# LIFE MODERN NEC

Air quality, the response of ecosystems

# LAYMAN'S REPORT

PROJECT RESULTS

LIFE MODERN NEC

Air quality, the response of ecosystems

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## The NEC Directive and the challenges of air pollution

Air pollution is one of the main threats to human health and ecosystem conservation in Europe. The NEC (National Emission Ceilings) Directive 2016/2284/EU is the European Union's response to this challenge, setting national emission ceilings for certain atmospheric pollutants with the ambitious goal of significantly reducing negative impacts on human health and the environment.

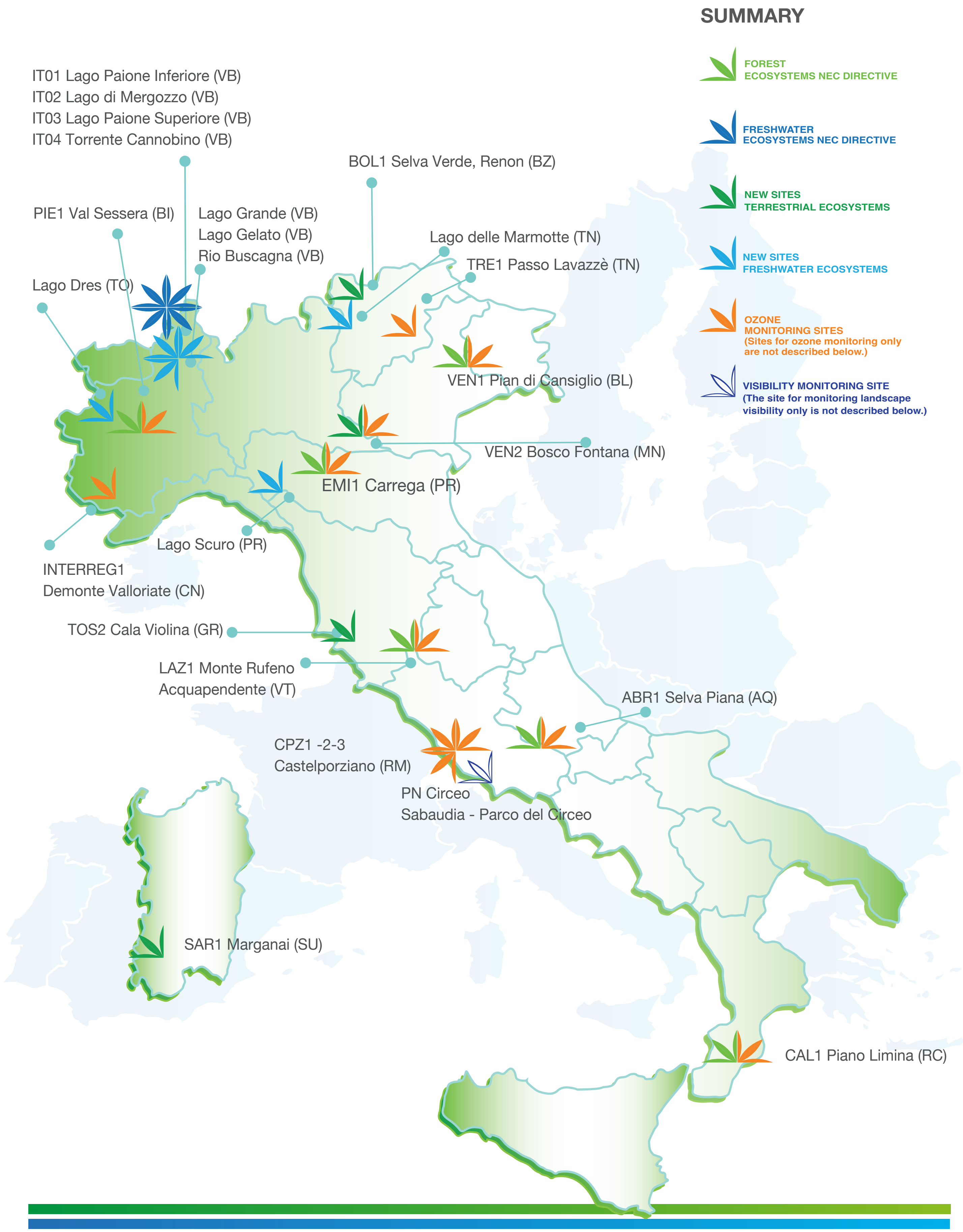
The directive does not merely set emission limits, but expressly requires Member States to monitor the effects of air pollution on ecosystems, creating a surveillance system that allows the effectiveness of the emission reduction measures implemented to be assessed. This integrated approach recognises that environmental protection requires not only the reduction of emissions at source, but also a thorough understanding of how pollutants affect natural ecosystems.

