



**All sites equipped with the new sensors for NO<sub>x</sub>, O<sub>3</sub> and aerosol fluxes and submitting real time data to the ITINERIS hub through the Terrestrial Biosphere hub**



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*All ICOS stations equipped with the new connection, power, loggers and sensors to ensure real time data transmission to the ICOS portal and ITINERIS HUB*

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## 1. INTRODUCTION

As a result of Activity 6.16, ITINERIS has successfully established and strengthened a national network of ecosystem monitoring stations in urban and peri-urban areas across Italy. This achievement represents a major step forward in developing a dedicated infrastructure for the assessment of Nature-Based Solutions (NBS) options and effects. The creation of this network is a significant and strategic accomplishment, as it provides, for the first time, a coordinated and standardized system specifically designed to evaluate how NBS perform and deliver multiple ecosystem services in real urban environments. The network plays a foundational role in enabling the scientific and operational assessment of NBS. It supports the collection of continuous, high-resolution environmental data essential for evaluating ecosystem functioning and resilience. Its design is fully consistent with international standards, such as the IUCN Global Standard for NBS, and it creates a platform that facilitates transparent, evidence-based evaluation, long-term monitoring, and cross-sectoral integration.

A key element of this initiative is that all stations in the network monitor carbon fluxes, allowing for a detailed quantification of the role of NBS in contributing to carbon neutrality. This includes measuring how trees and vegetation of urban and peri-urban environment capture and store CO<sub>2</sub> from the atmosphere, providing a tangible contribution to climate mitigation strategies. The data supports the evaluation of climate regulation services and their integration into urban climate adaptation and mitigation policies. In addition to carbon monitoring, three stations within the network, positioned along a latitudinal gradient, are also equipped to measure the deposition of secondary air pollutants such as nitrogen oxides (NO<sub>x</sub>) and ozone (O<sub>3</sub>). This is particularly relevant in urban and peri-urban contexts, where vegetation can influence the concentration and distribution of air pollutants through both physical and chemical processes, including the uptake of nitrogen oxides (NO<sub>x</sub>) and the interception of particulate matter (PM) on leaf surfaces. Moreover, plant activities can affect ozone (O<sub>3</sub>) formation dynamics, as plants modify the local microclimate (temperature, humidity, radiation) and participate in biogenic volatile organic compound (BVOC) emissions, which interact with anthropogenic precursors. By mitigating the accumulation of harmful pollutants generated by traffic, heating, and industrial activities, urban green spaces provide essential ecosystem services for air purification, contributing to healthier, more resilient urban environments. Thus, the ability to monitor these pollutants makes it possible to assess the contribution of NBS to improved air quality, a key ecosystem service with important health and regulatory implications.

One of the most innovative and impactful aspects of the network is that all environmental data collected are transmitted in near real-time to the thematic central data hub, making them immediately accessible to the scientific community and other stakeholders. This real-time availability not only

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enhances transparency and usability, but also promotes open science, citizen engagement, and policy relevance. This important result was made possible thanks to the strong integration and synergy with other activities within WP6, and in particular with Activity 6.01, which provided some of the technological infrastructure, protocols, and interoperability framework required to harmonize the monitoring network and ensure real-time data transmission and accessibility.

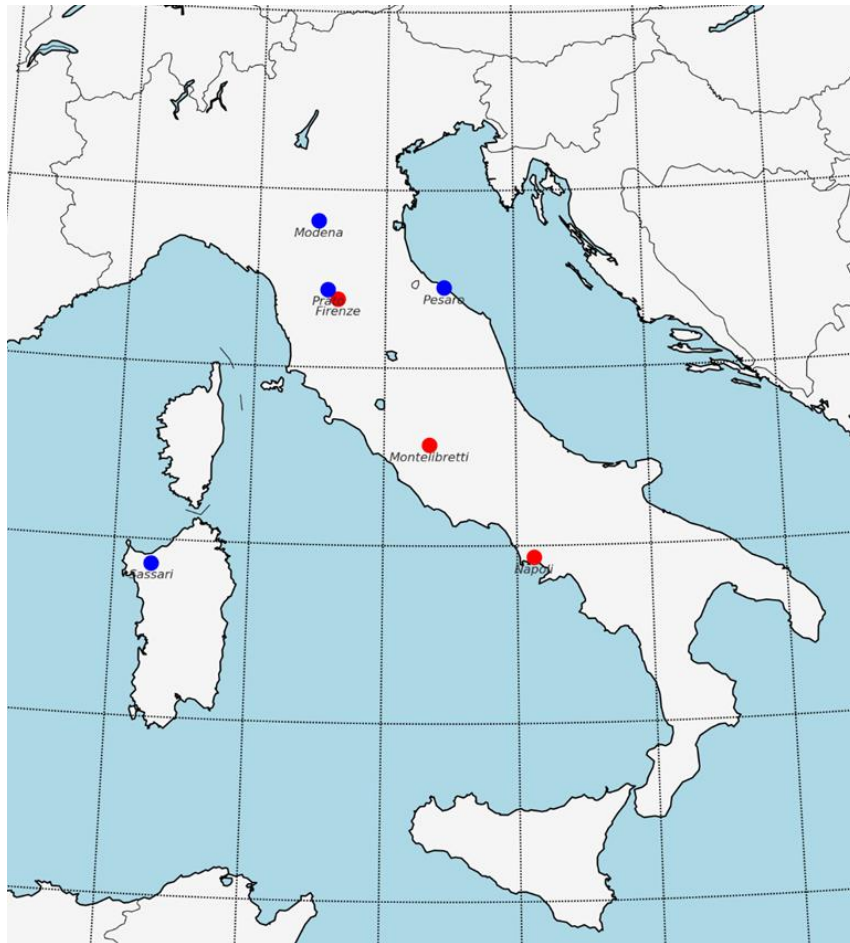
In summary, the establishment of this national network marks a substantial advancement in the capacity to monitor and evaluate NBS in urban and peri-urban contexts. It provides a robust, scalable, and accessible foundation for environmental assessment and supports future efforts to replicate, optimize, and mainstream NBS across different ecological and socio-urban landscapes in Italy.

