Exploration of Asthma & Allergy

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An expert position paper on environment, occupation and climate change effects on allergic respiratory diseases in Italy

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Abstract

This expert position paper was developed by experts from nine Italian scientific societies with the aim of addressing in an integrated and multidisciplinary way the complex interactions between environmental and occupational exposures, climate change, and the onset of respiratory allergic diseases in the adult and paediatric population.

Air pollution is the leading environmental risk factor for human health worldwide and in Italy. According to the State of Global Air 2025, it caused 7.9 million deaths in 2023, making it the second leading risk factor for mortality. In response to growing scientific evidence, the World Health Organization (WHO) updated its Air Quality guidelines in 2021, recommending substantially lower pollutant limits than those established by previous European legislation. The new European Ambient Air Quality Directive (2024/2881/EU), which entered into force in December 2024, introduces stricter air quality standards to be achieved by 2030, while strengthening monitoring systems and public access to air quality information.

Italian epidemiological studies have consistently shown that exposure to particulate matter [PM: atmospheric PM with a diameter ≤ 10 μm (PM_{10}) and atmospheric PM with a diameter ≤ 2.5 μm ($PM_{2.5}$)], nitrogen dioxide (NO_2), and ozone (O_3) is associated with increased odds of rhinitis, asthma, chronic obstructive pulmonary disease (COPD), respiratory hospitalizations, and mortality both in the short and long term. These effects are mediated by inflammatory responses, oxidative stress, and molecular and epigenetic mechanisms. Children, particularly those living in densely populated urban areas with poor air quality, are among the most vulnerable populations.

Climate change, which originates from the same anthropogenic emissions driving air pollution, i.e., from energy, transport, heating, cooling, and agriculture, is further aggravating the burden of respiratory disease through more frequent heatwaves, extreme weather events, and changes in the distribution and flowering seasons of allergenic plants. Rising pollen production, combined with air pollution, enhances allergen exposure and worsens allergic respiratory diseases. Therefore, integrated monitoring of pollen, air pollutants, and meteorological conditions is essential for improving disease prediction and prevention. Particular concern is raised by thunderstorm asthma, characterized by sudden outbreaks of severe asthma following thunderstorms.

Indoor air pollution is also emerging as a major public health concern because of the growing use of chemicals and the high fraction of time spent indoors. Passive smoking, combustion products from cooking and heating, volatile organic compounds, and inadequate ventilation are associated with respiratory symptoms and impaired lung function. Schools are of particular concern, as elevated levels of carbon dioxide and PM are frequently reported in classrooms.

Occupational exposure to dust, fumes and gases remains an important cause of occupational asthma and respiratory impairment.

This document promotes operational proposals for risk prevention and mitigation, encourages scientific research and fosters the dialogue with public health and environmental authorities, in order to strengthen respiratory health protection policies.

Keywords

air pollution, climate changes, pollens, occupational exposure, asthma, COPD, allergic diseases, prevention

Executive summary

Air pollution is considered the most significant environmental risk factor on a planetary level and in Italy. The State of Global Air 2025, published by the Health Effects Institute, showed that in 2023, air pollution caused 7.9 million deaths globally, becoming the second risk factor for mortality, even for children under five. In September 2021, the World Health Organization (WHO) published the Global Air Quality Guidelines (AQG), recommending values much lower than those accepted by the 2008 European Directive, based on new epidemiological studies that have shown damage to health even from exposure to low levels of air pollutants. The Ambient Air Quality Directive 2024/2881/EU entered into force on 10 December 2024, setting new and stricter limits for air pollutants to be achieved by 2030. The directive brings European standards closer to the WHO recommendations (but does not adopt them) and introduces provisions to improve monitoring, coordination, and access to air quality information.

The main diseases associated with air pollution are respiratory, cardiovascular, cerebrovascular, neurodegenerative, diabetes, arterial hypertension, premature birth and low birth weight, as stated by the WHO and the scientific societies European Respiratory Society (ERS) and American Thoracic Society (ATS). The European Academy of Allergy and Clinical Immunology (EAACI) guidelines on the Impact of Short-Term Exposure to External Pollutants for Asthma-Related Outcomes provide recommendations for prevention, patient care, and mitigation in a framework that supports rational decisions.

Environmental risk factors for asthma and chronic obstructive pulmonary disease (COPD) are ubiquitous and often overlapping. While asthma is strongly influenced by allergens and pollutants that promote predominantly allergic-type inflammation, COPD is predominantly linked to chronic exposures that cause structural damage and persistent inflammation.

In Italy, as early as the 1990s, it became clear that living in cities was associated with more respiratory symptoms and diseases than living in rural areas, but also that exposure to air pollution was associated with increased mortality and hospitalizations for respiratory causes and respiratory infections of the upper and lower airways. Over time, several analytical epidemiological studies conducted on the Italian territory have shown that rhinitis, asthma and COPD were associated with exposure to atmospheric particulate matter (PM) with a diameter ≤ 10 μm (PM_{10}), atmospheric PM with a diameter ≤ 2.5 μm ($PM_{2.5}$) and nitrogen dioxide (NO_2), and asthma attacks on exposure to summer ozone (O_3). In addition, the possible biological mechanisms of the effects of exposure to air pollution are being clarified, including activation of inflammatory stimuli, oxidative stress, molecular and epigenetic mechanisms. The association between respiratory outcomes and outdoor pollution emerged both in the general population and in preschool and school children, in whom the associations are particularly evident in areas characterized by high urban density and poor air quality.

The rapidity of climate change is causing a rapid increase in the burden of disease associated with extreme heat and heat waves; the occurrence of these events in some areas of southern and central Europe has doubled in the last twenty years. Climate change is exacerbating extreme events (including heat waves) and related natural disasters (including droughts, forest fires, hurricanes, floods, sandstorms and desert dust) and is changing plant phenology and the geographical distribution of allergenic plants, with a significant impact on respiratory and allergic health, posing larger risks to vulnerable populations, such as individuals with pre-existing conditions, children, the elderly and those who work outdoors.

In recent decades, respiratory allergic diseases have been increasing in frequency and severity in Italy and around the world. This trend is linked not only to the increased production of pollen and the prolonged duration of pollen seasons due to climate change, but also to the negative synergy between pollen and air pollution: pollutants and weather conditions can change the atmospheric concentration of pollen and other allergens and facilitate the penetration of allergens into the respiratory tract. Pollen monitoring therefore becomes a fundamental tool for understanding and managing the symptoms of these diseases. The adoption of integrated approaches that combine traditional standardized monitoring and emerging automatic systems appears particularly promising, especially in relation to the need to provide timely information and improve the predictive capacity of outdoor and indoor exposure models, integrated with all the information on aeroallergens, air pollution, weather and climate conditions, etc.

Of particular concern is the "thunderstorm asthma", sudden and severe asthma attacks, in many people at the same time, following thunderstorm episodes recorded in various parts of the world.

There is also growing concern about the health effects of indoor pollution, which has so far been less studied than outdoor pollution. The main pollutants include PM, of which passive smoke, fuels used for cooking/heating and volatile organic compounds (VOCs) are important sources. Analytical epidemiological studies have shown important associations between these exposures and respiratory symptoms/diagnoses and alterations in lung function. Recently, more and more attention has been paid to exposure in school environments, where children spend much of their time, confirming that indoor air quality is inadequate [high levels of carbon dioxide (CO_2) and PM_{10} in classrooms and poor ventilation] with effects on general and respiratory symptoms, as well as on the patency of the upper airways.

Despite the improvements of the last thirty years, the work environment continues to play a very important role in the etiopathogenesis and clinical course of respiratory allergy, even in Italy. In analytical epidemiological studies, an increased risk of asthma (symptoms and diagnosis) and respiratory functional alterations has been observed in subjects occupationally exposed to dusts, fumes and gases, as well as a higher prevalence of subjects with bronchial hyperreactivity in occupationally exposed subjects. Italian Workers' Compensation Authority (INAIL) data on occupational diseases document an increase in cases of occupational bronchial asthma in the last two years, although their number is still underestimated compared to the real extent of the phenomenon, as suggested by data from epidemiological studies in the occupational field.

Considering the impact of these exposures on the health of the general population, children and workers, the last chapter of the document is dedicated to prevention: anamnestic questions, practical advice and useful actions are reported with a view to preventing risks from exposure to outdoor, indoor and occupational air pollution and climate change.

Finally, a use of the electronic health record (EHR) is proposed to explore the environment-health relationships at the individual level.

Introduction

Over the last twenty years, the bulk of knowledge on the adverse effects of air pollution, either outdoor or indoor or occupational, has increased tremendously. Most papers have been published on environmental and/or occupational health journals, generally read by people interested in public health and not by practicing physicians. The resulting knowledge gap has become an obstacle to a holistic vision of prevention.

The need to suggest practicing physicians to become actors in prevention has prompted the Italian Society of Allergology, Asthma and Clinical Immunology (SIAAIC) to deal with the environmental health issue. From 2011 to 2024, a SIP-SIAAIC Task Force has been active, which, among other topics, has addressed the influence of climate change and outdoor and indoor air pollution on respiratory and allergic diseases. This activity has led to the development of two posters in recent years, which can be downloaded from the websites of the two societies:

- CAMBIARE "to change", presented at the 2022 SIP Congress in Catania and available at the web link https://www.sipirs.it/cms/ (https://infomed-news.it/newsletter/2022/siaaic165/POSTER-CAMBIARE.pdf);
- MITIGARE "to mitigate", presented at the 2024 SIAAIC Congress in Rome and available at the web link https://siaaic.org/ (https://siaaic.org/wp-content/uploads/2024/04/Crivellaro_LaGrutta_Liccardi_Milanese_Ridolo_POSTER-MITIGARE_16mar24_con-istituzioni.pdf).

During its meeting on November 15th, 2024, the SIAAIC Executive Committee approved the establishment of an inter-society Task Force focused on the "effects of environmental and occupational exposures and climate change on respiratory allergic diseases in the adult and paediatric populations in Italy" in order to provide allergists and pulmonologists with up-to-date information to implement prevention (primary, secondary, tertiary) and advocacy measures for patients with allergic respiratory diseases.

In the following months, eight societies accepted the invitation to join this effort: the Italian Association of Epidemiology (AIE), the Association of Italian Territorial and Hospital Allergists and Immunologists (AAIITO), the Italian Association of Hospital Pulmonologists (AIPO), the Italian Society of Paediatric Allergology and Immunology (SIAIP), the Italian Society of Aerobiology, Medicine and Environment (SIAMA), the Italian Society of Occupational Medicine (SIML), the Italian Society for Childhood Respiratory Diseases (SIMRI) and the Italian Society of Pneumology (SIP).

International epidemiological and environmental panorama

Air pollution

In 2017, the Lancet Commission on Pollution and Health reported an estimated 6.5 million deaths on a global scale attributable to outdoor and indoor air pollution, with predominant effects on COPD (50%) and lung cancer (40%) [1].

The first Global Conference on Air Pollution and Health held in Geneva in October 2018 [2] and the WHO Manifesto for a Healthy Recovery from COVID-19 [3] confirmed the estimate of 7 million premature deaths attributable to air pollution and the percentage of 90% of the world's population exposed to unacceptable levels of air pollution, concluding that "current knowledge is sufficient to act immediately .... in ten years we will not be able to say that we did not know".

In September 2021, the WHO published the Global AQG [4], recommending values much more stringent than those accepted by the 2008 European Directive, based on new epidemiological studies that have shown damage to health even from exposure to low levels of air pollutants.

The second WHO Global Conference on Air Pollution and Health, held in Cartagena (Colombia) in March 2025 [5], confirmed these estimates, and participants agreed on a shared goal to reduce the impact on health by 50% by 2040, in order to save millions of lives every year. In addition, new financial commitments and policies for environmental and health protection have been proposed.

The State of Global Air 2025, published by the Health Effects Institute [6], provided a comprehensive analysis of data related to air quality and health impact in countries around the world in 2023: air pollution caused 7.9 million deaths globally, becoming the second risk factor for mortality, even for children under five. Deaths attributable to $PM_{2.5}$ were 4.9 million; of these, 171,000 in children under the age of 5 years [6]. In addition, of the total deaths, non-communicable diseases, including heart disease, stroke, diabetes, lung cancer and COPD, account for almost 90% of the disease burden due to air pollution. In the previous edition of the report (2024), it was found that over 700,000 deaths of children under the age of 5 were linked to air pollution; this accounts for 15% of all global deaths in children under five years [7].

In March 2025, the Zero Pollution Monitoring and Outlook 2025 report [8], published by the European Environment Agency (EEA) and the Joint Research Centre (JRC), highlighted that significant progress has been made in Europe in reducing the impact of PM air pollution, with a 45% decrease in premature deaths attributable to $PM_{2.5}$ exposure between 2005 and 2022. However, more than 83% of residents in urban areas of the European Union (EU) are exposed, for all air pollutants, to pollution levels above the levels recommended by the WHO, with the exception of sulphur dioxide (SO_2) and benzo(a)pyrene (BaP), indicating persistent air quality problems. Reaching the objective of the Zero Pollution Action Plan (ZPAP) to reduce premature deaths by 55% in 2030 compared to 2005 requires the effective implementation of current and proposed policies, including those related to energy and climate change mitigation.

As far as Italy is concerned, the EEA's 2022 Air Quality report [9] showed that our country ranks 5th between 30 European countries for years lived with disability (YLD) due to COPD attributable to $PM_{2.5}$ in adults over twenty-five years of age (about 70 YLD per 100,000 inhabitants) and 3rd between 23 European countries for hospital admissions for respiratory diseases attributable to O_3 in adults over sixty-five years of age (about 22 hospitalizations per 100,000 inhabitants). In addition, the EEA's 2025 report on Health Harms from Air Pollution [10] provided estimates of annual premature deaths attributable to exposure to major air pollutants in 2023: in Italy, 43,083 for $PM_{2.5}$, 9,064 for NO_2 and 1,123 for O_3.