## The objectives of the LIFE MODERn (NEC) project

The LIFE MODERn (NEC) project arose from the awareness that Italy needed a more structured and representative monitoring system in order to respond effectively to the obligations of the NEC Directive. The initiative focused on the impact of air pollution on forest and freshwater ecosystems, with particular attention to sensitive areas of the country. From a scientific point of view, the project aimed to significantly improve the existing monitoring system by expanding the network of monitoring sites and developing new, more sensitive and representative indicators. From a regulatory point of view, the objective was to support national authorities in implementing the NEC Directive and to contribute concretely to the achievement of pollutant emission reduction targets.

It was essential to promote public awareness of the importance of air quality for the health of ecosystems and humans, recognising that environmental protection requires not only technical and regulatory measures, but also an informed and aware population.

## NEC Italy network and new sites






# 1. PROJECT ACTIVITIES

### Strategic Expansion of the Monitoring Network

The expansion of the NEC Italy network is one of the most significant results of the project. **The monitoring network has been** successfully **doubled**, bringing the total number of sites to 20, evenly distributed between forest ecosystems (10 sites) and freshwater systems (10 sites). This expansion was not merely quantitative, but followed rigorous scientific criteria to increase the representativeness of Italian biodiversity.

The inclusion of new types of forests and aquatic systems has made it possible to extend monitoring to **the Apennine**, **Mediterranean** and **Eastern Alpine ecosystems**, which were previously under- d. This strategic choice has made **it possible to obtain a more complete and representative picture of the effects of atmospheric pollution on a national scale**, taking into account the climatic, geological and biological diversity that characterises the Italian territory.

### Development of Innovative Indicators

An innovative aspect of the project was the development of **18 new indicators** to more effectively assess the effects of air pollution and its impact on biodiversity by observing different aspects of the ecosystem's response to pollution, from the morphological characteristics of leaves to chlorophyll content, from the taxonomic and functional diversity of vascular plants to specific indicators for epiphytic lichens.

Particular attention was paid to **biological indicators** (epilithic diatoms and benthic macroinvertebrates) of **water quality**, **recognising that aquatic ecosystems are often the final receptors of atmospheric pollutants**. The selection of these indicators was based on criteria of sensitivity, representativeness and ease of detection, ensuring that the monitoring system could be maintained over time with sustainable resources.

# NEW INDICATORS

| ECOSYSTEM | ENVIRONMENTAL MATRIX | INDICATORS |
|---|---|---|
| FOREST ECOSYSTEM | VASCULAR PLANTS | Leaf characteristics: surface area and dry biomass |
| | | Relative chlorophyll content in leaves, chlorophyll fluorescence |
| | | Taxonomic and functional diversity |
| | | Number of plant species combinations |
| | | Phenology from Remote Sensing (RS) at the plot/ROI (Region Of Interest) level |
| | EPIPHYTIC LICHENS | Number and abundance of functional groups: i) growth form; ii) species sensitive to nitrogen compounds |
| | | Vitality and conservation status of the indicator species Lobaria pulmonaria |
| | | Fruticose lichens fallen to the ground |
| | WILDLIFE | Taxonomic and functional diversity of Bats |
| | | Complexity of the soundscape of birdlife |
| | | Soil biological quality QBS - arthropods |
| | AREA | Visibility Index: relative humidity, sea salt, organic matter, elemental carbon, fine soil |
| | SOIL | Flows of pollutants leaving the soil |
| AQUATIC ECOSYSTEM | WILDLIFE | Number and abundance (relative and overall) of macroinvertebrate taxa |
| | FLORA | Number and abundance (relative and total) of diatom taxa |



## Visibility Monitoring: An Innovative Approach

The implementation of 'visibility' monitoring represents a particularly innovative approach to assessing the impact of atmospheric pollution on the optical view of the landscape. This methodology, originally developed for natural parks in the United States, has been adapted to the specific characteristics of the Italian territory.

Visibility monitoring not only has scientific value, but also an important communicative impact, as it makes **the effect of air pollution** tangible to the public **through the reduction in the visual quality of the landscape**. This aspect is fundamental for public awareness- nd understanding the importance of emission reduction policies.

## Harmonization of Protocols and Networking

The project has devoted significant resources **to harmonising existing monitoring protocols**, with a particular focus on the effects of ozone on forest vegetation, plant diversity and epiphytic lichens. This standardisation work is essential to ensure the comparability of data over time and space.

Networking activities with other LIFE projects and international networks such as ICP Forests, ICP Waters and IUFRO **have facilitated the exchange of experiences and methodologies, promoting the replicability of the approach developed in other European countries**. This international aspect of the project is crucial for addressing environmental problems that know no national boundaries, such as air pollution.