Another important achievement of the Activity is the contribution to ICOS. Two of the urban stations that have been equipped and organized have been added to the ICOS network and have been officially labelled by the ICOS General Assembly in 2024: Firenze in May and Sassari in November. This helped to increase the visibility of the ITINERIS project and made the Italian contribution to ICOS more strong and complete.

## 2. URBAN SITE NETWORK

Even in its initial stage, the network already ensures a representative coverage of Italy's geographic and climatic diversity and a diversity in the cities type, structure and size. The selected sites span a range of environmental and bioclimatic conditions, reflecting both coastal areas with a clear Mediterranean influence—such as Sassari, Napoli, and Pesaro—as well as more inland and continental regions, including Firenze, Prato, and Modena. Also in terms of city structure and characteristics that are heterogeneous, ranging from sites in a city center without vegetation (Firenze) to sites in the city neighborhood covering a local urban park (Napoli). For their heterogeneity also the vehicular traffic and heating systems are variables and covering a large spectrum of conditions.

This distribution captures an important set of gradients, which is crucial for evaluating how Nature-Based Solutions (NBS) perform under different climatic, urban, and landscape contexts across the country and also make Italy the country with the largest number of urban tower in Europe (Figure 1).



**Figure 1.** The urban monitoring network, strategically positioned to gather crucial data. The blue dots pinpoint stations are specifically dedicated to monitoring CO<sub>2</sub>, H<sub>2</sub>O and energy fluxes. The red dots highlight stations that in addition to the above-mentioned fluxes are also monitoring various secondary air pollutants.

## 2.1 Firenze

The Eddy Covariance tower in Firenze, is located atop the Ximeniano Historical Observatory in the heart of the city (43°46'28''N, 11°15'18''E), offering a unique monitoring position within a densely urbanized and predominantly anthropogenic footprint. The station has been operational since September 2005 and continues to collect data up to the present day (May 2025), despite a few historical data gaps. It is managed by the National Research Council of Italy – Institute for BioEconomy (CNR-IBE) and serves as one of the longest-running urban CO<sub>2</sub> flux monitoring sites in southern Europe. The tower monitors carbon dioxide (CO<sub>2</sub>) fluxes using eddy covariance techniques and is equipped with a high-performance 3D sonic anemometer and closed-path infrared gas analyzer, both of which were provided through the ITINERIS project (Activity 6.01). In addition to these core instruments, ITINERIS also supplied a complete system for the high-frequency

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monitoring of ozone ( $O_3$ ) and nitrogen oxides ( $NO_x$ ), enabling the site to simultaneously assess greenhouse gas dynamics and air quality impacts in real time. This comprehensive instrumentation allows the site to contribute critically to the understanding of urban atmospheric exchange processes, especially in relation to the effectiveness of Nature-Based Solutions (NBS) in mitigating carbon emissions and improving air quality. By integrating carbon and pollutant flux measurements, the Firenze tower represents a valuable node within the national and European urban monitoring network, supporting both long-term scientific research and policy-relevant environmental assessments. The site is also part of ICOS and Associated station and it has been labelled in May 2024 by the ICOS General Assembly.