The Ambient Air Quality Directive 2024/2881/EU [11] entered into force on 10 December 2024, setting new and stricter limits for air pollutants, such as $PM_{2.5}$ and NO_2, to be achieved by 2030, with the aim of zero pollution by 2050. The directive brings European standards closer to the recommendations of the WHO (but does not adopt them) and introduces provisions to improve monitoring, coordination and access to information.

On the basis of these premises, air pollution is to be considered the most significant environmental risk factor on a planetary level and in Italy, therefore requiring immediate prevention actions.

Table 1 shows the levels of AQG and intermediate targets recommended by the WHO.

Table 1. Recommended Air Quality Guidelines (AQG) levels and interim targets.

Pollutant	Averaging time	Interim target				AQG level
		1	2	3	4	
$PM_{2.5}$, μg/m^3	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, μg/m^3	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3, μg/m^3	Peak season[b]	100	70	-	-	60
	8-hour[a]	160	120	-	-	100
NO_2, μg/m^3	Annual	40	30	20	-	10
	24-hour[a]	120	50	-	-	25
SO_2, μg/m^3	24-hour[a]	125	50	-	-	40
CO, mg/m^3	24-hour[a]	7	-	-	-	4

[a] 99th percentile (i.e., 3–4 exceedance days per year). [b] Average of daily maximum 8-hour mean ozone (O_3) concentration in the six consecutive months with the highest six-month running-average O_3 concentration. CO: carbon monoxide; NO_2: nitrogen dioxide; PM_{10}: atmospheric particulate matter with a diameter ≤ 10 μm; $PM_{2.5}$: atmospheric particulate matter with a diameter ≤ 2.5 μm; SO_2: sulphur dioxide. Reprinted from [4]. © WHO 2021. Licensed under the Creative Commons Attribution-NonCommercial-Share Alike 3.0 IGO licence (CC BY-NC-SA 3.0 IGO).

Climate change

The climate crisis is a phenomenon that risks substantially and irreversibly transforming natural ecosystems and the human living environment. 2024 was the hottest year on record (around + 1.55°C compared to the pre-industrial level), with an uninterrupted increase in global temperatures, particularly over the past decade, and an increase in exposure to heat waves globally [12]. Climate change is also intensifying the effects of other environmental exposures, particularly among the most vulnerable populations and regions: sandstorms, forest fires aggravated by drought and land degradation, peaks in local O_3 air pollution, and heavy rainfall.

The Mediterranean is a region particularly vulnerable to climate change "hot spots": the temperature in the Mediterranean basin is increasing at a rate 20% faster than the global average, leading to a series of changes in the climate system with an increase in the intensity and duration of extreme events, including heat waves and impacts on natural systems and human health [13]. The latest Lancet Countdown report estimated that 84% of heatwave days that occurred in the last 5 years would not have occurred in the absence of climate change [14].

Other extreme weather events such as heavy rainfall can also increase in frequency and intensity in some regions and are sometimes associated with floods and flooding [13]. Such episodes can have a range of acute effects, such as trauma and mortality, but the experience of regions where these episodes are more frequent has also shown health risks due to the proliferation of mould and fungi in flooded homes.

Also in the Mediterranean area, the frequency of drought episodes is increasing, understood as an unusual and prolonged shortage of water availability, caused by reduced rainfall and increased evaporation [15]. Heat and drought in turn increase the frequency of forest fires [13]. Finally, drought leads to the progressive desertification of increasingly large areas: in Italy, the frequency of previously very rare phenomena is increasing, such as dust transport events from desert areas, especially from North Africa. Such dust can be transported thousands of km away, with worsening air quality and possible health effects, particularly respiratory health, in countries affected by the passage of the desert sand cloud [16].

Such exposures associated with climate change can have consequences on respiratory and allergic health, especially in the short term, and, in some cases, even in the long term. However, the respiratory health impact of the climate crisis is very difficult to study and must take into account complex causal mechanisms, which can be directly (e.g., exposure to increasingly higher temperatures) and indirectly (e.g., higher levels of food insecurity, sensitivity to extreme weather events) related to climate change, interacting with population susceptibility, health and socio-demographic conditions, availability of infrastructure and adaptive capacities [13].

In view of the ongoing climatic changes, as also underlined by a recent review by Annesi-Maesano et al. [17], there is increasing evidence that extreme events (including heat waves, forest fires, hurricanes, floods) have a significant impact on respiratory health, posing greater risks for vulnerable populations, such as individuals with pre-existing diseases, children, the elderly and those who work outdoors. Also considering the future scenarios of further intensification of exposures to such events, including in our country, it is urgent to increase awareness and response capacity to protect public health starting from the population groups at greatest risk [18].

Recommendations—guidelines of international scientific societies

The main diseases associated with air pollution are respiratory, cardiovascular, cerebrovascular, neurodegenerative, diabetes, arterial hypertension, premature birth and low birth weight, as stated by the WHO and the scientific societies ERS (which in 2012 had published a decalogue of principles for clean air [19]) and the ATS, which, also in 2017, published a paper on what constitutes an adverse effect of air pollution [20]: Table 2 is derived from this document.

Table 2. Examples of clinical effects associated with air pollution*.

Respiratory	Cardiovascular	Neurological and psychiatric conditions
Increased respiratory mortality	Mortality from cardiovascular diseases	Alzheimer's disease and other dementias
Increased incidence of malignant tumors of the respiratory tract	Myocardial infarction	Parkinson's disease
Increased incidence, prevalence, or frequency of exacerbations in chronic lung diseases: asthma, COPD, and cystic fibrosis	Stroke	Reduced cognitive function in adults
Increased incidence or severity of upper and lower respiratory tract infections	Increased blood pressure	Neurodevelopmental delay in Children
Increased respiratory symptoms affecting quality of life: cough, phlegm, wheezing, dyspnoea and nasal secretion	Arrhythmias	Depression
Increased incidence of premature births, low birth weight, or growth limitation leading to adverse respiratory outcomes	Hospital admissions for congestive heart failure	Anxiety disorders
Reduced growth of lung function in children		
Transient reductions (hours) in lung function associated with symptoms in healthy individuals		
Transient reductions (hours) in symptom-free lung function in particularly sensitive individuals (e.g., children with severe asthma)		
Persistent or chronic (weeks, months, or years) decreases in lung function		

*: Modified from [20]. COPD: chronic obstructive pulmonary disease.

The EAACI guidelines on the Impact of Short-Term Exposure to External Pollutants for Asthma-Related Outcomes [21] provide recommendations for prevention, patient care, and mitigation in a framework that supports rational decisions: for healthcare professionals and patients, in order to personalize and improve asthma management; for decision-makers and regulatory bodies, as an evidence-based reference to help establish legally binding standards and targets for outdoor air quality at international, national, and local levels. The guidelines were developed using the internationally recognized GRADE approach to produce evidence-based clinical recommendations in a rigorous and transparent manner, and evaluated the outdoor pollutants mentioned in the current WHO AQG as single or mixed pollutants and pesticides for outdoor use. These guidelines provide "conditional recommendations", i.e., strong but not stringent indications to be assessed according to the local context by policy makers, for short-term asthmatic events (Table 3).

Table 3. Guidelines on the impact of short-term exposure to major pollutants on asthma-related outcomes*.

Pollutant	Increase above the WHO threshold	Health effect (latency of effect)
CO	10 μg/m^3	> ED access risk (Lag 0–4)
		> Risk of hospitalization (Lag 2 and 4)
NO_2	10 μg/m^3	> ED access risk (Lag 0–4)
		> Risk of hospitalization (Lag 1–4)
O_3	10 μg/m^3	> ED access risk (Lag 1)
		> Risk of hospitalization (Lag 1 and 2)
$PM_{2.5}$	10 μg/m^3	> ED access risk (Lag 0–3)
		> Risk of hospitalization (Lag 3)
PM_{10}	10 μg/m^3	> ED access risk (Lag 0–4)
		> Risk of hospitalization (Lag 1–3)
SO_2	10 μg/m^3	> ED access risk (Lag 0–3)
		> Risk of hospitalization (Lag 1)
TRAP	-	< Asthma control
		> Risk of asthma exacerbations and asthma hospitalizations
		> Use of asthma medication or ED access
		< Lung function and asthma-related quality of life

*Modified by [21]. Lag: time interval in days between peak exposure to pollutant and health event. CO: carbon monoxide; ED: emergency department; NO_2: nitrogen dioxide; O_3: ozone; PM_{10}: atmospheric particulate matter with a diameter ≤ 10 μm; $PM_{2.5}$: atmospheric particulate matter with a diameter ≤ 2.5 μm; SO_2: sulphur dioxide; TRAP: traffic-related air pollution; WHO: World Health Organization.

Methods

Each society has nominated two experts, who have worked hard until late spring of 2026 to realize this expert position paper.

At first, a narrative review of the relevant papers, mostly published in the last ten years, with a special focus on Italian scientific studies, has been performed for each topic covered by the Task Force.

Each chapter has been written by a team of 2–4 experts, dealing with the adverse environmental effects on allergic respiratory diseases, assessing the consistency of studies, the strength of association, and potential knowledge gaps, while identifying susceptible subgroups. Studies on the general and paediatric populations have been evaluated separately. To support disease prevention and clinical management across various exposure types (indoor and outdoor air pollution, climate change, occupational exposure, and pollen), indications for both clinicians and patients have been proposed.

Results

Integrated analysis of environmental risk factors for asthma and COPD

Asthma and COPD are the most frequent non-communicable respiratory diseases in the general population. The distinguishing features of both diseases are reported in Supplementary material 1.

Asthma and COPD are complex chronic respiratory diseases, whose etiology is multifactorial, resulting from a complex interaction between genetic predisposition and multiple environmental factors.

Although cigarette smoking is the main risk factor for COPD, a growing body of scientific evidence shows that exposure to a wide range of environmental pollutants and occupational agents plays a crucial role not only in the development of COPD, but also in asthmatic onset and exacerbations [22, 23].

Outdoor air pollution

Air pollution is a complex mixture of gases and PM, the latter classified according to aerodynamic diameter. Exposure to these pollutants is a well-established risk factor for both diseases.

- Asthma: exposure to vehicular traffic, in particular NO_2 and $PM_{2.5}$, is associated with an increased incidence of asthma in children and an increased risk of exacerbations in all ages. These pollutants act as adjuvants, promoting allergic sensitization and inducing a state of oxidative stress and inflammation in the airways [24, 25].
- COPD: long-term exposure to NO_2 and $PM_{2.5}$ is associated with an accelerated decline in lung function and an increased risk of developing COPD, regardless of cigarette smoking. In individuals already suffering from COPD, pollution peaks are correlated with an increase in hospital admissions for acute exacerbations [26, 27].

Indoor pollution and biomass fuels

The home environment is a significant source of exposure to pollutants that can affect respiratory health.

- Passive smoking: It is a known risk factor for both the onset of childhood asthma and the development of respiratory symptoms and COPD in adulthood in non-smokers.
- Indoor allergens: Exposure to dust mites, mold, pet dander, and cockroaches is a primary trigger for the development and exacerbations of allergic asthma [28].
- Biomass fuels: Globally, the burning of biomass (wood, charcoal, animal dung) for cooking and heating in poorly ventilated rooms is one of the main causes of COPD, especially in women in low- and middle-income countries. The smoke generated contains very high levels of PM and toxic substances that cause intense lung inflammation [29].

Occupational exposures

The workplace is another crucial source of exposure to substances that can cause or worsen respiratory diseases. It is estimated that about 15–20% of cases of asthma and COPD in adults are attributable to occupational factors [30].

- Occupational asthma: It is the most common work-related respiratory disease in industrialized countries. It can be triggered by high molecular weight agents (e.g., flours, enzymes, latex) that induce IgE-mediated sensitization, or by low molecular weight substances (e.g., isocyanates, acid anhydrides) that act through complex immunological mechanisms.
- Occupational COPD: Chronic exposure to inorganic dusts (coal, silica in miners), organic dusts (cotton dust in textile workers, grain dusts in farmers), and chemical fumes (e.g., cadmium) is a recognized cause of COPD. These agents induce chronic inflammation and a progressive decline in lung function, acting additively or synergistically with cigarette smoking [31].

VOCs

VOCs represent a heterogeneous category of chemical compounds with high vapor pressure at room temperature. Indoor concentrations are typically 2–5 times higher than outdoor concentrations, reaching 50–500 μg/m^3. The main VOCs present in indoor environments are formaldehyde (10–100 μg/m^3), benzene, toluene, xylenes, and chlorinated organic compounds. The main sources are building materials and furniture, household cleaning products, cosmetics and personal hygiene products, paints and adhesives. Exposure to VOCs is associated with increased asthma development [relative risk (RR) 1.37] [32]. VOCs can be ubiquitously distributed in home, school, work and recreational environments.

Radon

Radon is a natural gas generated by the radioactive decay of radium, which is found in rocks, soils and derived building materials. It penetrates and spreads in buildings (indoor radon), reaching concentrations that vary from environment to environment. The average concentration in Italy amounts to about 70 Bq/m^3, but there are areas at risk with radon gas levels > 300 Bq/m^3 [33]. Radon is a certain carcinogen (Group 1) for lung cancer in exposed populations [34]. However, it has also been identified as a potential risk factor for the development and worsening of asthma control, increasing IL-6 and IL-5 levels by 14.9% and 13.4%, respectively, even in patients and healthy subjects with no history of atopy [odds ratio (OR) 1.149] [35, 36].