# 2. STUDY AREAS: CHARACTERISTICS AND DISTRIBUTION

## Forest Ecosystems: Diversity and Representativeness

The selection of forest sites followed rigorous scientific criteria to ensure the representativeness of the main types of Italian forests. **The existing sites already included significant ecosystems**, such asla nd Selva Piana in Abruzzo (ABR1), Piano Limina in Calabria (CAL1), and the Carrega forest in Emilia- Romagna (EMI1), **representing different types of forest and climatic conditions**.

**The expansion of the network has made it possible to include new strategic ecosystems** such as Cala Violina in Tuscany (TOS2), which represents **Mediterranean coastal ecosystems**, and Selva Verde at the Renon Pass in South Tyrol (BOL1), **which extends the monitoring of alpine ecosystems**. Particularly significant is the inclusion of Bosco Fontana in Veneto (VEN2), one of the few examples of lowland forest in the Po Valley, and the Marganai site in Sardinia (SAR1), **which represents island ecosystems**.

**This geographical and typological diversification makes it possible to assess how different forest types respond to atmospheric pollution,** taking into account factors such as altitude, proximity to sources of pollution, and the specific characteristics of the dominant plant species.

## Freshwater Ecosystems: Environmental Sentinels

Freshwater ecosystems are particularly sensitive indicators of atmospheric pollution, as they act as final receptors for many pollutants that reach the ground through atmospheric deposition. **The monitoring network includes sites distributed mainly in the Alpine and pre-Alpine regions**.

High-altitude lakes, such as Lago Paione Inferiore and Lago Paione Superiore in Piedmont, are ecosystems that are particularly vulnerable to acid deposition. **The inclusion of streams** such as Cannobino and Rio Buscagna also allows for the assessment of lotic ecosystems (running water ecosystems, such as rivers, streams, brooks and rapids, characterised by a continuous flow of water), **integrating the information obtained from lake environments**.

The selection of these sites took into account criteria relating **to distance from direct sources of pollution**, chemical sensitivity of the waters and the presence of representative biological communities. These ecosystems act as veritable '**environmental sentinels**', capable of showing and signalling the effects of atmospheric pollution.



# 3. RESULTS OF CHEMICAL-PHYSICAL

## Monitoring Atmospheric Deposition

Analysis of atmospheric deposition revealed significant trends in the evolution of pollution. **Sulphur deposition**, which was high in the second half of the last century, **has decreased significantly**, allowing the pH of precipitation to return to values closer to natural levels. This improvement reflects the effectiveness of European environmental policies to reduce sulphur compound emissions.

The situation with nitrogen is more complex: while there has been a reduction in nitrate, derived from nitrogen oxides emitted by industrial combustion and traffic, **ammonium levels have remained relatively constant over time.** This compound, mainly of a**gricultural and livestock origin, represents a particular challenge for areas of the Po Valley**.

The geographical distribution of nitrogen deposition shows **high values in the Po Valley and neighbouring hills**, where levels often exceed those critical for the health of forest ecosystems, i.e. the thresholds above which an impact is more likely. In the rest of the country, values are generally lower, although they remain significant in some areas.

## Soil Solutions and Water Flows

Monitoring soil solutions has made it possible to observe the movement of pollutants in the soil- plant system and potential losses to groundwater. Ammonium emerges as the most problematic pollutant, being the only one actually capable of causing soil acidification at the monitored sites.

Estimating water flows through the soil has proven technically feasible but requires accurate assessments of the specific conditions at each site, **considering factors such as soil texture**, **slope**, **vegetation cover and local climatic conditions**.

## Meteorological conditions

**Weather monitoring**, which has been ongoing since 1997, **has shown an upward trend in average temperature of approximately 0.09°C per year**, consistent with global climate change. With regard to precipitation, there is considerable spatial variability, with some areas recording decreases of up to 5% and a slight increase in the frequency of extreme weather events.

## Visibility Monitoring

The visibility monitoring campaign represents an innovative approach to **assessing the impact of air pollution on the visual perception of the landscape**. Using protocols derived from the experience of American natural parks, this activity has made it possible to characterise the airborne pollutants that reduce atmospheric transparency, linking technical aspects of pollution with the public perception of environmental degradation.



# 4. HEALTH STATUS OF FOREST

## Ecosystems Canopy

**Analysis of tree canopy conditions**, using the parameter of defoliation, **has revealed worrying trends**. There has been a general deterioration in beech forests and a persistent decline in alpine conifers, particularly evident in *Picea abies* spruce forests. This deterioration is **closely related to the recurring hot and dry summers that are increasingly characteristic of the Italian climate**.

## Tree growth

**The study of tree growth has revealed the sensitivity of this parameter to environmental changes**. Periodic five-yearly measurements on approximately 2,300 trees at 10 sites provide a 'thermometer' of forest vitality, while intra-annual monitoring of 165 trees of seven different species describes immediate reactions to environmental stress.