**Figure 2.** Image of the site above Xymeniano Observatory in Firenze.

## 2.2 Modena

The urban observation site (Figure 3) in Modena, located at  $44^{\circ}38'52.59''N$ ,  $10^{\circ}55'47.22''E$ , is specifically designed for the monitoring of carbon dioxide ( $CO_2$ ) fluxes in a densely built environment. The measurement system is positioned at a height of 48 metres above ground level, consisting of an 8-metre mast installed on top of a 40-metre rooftop, providing an unobstructed sampling footprint over the surrounding urban landscape. The instrumentation includes a LiCor 7200 closed-path infrared gas analyzer equipped with a heated inlet, paired with a SmartFlux2 processing system, and a Windmaster 3D sonic anemometer, ensuring high-frequency, high-precision measurements essential for eddy covariance analysis. The site is managed by the University of Modena and Reggio Emilia, which is responsible for installation, maintenance, and data processing.

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The station was partially equipped thanks to the instrumentation provided by ITINERIS is currently under finalization and is expected to become operational by summer 2025. Once active, it will play a key role in expanding the national urban monitoring network and contribute valuable data for assessing urban carbon dynamics and evaluating the performance of Nature-Based Solutions.



**Figure 3.** Image of the site above university of Modena.

### 2.3 Montelibretti

The new eddy covariance station in Montelibretti (Rome), located within the CNR Research Area near Rome, is poised to become a key site for advanced atmospheric flux monitoring in a peri-urban context. The tower, managed by the National Research Council – Institute for Research on Terrestrial Ecosystems (CNR-IRET) and completely funded by the ITINERIS project, is designed to measure high-frequency exchanges of CO<sub>2</sub>, H<sub>2</sub>O, O<sub>3</sub>, NO<sub>x</sub>, and CH<sub>4</sub>, making it one of the most comprehensive multi-gas monitoring platforms in the national network. Measurements will be taken from an intake height of 20 meters, enabling robust data collection representative of land-atmosphere interactions across heterogeneous land use types in the research area. The station is expected to become

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operational by July 2025, and all the preparatory activities have been completed and it is ready for the data collection. Safety inspections and reinforcement of the tower infrastructure have been successfully carried out, including all the needed stability tests and training to operate on it, ensuring long-term safety operational. In addition, all gas analyzers and dataloggers have been interconnected, calibrated, and fully tested, confirming their readiness for deployment that is happening at the time of the deliverable preparation. The final step before activation involves the test of the electrical connection that must be analysed by the specialists in order to ensure sensors protection and robustness in terms of energy provision to avoid gaps in the measurements. This site is particularly strategic and innovative, as it is situated in a peri-urban zone within the metropolitan area of Rome, allowing for the assessment of ecosystem-atmosphere exchanges influenced by recent large-scale afforestation efforts. In addition, being inside the Research Area owned by the National Research Council, it offers a unique opportunity to link the measured emissions with the inventory of the activities in the area. In fact the vehicular and human access to the area is controlled and limited and the heating system centrally controlled. This will give the possibility to estimate emissions by cars, heating and human respiration and compare it with the measured fluxes, something in general impossible in the urban flux towers due to the difficulties to control and count all the emission sources.

As such, the Montelibretti tower will provide unique data to evaluate the effectiveness of urban and peri-urban Nature-Based Solutions (NBS) in mitigating greenhouse gas emissions and improving local air quality as well as a tool to compare different approaches for the urban GHG emissions. Its ability to monitor multiple trace gases simultaneously makes it an important research and policy-support tool, bridging the gap between scientific observation and sustainable urban planning.



**Figure 4.** Image of the site above university of Montelibretti (Rome)

## 2.4 Napoli

The Capodimonte monitoring station, located within the urban forest of the Bosco di Capodimonte in Napoli, represents a critical node in Italy's atmospheric observation infrastructure. Managed by the National Research Council Institute for Research on Terrestrial Ecosystems (CNR-IRET), the station operates a multi-gas eddy covariance system measuring fluxes of carbon dioxide ( $\text{CO}_2$ ), water vapor ( $\text{H}_2\text{O}$ ), ozone ( $\text{O}_3$ ), nitrogen oxides ( $\text{NO}_x$ ), and methane ( $\text{CH}_4$ ). Measurements are taken from a 30-meter-high tower situated within a densely vegetated and ecologically significant urban green space. Originally active from 2015 to 2019, the station experienced a prolonged interruption before being reactivated through the support of the ITINERIS project, which has provided cutting-edge instrumentation and technical upgrades to restore and enhance its monitoring capabilities. Thanks to ITINERIS, the site is now equipped with a 3D sonic anemometer for high-resolution wind vector measurements, an infrared gas analyzer for  $\text{CO}_2$  and  $\text{H}_2\text{O}$  concentrations, a suite of environmental sensors for measuring key atmospheric parameters (including solar radiation, air temperature and humidity, and photosynthetically active radiation), and soil instrumentation to monitor variables such as soil moisture content, temperature, and heat flux. The station is a candidate Associated ICOS station, not yet labelled due to the late re-start of the activities and is one of the few urban flux towers in southern Europe installed in a vegetated area, with a combination of signal from the natural and the anthropogenic components. Its unique location within the Bosco di Capodimonte, a large and

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historic urban woodland, allows for the direct assessment of the ecosystem services provided by an important type of NBS such as urban forests, particularly in relation to air quality regulation and carbon sequestration.