The main risk factors for asthma and COPD are shown in Table 4.

Table 4. Environmental risk factors for asthma and COPD.

Environmental risk factor	Impact on asthma	Impact on chronic obstructive pulmonary disease (COPD)	Main agents and sources
Air pollution (outdoor)	It increases the incidence (especially in children) and causes exacerbations. Promotes allergic sensitization.	It accelerates the decline in lung function and increases the risk of developing and exacerbating the disease.	Particulate matter (PM), nitrogen dioxide (NO_2), ozone (O_3) deriving from vehicular traffic and industrial emissions.
Domestic pollution (indoor)	Exposure to allergens causes onset and exacerbation. Secondhand smoke is a key risk factor.	Biomass burning is one of the main global causes. Passive smoking increases the risk.	Allergens (mites, moulds, animals), second-hand smoke, smoke from burning wood/charcoal for cooking or heating. Volatile organic compounds (VOCs).
Occupational exposures	Cause of occupational asthma (sensitizing or irritative), the most common occupational respiratory disease.	About 15–20% of cases are attributable to work. Cause of chronic inflammation and lung damage.	Asthma: flours, isocyanates, latex, wood dust. COPD: mineral dusts (coal, silica), organic dusts (cotton, cereals), chemical fumes.

Relevant Italian data on the effects of outdoor pollution

General population

By the 1990s, it became clear that living in cities was associated with more respiratory symptoms and diseases than living in rural areas [37–39], but also that exposure to air pollution was associated with an increase in mortality and hospitalizations for respiratory causes [40, 41].

Mortality and hospitalizations for natural and respiratory causes

A large Italian multicenter study, "Air pollution and health: epidemiological surveillance and prevention interventions" (EpiAir2), used routine statistics to assess the effects of air pollution in 25 Italian cities in the period 2006–2010. An immediate effect of PM_{10} on natural mortality was found. More relevant and prolonged effects [lag (delay) 0–5 days] were found for $PM_{2.5}$ and NO_2. Exposure to NO_2 and PM_{10} played an important role in respiratory mortality [40]. In addition, the study analyzed more than two million urgent hospital admissions for non-accidental diseases, estimating a relationship with a 10 μg/m^3 increase in air pollutants. Increased hospital admissions for respiratory diseases have been associated with PM_{10} and NO_2 [41].

Thanks to the use of Big Data (links to large amounts of geographical, environmental and health data), new important results have recently been obtained on the Italian territory in the context of two studies funded by the INAIL, the BEEP study "Big Data in environmental and occupational epidemiology" and the BIGEPI study "Use of Big Data for the evaluation of acute and chronic health effects of air pollution in the Italian population". Big Data have made it possible to improve the estimation of NO_2, O_3, $PM_{2.5}$ and PM_{10} concentrations on the national territory, using chemical transport models, machine learning, and population exposure assessment [42]. The results showed daily increases in respiratory mortality nationwide due to increases in PM_{10}, $PM_{2.5}$, and NO_2 in the period 2013–2015, with higher values in urban and suburban areas [43]. In the period 2006–2015, more than 4 million hospitalizations for respiratory diseases were recorded, of which 29% were for lower respiratory tract infections, 12% for COPD, 6% for upper respiratory tract infections, and 3% for asthma. An increased risk of daily hospitalizations for respiratory diseases, higher for asthma and COPD, was associated with a 10 μg/m^3 increase in PM_{10}. The highest effects emerged in the elderly and in less urbanized areas. In addition, it was shown that compliance with a theoretical daily PM_{10} standard of 25 μg/m^3, a value suggested by the 2005 WHO guidelines, would have avoided about 4,900 hospitalizations for respiratory problems. Similarly, a total of

8,917 hospitalizations were attributed to exposure to daily $PM_{2.5}$ concentrations above 10 μg/m^3 in the period 2013–2015 [44].

COPD and airway obstruction

The BEEP and BIGEPI studies have made it possible to analyze the association between long-term exposure to air pollution and morbidity also in analytical epidemiological studies. The analysis carried out in 6 Italian cities showed that COPD is associated with exposure to PM_{10}, $PM_{2.5}$ and NO_2 [45, 46].

Three cross-sectional surveys conducted in the urban and suburban area of Pisa from 1985 to 2011 showed an increase in the prevalence of respiratory symptoms and diseases. In these surveys, it was shown that living in urban areas was associated with an increased likelihood of having cough (+ 14%), phlegm (+ 30%), and COPD (+ 54%), compared to living in suburban areas [47]. In the same investigations, a spatial analysis was also conducted, which showed that residents closer to busy roads had a higher probability of having COPD and airway obstruction, measured by the ratio of forced expiratory volume in the 1st second/forced vital capacity (FEV_1/FVC) [48].

In Pisa, those who lived in busy traffic areas had an increased risk of cumulative incidence of COPD (+ 140%) over 18 years [49]. In addition, the increased incidence of chronic phlegm and COPD was associated with 1 μg/m^3 increase in $PM_{2.5}$ and PM_{10}, respectively [50].

Asthmatic/allergic symptoms and diseases

As part of the BIGEPI study, the analysis carried out in six Italian cities showed that rhinitis and asthma were associated with exposure to PM_{10}, $PM_{2.5}$ and NO_2, and asthma attacks with summer O_3 exposure [45, 51]. In a subsample of this population, it emerged that exposure to air pollution can increase oxidative stress in individuals with airway diseases (asthma, rhinitis and COPD) [52].

Regarding asthma and allergic rhinitis, it was shown that a 10% increase in residential exposure to grey space corresponding to urbanized areas (assessed using the ground cover classes of the Corine Land Cover) was significantly related to a higher likelihood of having allergic diseases or allergic sensitization [53]. In the three cross-sectional surveys conducted in the urban and suburban area of Pisa, it was shown that living in urban areas was also associated with an increase in the probability of having allergic rhinitis (+ 19%) [47].

In the population of Pisa, living in busy areas has been associated with an increased risk of cumulative incidence, over 18 years, of asthma attacks (+ 120%) and allergic rhinitis (+ 80%) [49]. In addition, a significant increase in the risk of rhinitis incidence due to the 1 μg/m^3 increase in $PM_{2.5}$ has been shown [50]. Another population study of individuals diagnosed with asthma showed that exposure to vehicular traffic near home increases the likelihood of having persistent or incident asthma symptoms [54].

Respiratory infections

A recent review showed that exposure to PM_{10}, $PM_{2.5}$ and NO_2 is associated with a higher likelihood of having upper and lower respiratory tract infections, particularly in boys [55].

Studies on respiratory infections in adults focus in particular on hospitalizations and mortality. A study conducted between 2001 and 2005 in six Italian cities (Bologna, Florence, Milan, Palermo, Rome, and Turin) showed that increases of 10 μg/m^3 of PM_{10} augmented the risk of hospitalization for respiratory infections of the lower respiratory tract in patients with COPD [56]. More recently, the BEEP study confirmed in adult subjects, in the period 2006–2015, an enhanced risk of daily hospitalizations for respiratory infections of the lower respiratory tract due to a 10 μg/m^3 increase in PM_{10} and $PM_{2.5}$ [44].

More recently, an association has been shown between chronic exposure to PM_{10}, $PM_{2.5}$, and NO_2 and increased incidence and mortality rates for SARS-CoV-2 [57, 58]. This relationship is still controversial today, but one of the most accredited hypotheses is that previous exposure to high concentrations of air pollutants makes the respiratory system more susceptible to infection and complications of the coronavirus disease. Air pollution could act as an amplifier (booster) of the contagion and the effects of the virus.

Paediatric population

Paediatric evidence from the Italian context confirms a relevant contribution of air pollution, urban green/grey exposures, aeroallergens and indoor pollutants (in particular, VOCs) in rhinitis symptoms and allergic respiratory conditions.

The cross-sectional study conducted by Cilluffo et al. [59] on children aged 8–10 years residing in Palermo showed a significant relationship between characteristics of the urban environment and the prevalence of nasal symptoms attributable to allergic rhinitis. The results showed that a low value of the normalized difference vegetation index (NDVI) (indicator of exposure to urban greenery) is associated with a significant increase (+ 47%) in the probability of reporting symptoms. Similarly, residence within 200 meters of busy traffic roads results in a comparable increase in the risk of rhinitis. The “greyness” indicator, which reflects the density of impermeable surfaces and anthropogenic infrastructures, is coherently associated with both nasal symptoms and other respiratory and ocular symptoms, suggesting the unfavorable effect of urbanized contexts characterized by low biodiversity and greater pollution [59]. The same authors studied the effect of NDVI on asthma control, finding that a reduction in urban greenness was associated with an increased likelihood of having uncontrolled asthma (+ 166%) [60]. Overall, the data support an interpretative model based on a dual pathophysiological mechanism: (1) the scarce presence of urban greenness reduces exposure to environmental microbes and natural components of biodiversity, believed to promote a correct immunological maturation of the respiratory mucosa; (2) proximity to vehicular traffic increases chronic exposure to irritating and oxidizing pollutants (fine PM, NOx, VOC), capable of inducing inflammation of the upper airways, increasing epithelial permeability and promoting allergic sensitization [61].

In a Turin study, a significant role of green availability in modulating paediatric respiratory health was confirmed [62]: children exposed to higher NDVI values were significantly less likely to have asthma (–87%), bronchitis (–86%) and current wheezing (–75%), compared to those exposed to lower levels of vegetation. In addition, the analysis of spirometry values showed a significant reduction in forced expiratory flow between 25 and 75% of forced vital capacity ($FEF_{25–75}$) in children residing in less green areas, indicative of possible small airway involvement. Although the study does not directly analyze “greyness”, the reported environmental data show average exposures to NO_2 of 55.6 μg/m^3 [62], a value higher than the WHO 2005 guidelines, suggesting an urban context in which scarce vegetation coexists with high levels of traffic pollutants, strengthening the hypothesis of an interaction between urbanization, air quality and respiratory health.

The study by Di Cicco et al. [63] provides particularly useful information on the role of outdoor aeroallergens in causing a worsening of children’s respiratory conditions, with effects that involve both the lower airways and the nasal district in an integrated way. The analysis conducted on children aged 0–17 years residing in Tuscany, hospitalized for asthma or asthmatic symptoms, showed that an increase of 10 granules/m^3 of total aeroallergens is associated with an increase (+ 2–4%) in the risk of hospitalization for asthma (OR ≈ 1.02–1.05), with more evident effects in the first 1–2 days after exposure [63]. Particularly relevant is the contribution of the fungal spore *Alternaria alternata*, known for its high allergenic potential and ability to induce acute inflammatory responses even at low concentration levels. In addition, the increase in aeroallergens produces more marked effects in sensitized children, boys and subjects over 10 years of age, emphasizing the interaction between individual immunological structure and environmental exposure. The temporal dynamics documented in the study (up to 48 hours) are compatible with the immunological processes that follow exposure to aeroallergens and that manifest clinically with symptoms involving both the upper and lower airways [63].

In the main Italian multicenter study dedicated to the evaluation of air quality in schools and its effects on children’s respiratory health, funded by the National Center for Disease Prevention and Control (CCM) of the Ministry of Health, it has been documented that residence near agricultural areas subjected to pesticide treatments is associated with a significant increase in allergic and irritative symptoms in children. In particular, children living near treated crops are more likely to have symptoms of the upper airways (+

125%), eye disorders (+ 281%) and skin manifestations (+ 160%), compared to their unexposed peers [64].

The “Viadana III” cohort represents one of the main Italian studies on the impact of industrial pollution on respiratory and allergy health in subjects aged 0–21 years, residing in the Viadana (MN) area. The study showed that chronic exposure to PM_{10}, $PM_{2.5}$ and NO_2 is associated with a significant increase in health outcomes attributable to paediatric allergy disease. In particular, there is an increase (+ 32%) in allergy visits for every unit increase in PM_{10} exposure [65].

A cross-border study examined the association between outdoor $PM_{2.5}$ concentration, elemental composition of PM (metals and other components) and the prevalence of respiratory diseases (asthma, rhinitis) in primary school children in Sicily and Malta. At higher $PM_{2.5}$ levels, a higher probability of asthma was observed (+ 5–6%). These risks were higher when considering individual heavy metals [66].

A recent study investigated the relationship between outdoor air pollution (PM_{10}, NO_2, SO_2) and structural and inflammatory changes of the airways in children aged 3–8 years, with bronchoscopy with broncholavage and bronchial biopsy performed. The study shows that air pollution, particularly PM_{10}, contributes to early structural changes of the airways in children. In particular, in children with wheezing, chronic exposure to PM_{10} promotes the appearance of bronchial remodelling phenomena and increases eosinophilic inflammation [67]. The same research group evaluated whether acute exposure to air pollutants (PM_{10}, NO_2, SO_2) can influence the antiviral response of the bronchial epithelium in preschool children, showing an association of PM_{10} and NO_2 levels with impaired epithelial antiviral response [68].

The results described above have been reported in detail in Table 5 and Table 6.

Table 5. Effects of outdoor air pollution on adult respiratory health.