Extreme climatic events have left clear traces in growth: the late frost of 2016 in Abruzzo reduced growth to minimum values (0.061 cm), while the drought of 2017 hit Turkey oaks and English oaks in central Italy hard, with growth reduced to 0.10-0.14 cm.

## Effects of ozone

**Monitoring of tropospheric ozone showed persistently high concentrations** (40-44 ppb) throughout the study period. Only 3 out of 10 sites showed no visible leaf symptoms on the dominant species, while at the other 8 sites the percentage of symptoms ranged from 18% to 51%, with the Abruzzo site recording the highest values.

## Foliar Chemistry and Physiological Indicators

Thirty years of monitoring of leaf chemistry showed **substantial stability**, with temporary fluctuations that were promptly reabsorbed. The introduction of new indicators such as chlorophyll content and fluorescence provided additional tools for assessing tree vitality, representing a starting point for future long-term data series.

# 5. BIODIVERSITY AND BIOLOGICAL

## Indicators Epiphytic Lichens

**The epiphytic lichen community showed a richness of 112 species distributed across the 10 forest sites, with considerable variability between sites** (from 10 to 42 species per plot). The Lichen Biodiversity Index varies between 12 and 102, reflecting the different environmental conditions of the sites.
The proportion of nitrophilous species is confirmed as an excellent indicator for distinguishing forest areas subject to different levels of nitrogen deposition. Particularly significant is the monitoring of Lobaria pulmonaria, a species sensitive to pollution and considered a flagship species, currently present in only 2 of the 10 sites with a good conservation status.

## Vascular Plants

Monitoring of vascular flora detected a total of **273 species in 2023 and 287 in 2024 at the 10 sites in the NEC network**. Analysis of historical trends since 1999 indicates a **reduction in the number of species over time**, particularly evident in boreal and nemoral mixed oak forest sites, while Mediterranean sites show greater stability.
The new indicators developed, such as 'Compositional Diversity' and 'Specific Leaf Area', provide information on the complexity of the spatial organisation of vegetation and the ecological strategies of plants, with values reflecting the different environmental and climatic conditions of the sites.

## Fauna and New Indicators

The introduction of fauna indicators has significantly enriched monitoring. The QBS-ar index was applied to forest sites in 2023–2024, showing generally high values, indicating very good or excellent soil quality.

**Bat diversity and acoustic analysis of birds provided valuable information on the complexity of forest habitats**.
The innovative application of environmental DNA (eDNA) has made it possible to identify vertebrate and invertebrate species **through the analysis of genetic traces**, providing a detailed 'snapshot' of biodiversity, even for elusive or rare species.



# 6. THE STUDY OF FRESHWATER ECOSYSTEMS

The extension of the freshwater monitoring network **has made it possible to include sites with different sensitivities to atmospheric pollutant deposition**. The analysis of the chemical composition of the waters assessed nitrogen enrichment and possible acidification, using two particularly sensitive biological indicators: epilithic diatoms and benthic macroinvertebrates.

Diatoms have proven to be excellent indicators of the state of water with regard to acidification, also showing sensitivity to meteorological and climatic factors such as temperature and water level. Benthic macroinvertebrates are less sensitive to the effects of atmospheric deposition, but more influenced by climatic factors and nutrient levels.

Chemical data confirmed a positive response to the decrease in sulphur and nitrogen compound deposition, even though the latter continue to be present in quantities often exceeding critical loads. This highlights the need to continue efforts to reduce nitrogen compound emissions.

# 7. FUTURE PROSPECTS

## Replicability

**The project has developed a comprehensive strategy for replicability in other European countries with the aim of supporting them in complying with the NEC Directive in order to improve air quality**. This strategy has been successfully tested in collaboration with the Romanian National Institute for Forest Research and Development (ICAS) 'Marin Dracea'. The strategy consists of four progressive phases: preliminary assessment of existing activities, in-depth analysis of overlaps, detailed assessment of available variables, and collaborative implementation of indicators.

## 8. THE PROJECT IN NUMBERS

- **4** years of activity.

- **10** new monitoring sites (for a total of 20: 10 forest and 10 freshwater sites).

- **18** new indicators of the health of ecosystems affected by air pollution.

- **30** trained detection technicians from the Forestry Police.

- Over **100** national and international initiatives in which the project was presented.

- Over **2.000** citizens involved in awareness-raising initiatives, flash mobs and clean air days.

- Over **50** journalists trained on the topic of air pollution and its impact on ecosystems.

- **200** teachers trained on the topic of air pollution.

- Over **1.000** students involved in educational activities on air pollution and the LIFE MODERn NEC project.

- Over **10.000** insights on social networks.

- **30** press releases to report on the project's initiatives.

- **30** projects involved in networking activities.

- **8** partners with over **100** staff members involved.