**Figure 5.** Bird's eye view of the Napoli - Capodimonte Station

## 2.5 Pesaro

The eddy covariance tower in Pesaro is installed on the rooftop of the Osservatorio Meteorologico Storico Valerio, a historic meteorological observatory located in the heart of the city ( $42.91221^{\circ}$  N,  $12.90477^{\circ}$  E). This central urban location provides an ideal setting for monitoring atmospheric carbon dynamics in a densely populated, anthropogenically influenced environment. The station has been operational since January 2014, making it one of the longer-running urban flux monitoring sites in Italy. It continuously measures carbon dioxide ( $\text{CO}_2$ ) fluxes using the eddy covariance technique, offering high-resolution data on the exchanges of carbon between the urban surface and the atmosphere. These measurements are essential for understanding how urban infrastructure, vegetation, and human activities influence the city's carbon budget and environmental footprint, key elements that make it crucial within the ITINERIS cluster. The tower is managed by the Institute for BioEconomy of the National Research Council (CNR-IBE), which is responsible for maintaining the instrumentation, managing data flows, and ensuring quality control in accordance with international standards. Thanks to its long-term operation and strategic location with a mix of contributions for the different sources, the Pesaro station contributes valuable insights into urban greenhouse gas dynamics.

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**Figure 6.** Image of the site above Osservatorio Valerio, Pesaro

## 2.6 Prato

The eddy covariance tower in Prato is located in a unique and historically significant setting on the rooftop of the Palazzo Pretorio, the ancient town hall situated in the heart of the city's historic center (43°52'50''N, 11°05'47''E). This strategic location allows for continuous monitoring of urban carbon dioxide (CO<sub>2</sub>) fluxes within a densely built environment, providing valuable data on anthropogenic emissions and the influence of urban vegetation and infrastructure on atmospheric dynamics. The system has been fully operational since June 2021, and continues to function effectively as of May 2025, delivering high-frequency, real-time data essential for understanding urban carbon budgets. The station is managed by the Institute for BioEconomy of the National Research Council (CNR-IBE), which oversees its maintenance, calibration, and data management. The Prato site is particularly relevant for assessing the effectiveness of Nature-Based Solutions (NBS) in compact historical urban areas, where interactions between built infrastructure, vegetation, and human activity are complex and highly localized. The tower thus serves as a crucial platform for both scientific research and urban sustainability planning, supporting data-driven environmental management at the municipal level so is fundamental its presence within the ITINERIS cluster.

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**Figure 7.** Image of the site above Palazzo Pretonio, Prato

## 2.7 Sassari

The urban observation site in Sassari, located at  $40.716957^{\circ}$  N,  $8.575956^{\circ}$  E, is part of an effort to improve the understanding of greenhouse gas (GHG) emissions and fluxes in Mediterranean urban environments. The station is situated in the city of Sassari, in northern Sardinia (Italy), and is managed by the University of Sassari. Positioned at a measurement height of 23 meters, the system enables continuous, high-resolution monitoring of atmospheric exchanges in a complex urban setting characterized by a mixture of built-up surfaces and vegetation. Operational since 2024, the station focuses on observing urban land-atmosphere interactions, particularly in the category of Urban and Built-Up Lands. The site provides crucial data to characterize and quantify the primary sources of GHG emissions within the city, with the goal of supporting local policymakers and urban planners in identifying effective mitigation strategies. A key objective of the monitoring effort is to disentangle the role of vegetation in regulating urban fluxes. This is particularly important in Mediterranean cities, where fragmented green spaces, climate variability, and urban morphology influence the dynamics of carbon dioxide and other trace gases. The site has been officially labelled and ICOS Associated station in November 2024 and for this reason the data collection and distribution is particularly robust and continuous.

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**Figure 8.** Image of the site in Sassari

### 3. CONCLUSIONS

With the activities performed in ITINERIS, the sub-network of urban and peri-urban stations in Italy have been organized and strength, becoming the largest and more heterogeneous in Europe. Not all the stations received direct or indirect support from ITINERIS however the project helped to establish the network, gather all the information and metadata needed to add them to the thematic hub and start receiving data. The sites more directly linked to the OU IRET-RM or registered in ICOS have a more robust data transmission but also the other sites, thanks to agreements among the intritions and the common willingness to establish a strong network and collaboration, provided the data and are engaged also for the future updates. ITINERIS, with the support to the training and the possibility to access the instrument hub for short and long term loans have been a key project to establish this Italian urban GHG fluxes sub-network.

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