Study	Population/Area	Exposure	Outcomes	Effect estimation (95% CI)
Mortality and hospitalizations for respiratory causes				
Alessandrini et al., 2013 [40]	25 Italian cities *n* = 31,008 deaths (7.3% of the total)	PM_{10} (10 μg/m^3 increase)	Mortality from respiratory causes	Increase 1.41% (–0.23–3.08) (Lag 2–5)
		NO_2 (10 μg/m^3 increase)		Increase 1.67% (0.23–3.13) (Lag 2–5)
Gariazzo et al., 2023 [43]	Italy *n* = 131,389 deaths (7.4% of the total)	PM_{10} (10 μg/m^3 increase)	Mortality from respiratory causes	Increase 3.54% (2.13–4.97) (Lag 0–5)
		$PM_{2.5}$ (10 μg/m^3 increase)		Increase 4.55% (1.78–7.40) (Lag 0–5)
		NO_2 (10 μg/m^3 increase)		Increase 6.68% (1.04–12.62) (Lag 0–5)
Scarinzi et al., 2013 [41]	25 Italian cities *n* = 331,289 hospitalizations (14.7% of the total)	PM_{10} (10 μg/m^3 increase)	Hospitalization for respiratory causes	Increase 0.75% (0.25–1.25) (Lag 0–5)
		$PM_{2.5}$ (10 μg/m^3 increase)		Increase 1.23% (0.58–1.88) (Lag 0–5)
		NO_2 (10 μg/m^3 increase)		Increase 1.29% (0.52–2.06) (Lag 0–5)
Renzi et al., 2022 [44]	Italy *n* = 4,154,887 hospitalizations (period 2006–2015)	PM_{10} (10 μg/m^3 increase)	Hospitalization for respiratory causes	Increase 0.65% (0.38–0.92) (Lag 0–5)
		$PM_{2.5}$ (10 μg/m^3 increase)		Increase 1.22% (0.76–1.68) (Lag 0–5)

Table 5. Effects of outdoor air pollution on adult respiratory health. (*continued*)

Study	Population/Area	Exposure	Outcomes	Effect estimation (95% CI)
COPD and airway obstruction				
Marchetti et al., 2023 [45]	Pavia, Turin, Verona, Terni, Pisa, Ancona, Palermo, Sassari *n* = 4,111	NO_2 (10 μg/m^3 increase)	Chronic bronchitis/COPD	OR 1.23 (1.03–1.46)
Maio et al., 2025 [46]	Ancona, Pavia, Pisa, Sassari, Turin, Verona *n* = 14,420	PM_{10} (10 μg/m^3 increase)	COPD (diagnosis and symptoms)	OR 1.26 (1.03–1.54)
			Dyspnea	OR 1.21 (1.05–1.39)
		$PM_{2.5}$ (10 μg/m^3 increase)	COPD (diagnosis and symptoms)	OR 1.31 (1.03–1.65)
			Dyspnea	OR 1.24 (1.05–1.47)
		NO_2 (10 μg/m^3 increase)	COPD (diagnosis and symptoms)	OR 1.07 (1.00–1.15)
			Dyspnea	OR 1.06 (1.01–1.11)
Nuvolone et al., 2011 [48]	Pisa/Cascina *n* = 2,062	Distance from main roads: < 100 m (a) 100–250 m (b)	COPD	(a) OR 1.80 (1.03–3.08) in males
			GOLD Airway Obstruction	(a) OR 2.07 (1.11–3.87) in males (b) OR 2.53 (1.42–4.53) in males
Maio et al., 2016 [47]	Pisa/Cascina *n* = 4,848	Exposure to traffic	COPD	OR 1.54 (1.25–1.90)
Maio et al., 2019 [49]	Pisa/Cascina *n* = 970	Exposure to traffic	Incidence of COPD	OR 2.40 (1.10–5.20)
Fasola et al., 2020 [50]	Pisa *n* = 305	PM_{10} (1 μg/m^3 increase)	Incidence of COPD	OR 2.96 (1.50–7.15)
Asthmatic/Allergic symptoms and diseases				
Maio et al., 2023 [51]	Ancona, Pavia, Pisa, Sassari, Turin, Verona *n* = 14,420	PM_{10} (10 μg/m^3 increase)	Allergic rhinitis (diagnosis or symptoms or medications)	OR 1.16 (1.06–1.26)
			Asthma (diagnosis or symptoms or medications)	OR 1.23 (1.08–1.40)
			Nocturnal awakenings due to difficulty breathing	OR 1.30 (1.16–1.46)
		$PM_{2.5}$ (10 μg/m^3 increase)	Allergic rhinitis (diagnosis or symptoms or medications)	OR 1.17 (1.06–1.30)
			Asthma (diagnosis or symptoms or medications)	OR 1.26 (1.08–1.47)
			Nocturnal awakenings due to difficulty breathing	OR 1.33 (1.16–1.52)
		NO_2 (10 μg/m^3 increase)	Allergic rhinitis (diagnosis or symptoms or medications)	OR 1.07 (1.04–1.10)
			Asthma (diagnosis or symptoms or medications)	OR 1.07 (1.03–1.12)
			Nocturnal awakenings due to difficulty breathing	OR 1.12 (1.08–1.17)
Marchetti et al., 2023 [45]	Pavia, Turin, Verona, Terni, Pisa, Ancona, Palermo, Sassari *n* = 4,111	PM_{10} (10 μg/m^3 increase)	Rhinitis	OR 1.62 (1.19–2.20)
		$PM_{2.5}$ (10 μg/m^3 increase)		OR 1.80 (1.16–2.81)

Table 5. Effects of outdoor air pollution on adult respiratory health. (*continued*)

Study	Population/Area	Exposure	Outcomes	Effect estimation (95% CI)
		NO_2 (10 μg/m^3 increase)		OR 1.22 (1.07–1.38)
Nuvolone et al., 2011 [48]	Pisa/Cascina *n* = 2,062	Distance from main roads: < 100 m (a)	Persistent wheezing	(a) OR 1.76 (1.08–2.87) in males
			Dyspnea	(a) OR 1.61 (1.13–2.27) in females
			Skin prick tests positive	(a) OR 1.83 (1.11–3.00) in females
Maio et al., 2016 [47]	Pisa/Cascina *n* = 4,848	Exposure to traffic	Allergic rhinitis	OR 1.19 (1.05–1.35)
Maio et al., 2019 [49]	Pisa/Cascina *n* = 970	Exposure to traffic	Incidence of asthma attacks	OR 2.20 (1.00–4.50)
			Incidence of allergic rhinitis	OR 1.80 (1.20–2.80)
Fasola et al., 2020 [50]	Pisa *n* = 305	$PM_{2.5}$ (1 μg/m^3 increase)	Incidence of allergic rhinitis	OR 2.25 (1.07–4.98)
Maio et al., 2020 [54]	Pisa/Po Delta *n* = 452	Exposure to traffic	Asthma with persistent/incident symptoms	OR 1.86 (1.02–3.38)
Maio et al., 2022 [53]	Pisa/Cascina *n* = 2,070	10% increase in grey spaces around the residential address	Skin prick test positivity	OR 1.07 (1.02–1.13)
			Polysensitization	OR 1.11 (1.04–1.19)
			Allergic rhinitis	OR 1.10 (1.04–1.17)
			Asthma/allergic rhinitis	OR 1.06 (1.00–1.12)
Respiratory infections				
Faustini et al., 2013 [56]	Bologna, Florence, Milan, Palermo, Rome and Turin *n* = 9,886	PM_{10} (10 μg/m^3 increase)	Hospitalization for Lower Respiratory Tract Infections in Patients With COPD	Increase 1.91% (0.06–3.79) (Lag 0–3)
Renzi et al., 2022 [44]	Italy *n* = 1,204,917 hospitalizations (period 2006–2015)	PM_{10} (10 μg/m^3 increase)	Hospitalization for lower respiratory tract infections	Increase 0.84% (0.40–1.28) (Lag 0–5)
		$PM_{2.5}$ (10 μg/m^3 increase)		Increase 1.34% (0.72–1.95) (Lag 0–5)
Ranzi et al., 2023 [57]	Italy *n* = 3,995,202 cases	PM_{10} (1 μg/m^3 increase)	Diagnosis of SARS-CoV-2	Increase 0.30% (0.20–0.40)
		$PM_{2.5}$ (1 μg/m^3 increase)		Increase 0.30% (0.10–0.40)
		NO_2 (1 μg/m^3 increase)		Increase 0.90% (0.80–1.00)
Stafoggia et al., 2023 [58]	Italy *n* = 124,346 deaths	PM_{10} (1 μg/m^3 increase)	Mortality from SARS-CoV-2	Increase 0.30% (0.20–0.50)
		$PM_{2.5}$ (1 μg/m^3 increase)		Increase 0.70% (0.50–0.90)
		NO_2 (1 μg/m^3 increase)		Increase 0.60% (0.50–0.80)

Lag: time interval in days between peak exposure to pollutant and health event. CI: confidence interval; COPD: chronic obstructive pulmonary disease; NO_2: nitrogen dioxide; OR: odds ratio; $PM_{2.5}$: atmospheric particulate matter with a diameter ≤ 2.5 μm; PM_{10}: atmospheric particulate matter with a diameter ≤ 10 μm.

Table 6. Effects of outdoor air pollution on the respiratory health of children and adolescents.

Study	Population/Area	Outdoor exposure	Outcomes	Effect estimation
Squillacioti et al., 2019 [62]	187 children (7–11 years)	NDVI; urban exposure to NO_2 (average 55.6 μg/m^3)	Asthma, bronchitis, wheezing; respiratory function	Higher NDVI associated with lower risk of asthma (OR 0.13), bronchitis (OR 0.14) and wheezing (OR 0.25). Reduction of forced expiratory flow between 25 and 75% of forced vital capacity ($FEF_{25–75}$) in children less exposed to greenness
Zammit et al., 2020 [66]	Primary school children, Sicily (*n* = 1,190) and Malta (*n* = 1,210)	$PM_{2.5}$ and elemental composition (V, Pb, Ni, Zn)	Asthma, rhinitis, medication use	↑ $PM_{2.5}$ associated with ↑ risk of asthma (OR ≈ 1.04); V and Pb more associated with respiratory outcomes
Bonato et al., 2021 [67]	98 children (5.3 ± 2.9 years) with and without wheezing	PM_{10}, NO_2, SO_2 (preceding 90 days)	Bronchial remodeling, inflammation	PM_{10} associated with basal membrane thickening and ↑ eosinophils; greater effect in children with wheezing
Bonato et al., 2021 [68]	34 preschool children	PM_{10}, NO_2, SO_2 (acute exposure)	Epithelial antiviral response	NO_2 associated with ↓ IFN-β and ↑ Rhinovirus replication
Di Cicco et al., 2022 [63]	85 children (0–17 years) hospitalized	Total pollens; spores of *Alternaria alternata*	Asthma/asthma-like hospitalizations (indicators of respiratory exacerbation)	Increments of 10 granules/m^3 associated with ↑ risk of hospitalization: Lag 0 OR 1.054; Lag 1 OR 1.037; Lag 2 OR 1.021. More marked effects in sensitized, males, and > 10 years
Cilluffo et al., 2022 [60]	179 asthmatic children	Urban greenness (NDVI), traffic, NO_2	Asthma control	↓ Urban green areas associated with uncontrolled asthma (OR ≈ 2.66); no association with NO_2 or traffic
Panunzi et al., 2023 [65]	7,525 subjects (0–21 years; ~6,800 < 18 years)	PM_{10}, $PM_{2.5}$, NO_2 (ELAPSE/EPISAT models), distance from plants	Allergological, ENT, pneumological visits; hospitalizations and respiratory ED accesses	PM_{10} associated with ↑ allergy visits (RR 1.32; 95% CI 1.14–1.52). J-curve with higher rates < 2 km and > 20 km from the industrial plants. NO_2 not significant
Sarno et al., 2024 [64]	2,367 children (6–14 years)	Residence near crops treated with pesticides	Upper airway, ocular, skin, systemic symptoms	Upper airway (rhinitis/nasal symptoms): OR 2.25. Ocular symptoms: OR 3.81. Skin: OR 2.60
Cilluffo et al., 2018 [59]	219 children (8–10 years)	NDVI, "greyness", distance from traffic (≤ 200 m), NO_2	Nasal, ocular, respiratory symptoms	Low NDVI associated with ↑ rhinitis (OR 1.47, 95% CI 1.07–2.03). Residence ≤ 200 m from traffic associated with ↑ rhinitis (OR 1.49, 95% CI 1.12–1.98). NO_2 not significant

Lag: time interval in days between peak exposure to pollutant and health event. CI: confidence interval; ED: emergency department; ENT: ear, nose and throat; NDVI: normalized difference vegetation index; NO_2: nitrogen dioxide; OR: odds ratio; $PM_{2.5}$: atmospheric particulate matter with a diameter ≤ 2.5 μm; PM_{10}: atmospheric particulate matter with a diameter ≤ 10 μm; RR: relative risk; SO_2: sulphur dioxide.

Relevant Italian data on the effects of climate change

Respiratory mortality and morbidity

The rapidity of climate change is causing a rapid increase in the burden of disease associated with extreme heat and heat waves; the occurrence of these events in some areas of southern and central Europe has doubled in the last twenty years [14].

At the international level, multicenter studies that also included Italian cities (EuroHEAT, PHEWE, EXHAUSTION) and systematic reviews have documented in the last 20 years a consistent effect of heat and heat waves on mortality from respiratory causes, especially in the population aged 75+ years [69, 70]. On heat wave days compared to non-wave days, there are percentage increases of even more than 90% in respiratory mortality in the population aged 65+ years in some Italian cities [69]. The greater vulnerability to heat due to respiratory causes emerges particularly clearly in hospital admissions, which show significant increases only for these diseases, while no increases are observed in hospitalizations for cardiovascular causes [71], probably because these events have a more frequent fatal outcome and therefore manifest themselves as an increase in heat-associated mortality. The recent EXHAUSTION study, thanks to the use of data with high spatial resolution, confirmed significant impacts on respiratory causes, with an increase (+ 27%) in respiratory mortality for temperatures between the 75th and 99th percentile of the area-specific distribution in three European countries [72].

