found that the trendlines are nicely following the model results: by the end of 2022, the capture capacity has already reached 30% of the targeted capture.

The knowledge accumulated in the CLAIRO project has been translated into a set of useful tools providing substantial support to European cities aiming at improving urban air quality with the help of urban green spaces. These tools include a detailed methodological guide, a shorter manual for non-specialists, and an online plant database.

The guide on the CLAIRO Methodology, untitled 'Green infrastructure and its impact on air quality' provides details about greenery design and the model of CLAIRO targeting at air quality and urban green infrastructure experts and the research community. The CLAIRO Manual, the simplified version of the Methodology is directed towards laypersons interested in the topic. The [English versions](#) of both documents are available since early 2022.

The Silesian University in Opava has developed an [online database of plants](#), which contains over 150 tree species that have relatively strong resistance to air pollution as well as high pollutant capture efficiency. The database provides direct support to cities in designing greenery for cutting back pollution exposure. Trees are classified in the database according to different parameters, such as climatic requirements, sensitivity to acid deposition and to ozone and the ability to remove particulate matter.

The main legacy of CLAIRO in terms of solutions implemented

The CLAIRO project has sent important signals auguring imminent changes for the use of sensors in air quality monitoring. The sensor system tested at the Radvanice and Bartovice target areas of CLAIRO was found to be quite robust and stable, especially in case of particulates. Sensor networks have many advantages over conventional monitoring instruments, such as fast responses to concentration changes, a high resolution in space and time, unnecessary sampling and laboratory analysis, and low costs. The findings of CLAIRO indicate, that sensors linked to official monitoring stations can provide high-density complementary data to urban authorities that can help in monitoring trends and enable accurate prediction of changes in air quality.

Early on, the City of Ostrava was seeking effective solutions to ensure long-term health of the trees and shrubs to be planted, otherwise many plants would have been lost over the years because of abiotic stress factors. It was already evident at that time that the newly planted greenery in Ostrava would be exposed to multiple environmental stressors, especially in one of the plots that is located on a slag deposit area in Bartovice. The soil in this location is dry, nutrient-deficient and contaminated with heavy metals, and on top of that the area is also exposed to air pollution. The Department of Chemical Biology at the Palacký University was eager to join the CLAIRO consortium to offer their innovative plant hormone based treatment method to help plants to withstand unfavourable conditions. Dealing with trees in the project was an interesting new area for the researchers of Palacký University, as they had been engaged by then in research linked to agriculture and medicine, but forestry was a new field for them. Moreover, the task at hand was quite inspiring for Palacký University because of the extreme target sites of CLAIRO were exposed to not only one, but several stressors at the same time.

The innovative technology has lived up to its expectations. One and a half year after planting, the trees treated with the innovative preparation of Palacký University were [healthy and thriving](#). The significance of the smart treatment will grow in the upcoming years when the extreme conditions at the target sites will manifest themselves. The mixture of phytohormones and biostimulants used in CLAIRO is patented and commercially available. There is

a huge potential for cities in using this fast and inexpensive method for protecting their existing or new urban green infrastructure from various abiotic stress factors.

During the project, as part of the modelling work, drones were used for the quantification of vegetation properties. Drone-based measurement ensured higher level of accuracy for predictions than the application of conventional field inventory.



The plantation in the Bartovice target area from drone view (Source: Silesian University in Opava)

The amount of leaf material area in the canopy directly affects the deposition rate of air pollutants, and as such it is a key component of the CLAIRO model. In standard practice, the area of leaf material is determined with the help of ground-based measurements. During project implementation the Silesian University in Opava switched from ground-based data collection to pioneering drone-based data measurements, to test and demonstrate the applicability of this novel technical solution. The use of drones proved to be quite effective. With their help it was possible to distinguish the effects of various plant species as well as life stages of vegetation on pollution capture. In addition, compared to ground-based measurements, drones provided finer spatial resolution at a relatively low cost.

Final reflections on the relevance of CLAIRO

Air pollution is the largest environmental health threat globally and cities are often hotspots for poor air quality. Reducing pollutant emissions is always the most direct way to improve urban air quality, but with the rapid rate of urbanisation, authorities struggle to provide adequate air quality improvements through emission control strategies alone. Urban green infrastructure can bring about positive health outcomes through reducing the public's exposure to air pollution. The use of vegetation for pollution mitigation can effectively complement conventional policies and measures on air pollution.

The CLAIRO project has successfully demonstrated in the City of Ostrava that exposure to air pollutants can be effectively reduced locally with the help of greenery if it is designed properly. Although the project target areas were relatively small, still their size with 2 hectares in total was more than sufficient to function as testbeds for similar future green infrastructure interventions.

What CLAIRO has offered was much more than simply verifying the viability of vegetation-based pollution mitigation. Design principles were created through which greenery can be optimized for pollution removal. A sophisticated model was developed that makes possible the quantification of the effects of greenery on air quality and the prediction of future pollution capture. The details on design and modelling were made available for

interested cities in the form of a methodological guide. A sensor-based monitoring system was piloted that allows tracking positive changes in pollution removal. Pioneering solutions were tested to improve plant health in green spaces created for improving air quality. Finally, professionals and city representatives were trained and consulted on the CLAIRO approach to support the replication of key project results across the Czech Republic and Europe.

This comprehensive package can open doors for other cities seeking to reduce the exposure of urban residents to air pollution with the use of nature-based solutions.

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