

# Air quality in Europe shows significant improvements over the last two decades, study finds

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A study led by the Barcelona Institute for Global Health (ISGlobal) has consistently estimated daily ambient concentrations of  $\text{PM}_{2.5}$ ,  $\text{PM}_{10}$ ,  $\text{NO}_2$

and O<sub>3</sub> across a large ensemble of European regions between 2003 and 2019 based on machine learning techniques. The aim was to assess the occurrence of days exceeding the 2021 guidelines of the World Health Organization (WHO) for one or multiple pollutants, referred to as "unclean air days."

The research team analyzed [pollution levels](#) in more than 1,400 regions in 35 European countries, representing 543 million people. The results, published in *Nature Communications*, show that overall suspended particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) and nitrogen dioxide (NO<sub>2</sub>) levels have decreased in most parts of Europe.

In particular, PM<sub>10</sub> levels decreased the most over the study period, followed by NO<sub>2</sub> and PM<sub>2.5</sub>, with annual decreases of 2.72%, 2.45% and 1.72% respectively. In contrast, O<sub>3</sub> levels increased annually by 0.58% in southern Europe, leading to a nearly fourfold rise in unclean air days.

The study also looked at the number of days on which the limits for two or more pollutants were exceeded simultaneously, a confluence known as a "compound unclean air day." Despite the overall improvements, 86.3% of the European population still experienced at least one compound unclean day per year during the study period, with PM<sub>2.5</sub>-NO<sub>2</sub> and PM<sub>2.5</sub>-O<sub>3</sub> emerging as the most common compound combinations.

The results highlight the significant improvements in air quality in Europe followed by the decline of PM<sub>10</sub> and NO<sub>2</sub>, while PM<sub>2.5</sub> and O<sub>3</sub> levels continue to exceed WHO guidelines in many regions, resulting in a higher number of people exposed to unclean air levels.

"Targeted efforts are needed to address PM<sub>2.5</sub> and O<sub>3</sub> levels and associated compound unclean days, especially in the context of rapidly increasing threats from climate change in Europe," says Zhao-Yue Chen, ISGlobal researcher and lead author of the study.

"Our consistent estimation of population exposure to compound air pollution events provides a solid basis for future research and policy development to address air quality management and public health concerns across Europe," points out Carlos Pérez García-Pando, ICREA and AXA Research Professor at the BSC-CNS.

## **Heterogeneous geographical distribution**

The research team has developed machine learning models to estimate high-resolution daily concentrations of major air pollutants like PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub> and O<sub>3</sub>. This data-driven approach creates a comprehensive daily air quality picture for the European continent, going beyond sparsely distributed monitoring stations.

The models gather data from multiple sources, including satellite-based aerosol estimates, existing atmospheric and climate data, and land use information. By analyzing these air pollution estimates, the team calculated the annual average number of days in which the WHO daily limit for one or more air pollutants is exceeded.

Despite [air quality](#) improvements, 98.10%, 80.15% and 86.34% of the European population lives in areas exceeding the WHO recommended annual levels for PM<sub>2.5</sub>, PM<sub>10</sub> and NO<sub>2</sub>, respectively. These results closely match the European Environment Agency (EEA)'s estimates for 27 EU countries using data from urban stations only.

Additionally, no country met the ozone (O<sub>3</sub>) annual standard during the peak season from 2003 to 2019. Looking at short-term exposure, over 90.16% and 82.55% of the European population lived in areas with at least 4 days exceeding WHO daily guidelines for PM<sub>2.5</sub> and O<sub>3</sub> in 2019, while the numbers for NO<sub>2</sub> and PM<sub>10</sub> were 55.05% and 26.25%.

During the study period, PM<sub>2.5</sub> and PM<sub>10</sub> levels were highest in northern

Italy and eastern Europe, while  $PM_{10}$  levels were highest in southern Europe. High  $NO_2$  levels were mainly observed in northern Italy and in some areas of western Europe, such as in the south of the United Kingdom, Belgium and the Netherlands.

Similarly,  $O_3$  increased by 0.58% in southern Europe, while it decreased or showed a non-significant trend in the rest of the continent. On the other hand, the most significant reductions in  $PM_{2.5}$  and  $PM_{10}$  were observed in central Europe, while for  $NO_2$  they were found in mostly urban areas of western Europe.

## **The complex management of ozone**

The average exposure time and population exposed to unclean air concentrations of  $PM_{2.5}$  and  $O_3$  is much higher than for the other two pollutants. According to the research team, this highlights the urgency of greater control for these pollutants and the importance of addressing the increasing trend and impact of  $O_3$  exposure.

Ground-level or tropospheric  $O_3$  is found in the lower layers of the atmosphere and is considered a secondary pollutant because it is not emitted directly into the atmosphere, but is formed from certain precursors—such as [volatile organic compounds](#) (VOCs), carbon monoxide (CO) and nitrogen oxides ( $NO_x$ )—that are produced in combustion processes, mainly in transport and industry. In high concentrations, ozone can damage human health, vegetation and ecosystems.

"Ozone management presents a complex challenge due to its secondary formation pathway. Conventional air pollution control strategies, which focus on reducing primary pollutant emissions, may not be sufficient to effectively mitigate  $O_3$  exceedances and associated compound unclean days," says Joan Ballester Claramunt, ISGlobal researcher and senior

author of the study. "However, addressing climate change, which influences ozone formation through increased sunlight and rising temperatures, is crucial for long-term ozone management and protection of public health."

## The challenge of compound episodes

Despite improvements in air pollution, the research team reported that over 86% of Europeans experienced at least one day with compound air pollution events each year between 2012 and 2019, where multiple pollutants exceeded WHO limits simultaneously.

Among those compound days, the contribution of PM<sub>2.5</sub>-O<sub>3</sub> compound days increased from 4.43% in 2004 to 35.23% in 2019, becoming the second most common type in Europe, indicating a worrying trend. They mainly occur in lower latitudes during warm seasons and are likely linked to climate change and the complex interplay between PM<sub>2.5</sub> and O<sub>3</sub>.

Warmer temperatures and stronger sunlight in summer boost O<sub>3</sub> formation through chemical reactions. Subsequently, higher levels of O<sub>3</sub> will accelerate the oxidation of organic compounds in the air. This oxidation process leads to the condensation of certain oxidized compounds, forming new PM<sub>2.5</sub> particles.

Additionally, climate change increases the likelihood of wildfires, which further elevates both O<sub>3</sub> and PM<sub>2.5</sub> levels. "This complex interplay creates a harmful loop, highlighting the urgent need to address [climate change](#) and air pollution simultaneously," explains Ballester Claramunt.

**More information:** Chen, Z.Y., Petetin, H., Turrubiates, R.F.M., Achebak, H., García-Pando, C.P. and Ballester, J., 2024. Population exposure to multiple air pollutants and its compound episodes in Europe,

*Nature Communications*. [DOI: 10.1038/s41467-024-46103-3](https://doi.org/10.1038/s41467-024-46103-3)

Related study: Zhao-Yue Chen et al, Estimation of pan-European, daily total, fine-mode and coarse-mode Aerosol Optical Depth at 0.1° resolution to facilitate air quality assessments, *Science of The Total Environment* (2024). [DOI: 10.1016/j.scitotenv.2024.170593](https://doi.org/10.1016/j.scitotenv.2024.170593)

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