The MultiCityMultiCountry study provided estimates of the impacts of heat on a global scale for the first time, including 532 locations in 33 countries, among which low-income countries and 16 Italian cities. A significant risk of respiratory mortality associated with exposure to extreme temperatures is confirmed in the 40+ age group, increasing with age from 1.14 at 40 years up to 1.25 at 85 years [73].

Systematic reviews of the evidence confirm consistent effects of heat and heat waves on mortality [74–79]. A meta-analysis of 54 articles from 20 countries, including Italy [78], found a strong association between heatwaves and respiratory mortality, with an overall mortality risk of 1.18 [95% confidence interval (CI): 1.09–1.28], although with high heterogeneity between studies, and a stronger association in some countries (e.g., Brazil, China, France, Germany, the Netherlands, Russia and Thailand). In subgroup analyses, the elderly population showed the greatest risks of heat-related mortality, especially during exceptional heat waves, such as the one in summer 2003 [78].

As far as non-fatal outcomes are concerned, effects of heat have been highlighted, in a less consistent way, not only in terms of increased hospital admissions, but also in terms of access to emergency and urgent services and outpatient visits [74–79]. An association between extreme heat or heat waves and respiratory morbidity (RR 1.043; 95% CI 0.995–1.093) was observed, with high heterogeneity between studies, more marked in the elderly and in specific areas [78]. In addition, heat and heat waves are associated with a high risk of asthmatic crises consistently across all age groups (children, adults, elderly) [77].

In the Italian context, thanks to the availability of daily temperature data with high spatial resolution, estimates of the effects of extreme temperatures on cause-specific mortality for the whole national territory are available from the BIGEPI study [80, 81]. The study reported an increased risk of mortality from respiratory diseases (+ 37%) for average temperature increases between the 75th and 99th percentiles of the summer temperature distribution in the years 2006–2015. In terms of attributable cases (%) of the total summer mortality from respiratory causes, about 2% of deaths from these causes are attributable to heat. Thanks to the availability of data with high spatial resolution (1 km × 1 km), the study documents for the first time an impact of heat and cold not only in Italian urban areas, but also in rural areas where there seems to be a high vulnerability.

There is increasing evidence of a possible synergistic effect of heat and some pollutants such as O_3 and fine PM on respiratory mortality [82, 83], in both the national [84] and international context [85–87], but the results vary according to the pollutant and the geographical area under study as they are possibly influenced by local weather and air quality conditions.

Desert dust transport

A systematic review investigated the effects of desert dust transport events on health by considering internationally conducted studies [88]. In general, respiratory health outcomes, mainly mortality and hospitalizations, were the most studied; although the evidence is not always consistent, most studies have shown an adverse effect of sandstorms on respiratory health. The impact of desert dust on mortality and morbidity due to respiratory causes has recently been studied in a meta-analysis [89]. The analysis considered 71 studies, including some Italian studies: although it did not find an increase in respiratory mortality, with an RR of 1.0001 (95% CI 0.9773–1.0277), it found an increase in respiratory morbidity, with an increased risk of 6.9% (95% CI 1.9–12.2) on days with high concentrations of PM of desert origin compared to days without desert dust.

In Italy, evidence indicates that desert dust transport is associated with increases in mortality and hospitalizations, particularly for respiratory causes, especially in the elderly. The multicenter Med-Particles study that included 8 Italian cities [90] distinguished the desert components of PM_{10} from those of other sources, showing an increase in natural and respiratory mortality, with risk increases in the order of 0.5–1% for increases of 10 $\mu g/m^3$ in PM_{10} from desert dust.

Even studies conducted on a local scale, such as the one carried out in Emilia-Romagna [91], have observed an increase in respiratory mortality, especially in the elderly, on days with Saharan dust transport, with more marked effects in the hot season.

In Rome, a time-series analysis [92] showed that the days affected by the transport of Saharan dust amplify the effects of atmospheric PM on respiratory mortality, suggesting a possible role of toxicological enhancement of mineral particles of desert origin. Overall, Italian evidence indicates that Saharan dust represents a significant environmental modifier, capable of worsening air quality and increasing acute risks for respiratory health, particularly in vulnerable individuals.

Drought

During periods of drought, air quality can deteriorate, increasing concentrations of fine PM and other suspended dust [93], causing exacerbations of chronic respiratory diseases such as COPD and asthma, and increasing the risk of respiratory mortality, particularly in conjunction with other extreme events such as heat waves [94]. No Italian studies on this exposure are available to date.

The effects of climate change on respiratory health are shown in Table 7.

Table 7. Effects of climate change on respiratory health.

Study	Population/Area	Exposure	Outcomes	Effect estimation
EXHAUSTION Zafeiratou et al., 2023 [72]	Norway, Germany, England and Wales, all ages	Warm: average temperature increases between the 75th and 99th percentiles of the summer temperature distribution	Respiratory mortality (total)	RR 1.27 (95% CI 1.19–1.34). Greater risk for the elderly and women
MultiCityMultiCountry Scovronick et al., 2024 [73]	532 cities in 33 countries (Americas, Europe, Asia, Africa) (including 16 Italian cities)	Extreme heat (99th percentile temperature vs. minimum mortality temperature)	Respiratory mortality (total)	Greater effect in the elderly
BIGEPI (Stafoggia et al., 2023; Di Blasi et al., 2023) [80, 81]	Italy (national)	Warm—average temperature increments between the 75th and 99th percentiles of the summer temperature distribution	Respiratory mortality (total)	+ 37% (95% CI 33–42) on hot days compared to milder summer days
Med-Particles (Stafoggia et al., 2016) [90]	13 cities in the Mediterranean basin (includes 8 Italian cities)	Desert dust (10 μg/m^3 increase in PM_{10}-desert component)	Respiratory mortality	Increase of 0.55% (95% CI 0.24–0.87)
Zauli Sajani et al., 2011 [91]	6 cities in Emilia Romagna	Desert dust (10 μg/m^3 increase in PM_{10}-desert component)	Respiratory mortality	Increase of 22.0% (95% CI 4.0–43.1)
Systematic reviews				
Cheng et al., 2019 [78]	27 studies on adults from 20 countries (Australia, America, Europe, Asia)	Heat waves (different definitions incl. extreme temperatures)	Respiratory mortality (total and COPD)	RR 1.18 (95% CI 1.09–1.28) on wave days compared to non-wave days. Greater effect on mortality from COPD and in the elderly
Cheng et al., 2019 [78]	20 studies on adults from 20 countries (Australia, America, Europe, Asia)	Heat waves (different definitions incl. extreme temperatures)	Respiratory morbidity (hospital admissions, ED visits, ambulance calls)	RR 1.043 (95% CI 0.995–1.093) on wave days compared to non-wave days. Significant effects only on admissions and admissions to the ED
Tobías et al., 2025 [89]	71 studies on all continents	Desert dust transport (days with desert dust advections vs. days without)	Respiratory mortality	RR 1.0001 (95% CI 0.9773–1.0277)
Tobías et al., 2025 [89]	71 studies on all continents	Desert dust transport (days with desert dust	Respiratory morbidity	RR 1.0693 (95% CI 1.0188–1.1224)

Table 7. Effects of climate change on respiratory health. (*continued*)

Study	Population/Area	Exposure	Outcomes	Effect estimation
		advections vs. days without)		

CI: confidence interval; COPD: chronic obstructive pulmonary disease; ED: emergency department; PM_{10}: atmospheric particulate matter with a diameter ≤ 10 μm; RR: relative risk.

Asthma

Extreme temperatures

Heat and heat waves are associated with a high risk of asthmatic crises consistently across all age groups (children, adults, elderly) [77].

It is important to note that in patients with asthma, a concomitant risk derives from the possible interaction between temperatures and O_3, a potent respiratory irritant [87].

Heat can induce bronchoconstriction and increase airway resistance through a mechanism mediated by a cholinergic reflex [95, 96] or through the activation of transient receptor potential vanilloid (TRPV) channels [97]. TRPVs are temperature-sensitive transmembrane ion channels, expressed in respiratory tract cells, that may be involved in temperature-related airway hyperresponsiveness, especially in the presence of specific genetic polymorphisms [97, 98].

Asthma symptoms may also be favored by the heat-induced increase in blood levels of heat shock proteins (HSPs) [99].

Respiratory heat and water loss have been hypothesized as a trigger for exercise-induced asthma, with bronchoconstriction severity increasing in relation to the water content of the inspired air and the level of ventilation achieved and maintained [96].

A different mechanism concerns the use of anticholinergic drugs used as bronchodilators in patients with asthma or COPD, which can increase the heat stress of the body and the risk of heat-related diseases, for example through sweat suppression [100].

Drought

An Italian study has shown a correlation between local climatic conditions and the prevalence of asthma and respiratory diseases; a higher prevalence of asthma was found in areas with hot and dry climates, while lower in rainy and cold climates [101].

The GEIRD (gene environment interactions in respiratory disease) study has shown that, in Italy, both the incidence of asthma and the climatic indices follow the same average periodicity of about 6 years and that there is a strong correlation between the phases of greatest drought and/or oscillations of the Summer North Atlantic Oscillation (S-NAO) and peaks of asthma [102].

It therefore seems that regional climate variability is a relevant factor in predicting long-term fluctuations in asthma in Italy. Similarly, another Italian study showed a relationship between climatic conditions and the prevalence of asthma, which was higher in areas with hot and dry climates, while it was lower in rainy and cold climates [101].

Another study suggests that in the first months of life, exposure to periods of intense drought is associated with an increased risk of wheezing, a possible early sign of respiratory disease [103].

Fires

The systematic review by Reid et al. [104], which examined the relationship between fires and health, found a consistent effect of fires on respiratory health, with increased medication usage, doctor visits, hospitalizations, and asthma emergency room visits. The results were confirmed by another systematic review and meta-analysis that revealed an increased risk of hospitalization (RR: 1.054, 95% CI:

1.026–1.082) and emergency department visits (RR: 1.117, 95% CI: 1.035–1.204) for asthma in the general population [105].

Desert dust transport

Desert dust clouds can also carry microorganisms such as bacteria and viruses, but also fungal spores and pollen, with a consequent increased risk of exacerbations of asthmatic disease in susceptible individuals such as children [106]. In Italy, these episodes are as frequent as in other Mediterranean countries, but to date there are no Italian studies on desert dust and asthmatic pathology in the country.

Allergic rhinitis

Temperatures

There is no evidence on the short-term effects of heat or heat waves on allergic rhinitis. Considering a possible long-term effect, a meta-analysis of 20 observational studies evaluated how global warming may affect the appearance or worsening of allergic rhinitis. The results show that every 1°C increase in average temperature is associated with an increased risk of symptoms or diagnosis of allergic rhinitis (+ 29%). The effect, however, varies according to the climate zone, suggesting that the local environmental context may affect sensitivity to heat and pollen [107].

Desert dust transport

Desert dust clouds can carry microorganisms such as bacteria and viruses, but also fungal spores and pollen, with a consequent greater risk of exacerbations of allergic diseases [108, 109]. In particular, via the dust cloud, pollen grains and fungal spores can be transported thousands of kilometers away, reaching potentially susceptible populations that had not previously been exposed to that type of allergen [110].

COPD

Temperatures

Heatwaves have consistent effects on COPD mortality, particularly in the elderly population [78]. Possible mechanisms include alterations in mucociliary clearance favored by heat-associated alterations in electrolyte balance and mechanisms of oxidative stress and inflammation that may promote dyspnea and exacerbations of the disease [111]. There is a lack of solid evidence regarding the possible chronic impact on the incidence and progression of diseases such as COPD and asthma, or on persistent alterations in lung function [112]. Some studies have hypothesized an association between repeated exposure to heat and worsening of respiratory capacity over time, especially in susceptible subgroups such as exposed workers, but the results are not consistent. In addition, it is complex to distinguish the direct effect of heat from that of concomitant environmental co-exposures, such as air pollution and forest fires, which can amplify its impact.

The temperature range (the difference between the annual maximum and minimum) was inversely associated with the incidence of chronic bronchitis [101].

Overall, the chronic effects of heat on the respiratory system remain poorly documented and represent an important research gap.

Drought

During periods of drought, air quality can deteriorate: concentrations of fine PM and other suspended dust increase [93], and worsening air quality can aggravate chronic respiratory diseases such as COPD, trigger exacerbations, promote respiratory infections, and may intensify allergic reactions such as rhinitis. International studies suggest that the concomitance of heat waves and droughts may worsen the health of patients with COPD by increasing the risk of heat-associated mortality [94]. In addition to the possible effect of air quality, the concomitance of high temperatures and drought could worsen chronic lung diseases through dehydration with increased blood viscosity, worsening of mucociliary clearance and possible increased susceptibility to infections and cardiopulmonary stress [113].

Fires

Systematic reviews that included mainly studies from the United States, Canada and Australia [104, 114] found a consistent effect on the increase in hospitalizations, emergency room visits, and medical visits for COPD following fire exposure, both in the general population and in specific age groups, particularly in the elderly ≥ 65 years of age. Some studies suggest that PM from fires may be more toxic due to its high content of polycyclic aromatic hydrocarbons (PAHs), VOCs that can stimulate oxidative stress and an inflammatory response resulting in worsening of lung disease [115].

Respiratory infections

Heat and heat waves

Evidence of a possible effect of heat and heat waves on respiratory infections is limited; individual international studies are available that, in particular, show associations in socio-economically deprived contexts and in low-middle income countries [116–118], e.g., for acute lower respiratory tract infections in children [119]. Some studies both internationally and in Italy suggest a possible interaction between heat and COVID-19 and mortality in the elderly population. In particular, the pandemic may have changed over time the group of most vulnerable individuals, characterized by certain susceptibility conditions (e.g., chronic diseases or socio-economic disadvantage), thus increasing their exposure to both the effects of heat and the more severe effects of SARS-CoV-2 infection [120].

Desert dust transport

In Italy, as in other Mediterranean countries, the long-distance transport of desert dust clouds is frequent [121], which can contain microorganisms and allergens with a consequent greater risk of respiratory infections [122].

A study carried out a metagenomic analysis of bacterial and fungal colonies transported with PM following the 2014 sandstorm, which were trapped in the snows of the Dolomites [123]. This analysis showed that such phenomena are capable of displacing large parts of entire microbial communities on a continental scale, including pathogens for the environment and important for humans. This is especially true if the sand is transported in winter and with snowfall, so that large quantities of microbes are released in high concentrations over a limited area during the melting of the snowpack. In addition, the abrasive action of mineral particles can damage the bronchial mucous membranes and the epithelial barrier, facilitating the adhesion and penetration of pathogens.

The systematic review by Tobías et al. [89] showed that, in environments with high desert dust, an increase in cases of pneumonia, rhinosinusitis and lower respiratory tract infections is observed, especially in the most vulnerable subjects. However, the evidence is still fragmentary and more accurate studies would be needed to clarify the role of desert dust as a trigger for respiratory infections, distinguishing the direct effect of dust from that of the microbiological component.

Fires

A recent systematic review that included studies predominantly from the United States, Australia, and Canada highlighted a possible increase in infections (especially respiratory) associated with short-term increases in air pollution from forest fires [124]. Specifically, a 10 μg/m^3 increase in $PM_{2.5}$ was associated with a 15% increase in COVID-19 infections and a 3% increase in general respiratory infections (including bronchitis and pneumonia). Although the evidence is limited, it is possible that $PM_{2.5}$ from fires can cause lung inflammation and oxidative stress, weakening the immune system and promoting infections, with a mechanism similar to that of PM from vehicular traffic. The review did not include Italian studies.

Drought

To date, there are no Italian studies. Studies conducted mainly in North America suggest that rainfall patterns and the duration of drought periods can modify the incidence of infectious respiratory diseases, for example from fungal spores such as coccidioidomycosis (Valley fever) [125].

Relevant Italian data on the effects of pollen and mould

Pollen monitoring, as a specification of aerobiological monitoring, was born as a protocol for measuring outdoor air quality with the aim of quantitatively assessing the presence and concentration of airborne pollen and providing useful information to both clinicians and patients. Knowing the seasonal trend of airborne allergenic pollen allows:

- Anticipate the start of therapy;
- Reduce exposure in critical periods;
- Correctly interpret the onset or exacerbation of symptoms.

Aerobiological monitoring is an investigation protocol extended to bioaerosols and analyzes the entire airborne biome. It can be conducted both indoors and outdoors to search for fungal spores, microalgae, viruses, and bacteria [126–128].

More methodological details on aerobiological monitoring are given in Supplementary material 2.

In recent decades, climate change, urbanization, the spread of invasive species and extreme weather phenomena have increased the incidence of respiratory diseases related to the exposome (the set of environmental exposures of an individual). In this scenario, air quality monitoring—in both its biological and chemical-physical components—has become an essential diagnostic and predictive tool. Aerobiological monitoring is therefore an indispensable element for the assessment of quality of life, making it a priority that the data produced are reliable, timely, and usable even by a non-specialist public.

Specifically, pollen-induced respiratory allergies—commonly known as pollinosis—represent one of the most common allergic conditions in the Italian population, with a significant impact on quality of life and social and health costs. In addition to individual predisposition, there are environmental factors of great importance that determine the increase in the frequency and severity of these conditions [129].

Higher temperatures and higher CO_2 concentrations generally contribute to the modification of pollen seasons also by prolonging them and/or increasing pollen production. Therefore, inducing a substantial increase in the degree of allergenicity of plant species [130]. In addition, the expansion of the range of some species northwards results in the exposure to pollen of populations that are not yet sensitized and therefore more vulnerable [13].

It should be noted that the climate change we are witnessing is manifesting itself in a worrying way as an increase in the frequency of extreme weather events; cyclones, lightning storms, floods, heat waves and prolonged droughts have a One Health impact. Respiratory health is undoubtedly compromised, even more so in sensitive subjects. Extreme events have an important influence on air quality and plant biodiversity, increasing exposure to allergens deriving from pollen and mold. High temperatures and humidity promote the growth of weeds and the proliferation of microfungi, intensifying respiratory symptoms both outdoors and indoors. In addition, extreme weather conditions and high atmospheric energy favor the frequency of high- or very high-speed currents that contribute to the long-distance transport of airborne allergens, which reach new areas and intercept new potentially sensitive subjects [131–133].

General effects of climate change on pollen and mould

Climate change and environmental and occupational exposures are significantly modifying the epidemiology, seasonality and severity of respiratory allergic diseases [129, 134–137]. Rising temperatures, changes in rainfall regimes and increasing air pollutants influence the production, dispersal and allergenicity of pollen and fungal spores, favoring the emergence of new clinically relevant allergens [138]. Among these, *Alternaria alternata* represents a paradigmatic model of an emerging allergen, associated with even severe forms of asthma [139, 140]. In addition, extreme weather events, such as thunderstorms, are increasingly related to outbreaks of acute asthma "thunderstorm asthma" [141–143].

In particular, global warming and rising CO_2 concentrations affect:

- Duration and intensity of the pollen season, anticipating its beginning and prolonging its end;
- Amount of pollen produced, growing for many allergenic species;
- Geographical distribution of allergenic plant species (migration northwards or to higher altitudes);
- Increase in fungal spores and molds (*Alternaria*, *Cladosporium*), especially in warmer and more humid urban and agricultural contexts.

The effects observed on the Italian territory are different between the Alpine and Mediterranean areas.

In alpine and subalpine environments, not only pollen, but also fungal spores remain more prolific [144, 145]. Variable weather conditions create an environment conducive to the production of allergenic spores of *Alternaria*, *Cladosporium*, and other genera, aggravating exposure to aeroallergens during allergy season. In addition, allergenic species typical of lowland areas are spreading to higher altitudes, where historically local production was low, as pollen exposure to non-native species (e.g., *Ambrosia*) is increasing [146].

In Mediterranean areas, an increase in the annual pollen concentration of some species has been found, accentuated by droughts and milder winters [147]. Earlier blooms and longer allergic seasons have been found, particularly for spring-flowering species (e.g., *Quercus*, *Olea*) [148] and an increase in atmospheric mold following episodes of heavy rain and flooding [139].

In recent years, several studies and reports have been published that specifically analyze the effects of climate change on pollen, mold and atmospheric allergens in Italy, with significant differences between Alpine and Mediterranean areas [134, 142, 147–150].

Health effects of pollen

The lengthening of pollen seasons and periods of spore presence favors greater allergenic exposure: more exposure time means more likelihood of allergic sensitization even to new allergens or migratory species (e.g., *Ambrosia* in new areas). Subjects who are already sensitized show more lasting and intense symptoms, with worsening of the quality of life. The consequences of these phenomena are reflected in the increase in allergic rhinoconjunctivitis and allergic asthma in Europe and worldwide. The WHO has estimated that respiratory disorders related to pollen and mold have increased by about 30% in the last two decades, with projections growing towards 2050 [135]. In Italy, a growth in cases of rhinitis and allergic asthma related to pollen and molds has been observed (+ 20–30% in the last 20 years in some regions) [151].

Epidemiological studies consistently report short-term effects of pollen (within 3 days of exposure) on asthma and allergy symptoms, in terms of increases in emergency department admissions, hospital admissions, or patient-reported symptoms (Table 8). Italian studies [63, 152] (Table 9) suggest a significant effect of pollen exposure on the risk of aggravation of asthmatic disease in children.

Table 8. Effects of pollen on allergic and respiratory health from meta-analysis of systematic reviews.

Study	Population/Area	Exposure	Outcome	Study design included	Effect estimation	Change of effect (if available)
Erbas et al., 2018 [153]	Australia, Canada, USA, Spain, Israel (0–18 years). 14 studies (3 included in meta-analysis)	*Graminaceae*	Emergency room visits for asthma and wheezing	Time series, case-crossover, descriptive studies	+ 1.88% (95% CI 0.94–2.82) with a 3-day lag per 10 pollen grains per m^3	Major effects in the 5–17 age group
Annesi-Maesano et al., 2023 [154]	Predominantly high-income countries (all age groups). 73 studies (2–4 studies in meta-analysis)	*Graminaceae*	Severe asthma exacerbations	Time series, case-crossover, cohort, cross-sectional	+ 2%; (95% CI 1–3) in all ages for increment from 0 to 50 granules/m^3. Borderline effect in children	Greater effects in children, no effect in the elderly

Table 8. Effects of pollen on allergic and respiratory health from meta-analysis of systematic reviews. (*continued*)

Study	Population/Area	Exposure	Outcome	Study design included	Effect estimation	Change of effect (if available)
Shrestha et al., 2021 [155]	United Kingdom, Australia, USA, Canada, Mexico, Sweden, Belgium (0–18 years). 12 studies (2–3 in meta-analysis)	*Graminaceae*, *Betula*	Asthma hospitalizations	Time series, case-crossover, cohort	Change (%) = + 0.85% (CI −3.24; 4.95) per increment of 10 granules/m^3 of *Graminaceae*; Change (%) = + 0.85% (CI 0.40, 1.30) for *Betula*	-
Kitinoja et al., 2020 [156]	France, Switzerland, USA, Spain, Finland, Austria, Germany, Denmark, United Kingdom, Australia (all age groups). 26 studies (16 in meta-analysis)	Total and taxa-specific pollen	Self-reported symptoms of asthma and allergy and lung function	Panel studies	At least one symptom of asthma or allergy: + 2% (CI 1–3%); lower respiratory symptoms: + 0.8% (CI 0–1.5%); upper respiratory symptoms: + 6.6% (CI 4.4–8.7%); ocular symptoms: + 10.9% (CI 5–17.2%) for a total pollen increase of 10 granules/m^3. No significant effect on lung function	-

CI: confidence interval.

Table 9. Italian epidemiological studies on the effects of pollen on respiratory and allergic diseases.

Study	Population/Area	Exposure	Outcomes	Susceptibility factors	Effect estimation
Di Cicco et al., 2022 [63]	Pisa Area, Italy 0–17 years	Total pollen	Hospital admissions for asthma symptoms (codes 466.0, 493, 519.11 and 518.81)	Greater effect in children sensitized to one or more outdoor allergens, in boys and in the 5–17 age group	Change (%): 5.4% (95% CI 1.1–9.8%) (Lag 0) (delta=10 granules/m^3)
Damialis et al., 2021 [157]	31 countries (including Italy) Population of all ages	Total pollen	SARS-CoV-2 infection	Behavioral/social (lockdown)	Effect of pollen on infection risk halved during lockdown
Bono et al., 2016 [152]	Turin, Italy 0–18 years	Total pollen	Emergency room admissions for respiratory problems (codes ICD9 460–466, 487, 490–493)	-	Change (%): 0.7% (95% CI 0.1–1.2%) (Lag 1) (delta=10 granules/m^3)

Lag: time interval in days between peak exposure to pollutant and health event. CI: Confidence interval.

Allergic asthma

Asthma is often caused or exacerbated by pollen and spores:

- Longer seasons with higher allergen peaks increase asthma exacerbations, especially during periods of peak concentration.
- Extreme weather events such as pollen thunderstorms and heat waves can trigger potentially severe acute asthma attacks.
- Humidity and sudden rainfall in Mediterranean regions can promote the proliferation of molds such as *Alternaria*, further shifting the allergenic load towards fungal spores, especially in autumn.

The available meta-analyses (Table 8) mainly indicate pollen effects of major grasses in children and the adult population, although individual studies report a risk of exacerbation of asthma and rhinitis also for other taxa, specific to the study areas (e.g., Oleaceae, *Ambrosia*, Cupressaceae) [154, 155]. Health effects are usually immediate (0–3 days), but may persist for several days up to 7–8 days after exposure. The onset of acute respiratory diseases following violent thunderstorms, such as thunderstorm asthma, has also been known for some time [142, 150]. That is, episodes of severe asthma, even fatal, in which a combination of particularly violent meteorological factors (lightning, wind, rain) and environmental factors (presence of airborne allergenic pollen) causes an increase in respiratory symptoms in sensitive people. The complex mechanism underlying these acute manifestations seems to be mainly determined by the breakdown of pollen grains [142, 150]. Lightning, strong gusts of wind, and rain can cause fractures in the pollen structure, with the consequent escape of microparticles, which, poured into aerosols, can be breathed in and easily penetrate the deep airways. As a result, individuals with asthma or allergies may experience a sudden intensification of symptoms, such as breathing difficulty, coughing, and chest tightness. These events can also lead to fatal episodes [134, 150].

Although this phenomenon has historically been associated with grass pollens, growing evidence suggests a possible role of fungal spores, in particular *Alternaria*, in contributing to the inhalable allergen load during thunderstorms.

Allergic rhinoconjunctivitis

The lengthening of pollen seasons and periods of spore presence favors greater allergenic exposure:

- More exposure time means more likelihood of allergic sensitization even to new allergens or migratory species (e.g., *Ambrosia* in new areas).
- Subjects who are already sensitized show more lasting and intense symptoms, with worsening of the quality of life.

General trends in the prevalence of allergic diseases

- The prevalence of allergic rhinoconjunctivitis and allergic asthma is increasing in Europe and worldwide, linked to increased exposure to pollen and aeroallergens, as well as interaction with air pollutants.
- The WHO has estimated that respiratory disorders related to pollen and mold have increased by about 30% in the last two decades, with projections growing towards 2050.

In the Mediterranean areas, there is an increase in cases of allergic rhinitis and allergic asthma linked to pollen and mold (+ 20–30% in the last 20 years in some regions). In specific Alpine contexts, epidemiological studies on Swiss paediatric cohorts indicate that, although traditionally considered “low allergic risk” areas due to the lower presence of allergens and pollutants, an increasing proportion of children show sensitisation to pollen and mould. This suggests that environmental and clinical factors interact complexly even in these mountain environments.

Air pollution

In parallel, air pollution, particularly in urban areas with high traffic density and industrialization, changes the composition of pollen and acts as a co-factor in exacerbating the allergic response. Pollutants such as NO_2, O_3 and PM can alter the surface of pollen grains, with chemical-physical changes that alter pollen functionality and allergen release [158]. Pollen is a class of airborne microbiota which, due to its size (average 30 μm) and structural morphology of the external wall (Hexin sculpturing), easily acts as a carrier for other airborne microparticulates, biotic and otherwise. In this way, the encounter with a pollen-carrier can facilitate inflammatory conditions in the mucous membranes of sensitive subjects, effectively amplifying the reactivity to pollen itself [159].

To confirm this, several epidemiological studies show that, although there are higher pollen concentrations in rural environments, pollinosis is found more frequently and severely in urban areas—a phenomenon attributable precisely to the synergistic effect between pollen and air pollutants, as well as to different exposures and environmental characteristics [131–133].

PM_{10}, $PM_{2.5}$ and O_3 play a causal role in facilitating the onset of respiratory symptoms:

- PM can act as a vector for allergens, increasing their penetration into the airways;
- O_3 induces oxidative stress, epithelial damage, and increased permeability of mucous membranes;
- Combined exposure to pollen and pollutants amplifies bronchial inflammation and hyperreactivity.

These synergistic effects can lower the clinical threshold of response to allergens, favoring asthma exacerbations even at moderate pollen concentrations.

In addition, lifestyle and chronic exposure to respiratory stress in urban environments may predispose more to sensitization and the onset of symptoms than those who live permanently in rural or semi-rural contexts, where air quality tends to be better as well as the set of environmental risk factors [158, 159], although epidemiological evidence of pollen-pollutant interaction is still limited [160].

Rhinitis

In patients with rhinitis, exposure to pollen can cause increased symptoms in the short term (nasal and eye symptoms, frequent cough, especially at night), especially in younger age groups and in relation to herbaceous pollens (*Graminaceae* and *Ambrosia*) [154, 161].

COPD and respiratory infections

Evidence on the possible effect of pollen on exacerbations of COPD or the risk of respiratory infections is still limited. A multicenter study that also includes Italy suggests a possible association between pollen exposure and risk of SARS-CoV-2 infection, and how this was significantly reduced during the lockdown period [157].

Land use: olive and hazelnut trees examples of intensive agriculture

Intensive agriculture, particularly for traditional crops in the Mediterranean area such as olive trees and, increasingly, hazelnuts, has a significant impact on biodiversity and respiratory health. The expansion of these intensive monocultures, often promoted by the interest of large investors, is leading to the replacement of less profitable traditional crops and even wooded or uncultivated areas, with a consequent alteration of the landscape and a potential loss of soil and aerosporological biodiversity.

Hazelnut and olive trees, characterized by anemophilous pollination, release large quantities of allergenic pollen. In addition, modern production plants, in order to maximize productivity, plan for the insertion in the orchard of a certain number of pollinating varieties, genetically selected to express almost exclusively the male character, in order to increase the extent and duration of the pollen cloud at the time of pollination.

The spread of intensive agriculture, which increases the density of these plants in specific areas, contributes to the significant increase in the concentration of their pollen in the air, aggravating the prevalence and severity of pollinosis in resident populations [162].

Emerging allergens in the course of climate change: the role of *Alternaria*.

- Effects of climate change on the spread of *Alternaria*: The increase in average temperatures and the greater frequency of hot and dry periods favor the growth and sporulation of *Alternaria*. Extreme weather events, such as prolonged droughts followed by heavy rainfall, can lead to peaks in the concentration of fungal spores in the air.
- Health effects: *Alternaria alternata* is a ubiquitous fungus, whose spores represent one of the most important outdoor fungal allergens. Sensitization to *Alternaria* is associated with allergic rhinitis, bronchial asthma and, in some cases, severe and potentially fatal asthmatic exacerbations, especially in children and young adults. The major allergen Alt a 1 is now considered a clinically significant exposure marker, with a central role in the IgE-mediated response and pathogenesis of fungal-related asthma.

Relevant Italian data on the effects of indoor pollution

General population

In the early 1990s, it became clear in Italy that fuel used for cooking or heating was associated with higher prevalence rates of respiratory symptoms or impaired lung function in both males and females, with greater likelihood of coughing, dyspnoea and wheezing if gas cylinders or cookers and stoves fuelled by other non-natural fuels were used [163, 164].

In the 2000s, interest and evidence on passive smoking increased: in over 2,000 non-smoking women, residing in Pisa, Po Delta, Rome and Viterbo, exposure to secondhand smoke by their husband/partner and at work was a risk factor for dyspnea, cough/phlegm, rhinoconjunctivitis, wheezing and attacks of shortness of breath with wheezing, diagnosis/symptoms of asthma, obstructive pulmonary disease (diagnosis of asthma/chronic bronchitis/emphysema) [165].

In the same years, environmental measurements were carried out in the homes of subjects residing in the Po Delta, showing that there were significantly higher indoor NO_2 levels in homes with gas heating and/or gas water heaters. $PM_{2.5}$ was significantly higher in smokers' homes and significantly correlated with the number of cigarettes smoked. In winter, significant associations emerged between bronchitis/asthmatic symptoms and exposure to above-average NO_2 and $PM_{2.5}$ values. In summer, this association emerged only for $PM_{2.5}$ in non-smokers [166, 167].

There are no recent Italian studies on the general population; most of the studies concerned the paediatric population.

Paediatric population

With regard to the paediatric age, the study by Cibella et al. [168] examined the association between exposure to NO_2 in indoor environments and respiratory symptoms and lung function in a population of adolescents (aged 10–17 years) residing in Palermo and undergoing allergic respiratory health assessment through questionnaires, spirometry and skin prick tests. Indoor NO_2 was significantly higher than outdoor NO_2 in both seasons ($p < 0.001$). Indoor levels were particularly high in the urban center and in condominium dwellings. Around 25% of adolescents were exposed to indoor NO_2 values above the limit set by the WHO in 2005 (threshold value used: 40 $\mu g/m^3$). Indoor NO_2 exposure was associated with an increased risk of current asthma. Indoor values > ~32 $\mu g/m^3$ (spring) and > ~41 $\mu g/m^3$ (winter) increased the likelihood of current asthma. Exposure to the highest levels of NO_2 was significantly associated with wheezing in the past 12 months, rhinoconjunctivitis, chronic cough, current asthma, and decreased respiratory function. The study also showed that the interaction between allergic sensitization and indoor NO_2 further increases the risk of asthma: among adolescents with allergy and high NO_2, the prevalence of asthma reached 22.4%, compared to 0% in non-allergic people exposed to lower levels [168].

A further study conducted in Palermo between 2015 and 2018 on asthmatic children aged 5 to 16 years longitudinally analyzed the relationship between asthma control and various environmental factors, outdoor (e.g., urban greenness, air pollution, traffic) and indoor (e.g., passive smoking, mold). The results indicate that living in areas with little greenness (NDVI ≤ 0.21) (+ 166%), being exposed to maternal smoke during pregnancy (+ 282%), and living in overcrowded housing conditions (+ 238%) are factors that increase the risk of uncontrolled asthma [60].

The HESE (Health Effects of School Environment) study, one of the main European multicentre projects (Italy, France, Denmark, Norway and Sweden) dedicated to the assessment of air quality in schools and its effects on children's respiratory health, consistently highlighted that poor classroom ventilation and the accumulation of indoor pollutants, in particular PM_{10} and CO_2, are associated with a higher prevalence of respiratory symptoms and an objectively measurable reduction in the patency of the upper airways of children, with a dose-response relationship directly involving the nasal district [169]. Within this general framework, the data from the Italian centers, Siena and Udine, take on particular relevance, as they show some of the most critical microenvironmental conditions of the entire European sample, with the highest pollutant values and poorest ventilation.

More recently, the multicenter study [Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE) database on chemical and biological pollutants] evaluated children between 6 and 14 years old residing in 23 European countries, including Italy, to define the prevalence of asthma, allergies and respiratory symptoms, considering the differences between different geographical areas. The most common conditions were: allergic rhinitis 17.8%, eczema 16.9%, pollen allergy 12.2%, asthma 7.7%. The most frequently reported symptoms in the last year were: sneezing/stuffy nose (20.8%) and dry cough at night (18.4%), particularly in Southern Europe. The study showed considerable geographical variability in the asthma and allergies of European children, influenced by environmental and socioeconomic factors such as climate, pollution levels, exposure to traffic, presence of mold [170].

In the SINPHONIE study, it was also shown that schoolchildren exposed to concentrations greater than or equal to the average of $PM_{2.5}$, benzene, limonene, O_3 and radon were significantly more likely to suffer from upper and lower respiratory disorders [171].

The assessment of endotoxin concentration in the classrooms showed levels that varied according to the geographical area, with the highest averages in Italy and the lowest in Finland. Elevated endotoxin levels were associated with higher odds of upper and lower respiratory symptoms (runny nose, nasal obstruction, cough, dry throat, breathing difficulty, and fever), as well as reduced lung function [172, 173].

The main effects of indoor air pollution on the respiratory health of children and adolescents are shown in Table 10.

Table 10. Effects of indoor air pollution on respiratory health of children and adolescents.

Study	Population/Area	Indoor exposure	Outcomes	Effect estimation
Simoni et al., 2010 [169]	Italy, France, Denmark, Norway, and Sweden	CO_2 in the classroom PM_{10} in classrooms	Dry cough, rhinitis, nasal patency	OR 2.99 (95% CI 1.65–5.44) OR 2.07 (95% CI 1.14–3.73) Reduced patency
Cibella et al., 2015 [168]	303 adolescents (10–17 years), Palermo	NO_2 indoor (spring and winter)	Asthma, respiratory symptoms, lung function	NO_2 indoor > outdoor; elevated levels associated with current asthma, wheezing, and decreased respiratory function
Cilluffo et al., 2022 [60]	179 asthmatic children (5–16 years), Palermo	Maternal smoking during pregnancy, overcrowding	Asthma control	Maternal smoking (OR 3.82, 95% CI 1.11–13.06) and overcrowding (OR 3.38, 95% CI 1.29–8.81) associated with uncontrolled asthma
Sarno et al., 2025 [170]	4,899 children (6–14 years), 23 EU countries	School indoor air quality, mould, environmental factors	Asthma, allergies, respiratory symptoms	High geographical variability; more symptoms in Southern Europe; Important role of the indoor environment
Baloch et al., 2020 [171]	5,175 children (6–14 years), 23 EU countries (including Italy)	School indoor air quality: benzene, limonene, CO, radon, ozone	Upper airway symptoms	OR 1.62 (95% CI 1.27–2.08) OR 1.72 (95% CI 1.33–2.22) OR 1.27 (95% CI 1.01–1.60) OR 1.36 (95% CI 1.04–1.78) OR 1.99 (95% CI 1.56–2.52)
		Benzene, limonene, $PM_{2.5}$, ozone	Lower airway symptoms	OR 1.73 (95% CI 1.30–2.31) OR 1.40 (95% CI 1.05–1.88) OR 1.32 (95% CI 1.00–1.75) OR 2.24 (95% CI 1.69–2.97)
Baloch et al., 2025 [172]	5,140 children (6–14 years), 22 EU countries (including Italy)	High concentration of endotoxins in classrooms	Runny nose, nasal obstruction, irritative cough, dry throat, breathing difficulty	OR 1.30 (95% CI 1.13–1.49) OR 1.23 (95% CI 1.07–1.41) OR 1.19 (95% CI 1.02–1.38) OR 1.19 (95% CI 1.01–1.41) OR 1.30 (95% CI 1.02–1.64)

Table 10. Effects of indoor air pollution on respiratory health of children and adolescents. (*continued*)

Study	Population/Area	Indoor exposure	Outcomes	Effect estimation
Moshammer et al., 2025 [173]	4,581 children (6–14 years), 21 EU countries (including Italy)	High concentration of endotoxins in classrooms	Lung function	For most parameters of lung function, a linear decline was observed with increasing endotoxin levels, without a clear threshold effect

Upper airway symptoms: runny nose/nasal obstruction; lower airway symptoms: dry throat/sore throat/irritative cough/breathing difficulty. CI: confidence interval; CO: carbon monoxide; CO_2: carbon dioxide; EU: European Union; NO_2: nitrogen dioxide; OR: odds ratio; PM_{10}: atmospheric particulate matter with a diameter ≤ 10 μm; $PM_{2.5}$: atmospheric particulate matter with a diameter ≤ 2.5 μm.

Relevant Italian data on the effects of occupational pollution

The data from the main international studies have shown for many years an association between occupational exposure to pollutants and obstructive pulmonary diseases that has remained almost constant over time, with a fraction attributable to occupational exposures to vapours, gases, dusts and fumes equal to 16% for asthma and 14% for COPD [174, 175]. For rhinitis, recent studies estimate the presence of an occupational cause in about 8% of all non-allergic rhinitis [176].

Data in Italy

In Italy, in the first population epidemiological studies carried out in the Pisa and Po Delta area, an increased risk of asthma (symptoms and diagnosis) and respiratory functional alterations was observed in subjects occupationally exposed to dust, fumes and gases [177], as well as a higher prevalence of subjects with bronchial hyperreactivity to methacholine in occupationally exposed ex-smokers [178].

The data of the first studies were confirmed by subsequent follow-ups, which showed an increase in the incidence of asthma and rhinitis in subjects occupationally exposed to dust, fumes and gases [49] and an association between exposure in the wood industry and in the textile industry and incidence of bronchial asthma diagnosis [179] 18 years after the first assessment.

In more recent multicenter studies involving the general Italian population, regular exposure to gases, vapors, dusts and fumes in the workplace was associated with a more severe form of bronchial asthma and a higher prevalence of asthma associated with COPD [180].

In asthmatic patients, work is often the cause, contributory cause, or aggravating factor of bronchial asthma. In a study of asthmatic patients performed in Tuscany, 48% reported that the condition was work-related (was caused by work or worsened during work) and that asthma was less controlled and needed continuous treatment with long-acting bronchodilators and inhaled steroids [181] compared to those who did not report work-related asthma.

INAIL data on occupational diseases document an increase in cases of occupational bronchial asthma in the last two years, although their number is still underestimated compared to the epidemiological data previously reported [182].

Prevention and health protection

The prevention of allergic respiratory diseases in the workplace passes through primary, secondary and tertiary prevention, as required by the consensus documents of the main pulmonary and allergological scientific societies [183, 184] and by current Italian legislation (Legislative Decree 81/08).

The primary prevention of allergic respiratory diseases is an activity that involves the elimination or, if not technically possible, the reduction of risk factors present in the workplace. In addition, any new chemicals introduced into these environments should be studied to assess their impact in terms of sensitization or potential irritation of respiratory tract that could worsen an underlying allergic condition.

Improving hygienic conditions in the workplace, through risk assessment and the implementation of mitigation measures, can contribute to primary prevention.

At this level, the role of politics and social partners in supporting these improvement actions, which aim to protect the health of the worker and reduce the socio-economic repercussions of a possible work-related pathology, is fundamental.

Secondary prevention is carried out on workers to intercept those who are developing early and potentially reversible symptoms and signs of a possible work-related respiratory allergic disease. In Italy, health surveillance by the competent doctor is mandatory for workers at risk. Health surveillance is a clinical activity characterized by a medical examination and supplementary tests aimed at assessing the worker's suitability for the specific task, but it is also an extraordinary opportunity to assess the health of workers exposed to sensitizing substances or bronchoirritants that allow the emergence of work-related respiratory allergic diseases, the effectiveness of which has also been emphasized in the consent documents of the main European scientific societies [183].

Tertiary prevention is an activity carried out on workers already suffering from respiratory allergy in which occupational physicians and allergy/pulmonologist specialists collaborate to adapt the work environment to the new needs of the patient/worker with a view to reducing the socio-economic repercussions related to the respiratory disability that characterizes the patient.

Discussion

Essential medical history information on environmental, occupational and climate change exposures

Table 11 and Table 12 show possible questions that both general practitioners and specialists could ask their patients with respiratory allergy to assess any environmental and occupational exposures that may affect disease control.

Table 11. Useful questions for a collection of environmental history.

Number	Questions
1	Is your home close to sources of external pollution?
	If so, what kind? Vehicle traffic, heavy traffic, industrial plants, landfills, crops with pesticide use, other (specify).
	If so, at what distance? Within 250 m, between 250 m and 500 m, over 500 m.
2	Is your home close to green areas (within 300 m)?
3	Are there pets in your home?
4	Are you exposed to other people's tobacco smoke (passive smoking)?
5	Do you use wood or charcoal for heating or cooking?
6	Do you use gas stoves for cooking?
	If yes, does it turn on the extractor hood while cooking?
7	Have you had any problems with moisture, water leaks, visible mould or a musty smell in your current home?
8	Do you use the air conditioner to cool the house in summer?

Table 12. Useful questions for a collection of work history.

Number	Questions
1	Have you ever been regularly exposed to gases, vapours, dust, fumes or allergens in the workplace?
2	How long was it exposed overall?
3	When were you first exposed?
4	Are you still exposed? If not, when did the exposure cease?
5	In which works have you been exposed?
6	Do/did the symptoms of your illness only occur at work or get worse during work or improve when not at work?
7	Are/were you regularly visited by a competent doctor? If so, are/were spirometry also performed? If yes, are/were allergy tests performed?

Indications for prevention

Tables 13, 14, and 15 provide practical advice and useful actions for patients with respiratory and allergic diseases with a view to preventing risks from exposure to air pollution. In general, these tips and actions are valid for the whole population.

Table 13. Practical tips to reduce exposure to outdoor air pollution.

Number	Practical tips
1	Find out about the pollution levels in the city where you live to plan your activities
2	Walk by choosing times and routes with less traffic
3	Avoid outdoor activities (e.g., walking, jogging, cycling) near busy roads and near industrial areas
4	In summer, avoid outdoor activities from noon to 4 pm, when ozone levels are very high
5	If you use a bicycle, it is better to stop in front of the first car at the traffic lights and not stop in the queue to breathe harmful gases
6	During winter, spend time outdoors during the warmest hours of the day; in cold weather, particulate matter condenses to form aerosol droplets that are more easily inhaled
7	When travelling by car, close the windows and use the air circulation setting in heavy traffic, but ventilate the vehicle periodically
8	Eat plenty of fruits and vegetables, foods rich in antioxidants
9	Cover your nose and mouth outside in cold or heavily polluted conditions
10	During pollution peaks, remember to keep medicines handy to avoid any worsening of the respiratory disease

Table 14. Practical tips to reduce exposure to indoor air pollution.

Number	Practical tips
1	Do not expose yourself to secondhand smoke
2	Open the windows for 10 to 15 minutes several times a day, especially early in the morning or in the evening, to promote air exchange. Avoid heavy traffic hours if you live in the city
3	Use the extractor hood in the kitchen to avoid exposure to particulate matter
4	Use electric or gas fires instead of wood or pellets (it is essential to choose closed and high-efficiency fireplaces)
5	During cleaning activities, ventilate frequently, reduce the use of chemicals, and do not mix them
6	Do not use braziers, charcoal grills, or unventilated stoves, and make sure there is adequate ventilation
7	Air out clothes that have just been picked up from the laundry and dry cleaned to prevent the release of volatile organic compounds
8	Limit the use of candles and incense
9	Limit the use of insecticides
10	Wash curtains and fabrics frequently and avoid carpets if possible
11	In case of renovation or new furniture, choose low-emission materials and ventilate for at least a couple of weeks
12	Regularly vacuum [possibly with high efficiency particulate air (HEPA) filters] and use damp rags on the floor to avoid resuspension of particulate matter from carpets and floors
13	Take care of cleaning the air conditioner filter and purifiers to avoid the proliferation of microorganisms
14	Install air purifiers with HEPA filters to capture pollen, mold, bacteria, and particulates*

*: EAACI guidelines indicate that filtering and air exchange devices are potentially useful in preventing both asthma and COPD exacerbations and increased decline in respiratory function. It should be noted, however, that to date scientific evidence allows only recommendations to be provided with a limited level of evidence [185, 186]. COPD: chronic obstructive pulmonary disease; EAACI: European Academy of Allergy and Clinical Immunology.

Table 15. Recommendations for enjoying the benefits of urban green spaces on the immune system [187].

Number	Recommendations
1	It is advised to visit and spend time in green spaces to strengthen the immune system. Additionally, this can improve both mental and overall physical health and reduce the need for medication
2	It is recommended to visit and spend time in green spaces in residential neighborhoods, especially for families with young children, to prevent the onset of new allergic sensitization
3	It is recommended to visit and spend time in green spaces to prevent the onset of new asthma cases and to improve asthma management in patients
4	It is recommended that patients with pollen-allergic asthma enjoy green spaces for most of the year, but also consider temporarily increasing the dosage of medication during the season with a high pollen concentration

Table 15. Recommendations for enjoying the benefits of urban green spaces on the immune system [187]. (*continued*)

Number	Recommendations
5	It is recommended that asthmatic patients combine exposure to green areas with regular physical activity to improve asthma control
6	It is recommended that patients with allergic rhinitis enjoy green spaces for most of the year, but patients with seasonal rhinitis should consider temporarily increasing the dosage of medications during the season with a high concentration of pollen

Pollen and moulds: clinical and public health implications

Pharmacological treatment and allergen-specific immunotherapy represent the fundamental pillars of the management of allergic diseases and the control of symptoms. However, non-pharmacological measures to avoid or reduce pollen exposure can be an important complement to therapy and are, in part, already considered in clinical guidelines for asthma and allergic rhinitis. The Italian National Prevention Plan (PNP) also provides for specific measures to reduce exposure to pollen, aimed at protecting the health of allergic people in the workplace (PNP 2020–2025).

For clinicians: it is essential to integrate environmental data (pollen, fungal spores, pollutants) into the risk assessment and personalized management of allergic and asthmatic patients.

For prevention: aerobiological monitoring and early warning systems for thunderstorms and pollution peaks can help raise awareness, to put in place measures to protect people with asthma and allergies, limit direct exposure to pollen (both outdoor and indoor), and reduce the risk of acute events. In urban areas, the management of green spaces in the areas of daily life of allergic or asthmatic subjects is important. To reduce pollen exposure, the replacement of highly allergenic species with plants with low allergenic potential is recommended [187].

For health policies: consider pollen exposure in clinical guidelines for asthma and allergic rhinitis, and inform and educate patients, especially the most vulnerable groups such as children and those more exposed (such as outdoor workers). In the long term, climate change mitigation and air pollution reduction are key interventions to contain the impact of allergic respiratory diseases.

Strategic action on two fronts is therefore essential:

- Aerobiological monitoring with high spatial resolution: a capillary territorial distribution of aerobiological monitoring centers is required. These centers not only record the amount of pollen in circulation and fungal pathogens, often very present in intensive plantations, but also trace the phenology (flowering times) specific to the monoculture areas;
- Timely and localized aerobiological bulletins: the data collected must flow into the drafting of extremely precise and localized bulletins. These information tools, if available with adequate timing, become essential for public health and employment, allowing allergy sufferers to take timely and targeted preventive measures, better managing their drug therapy.

Urban renewal and reforestation

Urban renewal and reforestation are now one of the fundamental pillars of city regeneration in response to the climate crisis. It is not simply a matter of "beautifying" inhabited centers, but of integrating multifunctional green infrastructures, capable of mitigating the "urban heat island" effect, improving air quality by capturing fine dust and promoting the management of rainwater through permeable surfaces.

An effective reforestation project, however, must be guided by rigorous scientific planning, based on:

- Biodiversity and resilience: the use of different native species guarantees greater resistance to pests and climate change, avoiding the fragility typical of monocultures;
- "Allergy-friendly" selection: in line with concerns about respiratory health, it is crucial to select tree essences with low allergenic potential, avoiding the massive concentration of anemophilous species (which entrust fertilization to the wind) near residential areas or schools;

- Ecological connectivity: the creation of green corridors, which connect parks, roof gardens and urban forests, allows the movement of wildlife and the maintenance of ecosystem services in the heart of the urban fabric;
- Psychophysical well-being: the presence of accessible green areas reduces stress levels, promotes physical activity and improves social cohesion, transforming abandoned or degraded industrial areas into new vital lungs for the community. For this reason, they must be managed correctly and made accessible, especially to low-income and more vulnerable population groups (children, the elderly, people with disabilities, pregnant women).

"Green" urban renewal is more necessary than ever, but a careful and qualified (therefore integrated) design of the skills necessary to reconcile plant density and respiratory health is needed. The "Low-Allergy" approach must guide urban reforestation and vertical forests: this means overturning the paradigm of urban green choice, moving from a purely aesthetic or opportunity selection (resistance, rapid growth, poor maintenance) to a selection based on the reproductive biology of plants.

The low allergic impact reforestation model

In traditional urban reforestation, anemophilous species (pollinated by the wind) are often chosen because they are very resistant and fast-growing. For an allergy-friendly project, the strategy shifts to the OPALS (Ogren Plant Allergy Scale), which ranks plants from 1 to 10 based on their allergenic potential.

Key strategies:

- Selection of sterile male species
- Sex selection (dioecious species): for trees that have separate sexes, preferring female specimens.
- Biodiversity: avoid monocultures (such as rows of a single species) to reduce the magnitude of peak pollen concentration.
- Balance between airborne pollen reduction and safety: entomophilous selection.
    i. Favoring entomophilous species is an effective strategy to reduce the pollen load in the air, but requires careful design so as not to increase the risk of negative interactions with the aculeate Hymenoptera (bees, wasps and hornets). While these plants are critical to biodiversity, a selective and strategic approach needs to be taken.
    ii. Green zoning: it is advisable to place plants with high attractiveness for pollinators (such as lavender or linden) in less man-made areas or in ecological corridors far from the entrances of schools, hospitals, and close rest areas, where the risk of accidental bites for subjects allergic to insect venom would be greater.
    iii. Selection of low-attractiveness species: species that, although technically entomophilous, do not attract massive swarms in short periods, or plants that bloom at less critical times of the year for frequenting open spaces, can be favored.
    iv. Variety management: in dense urban contexts, you can opt for ornamental varieties with double flowers (often sterile or with less nectar/pollen), which maintain the advantage of not dispersing anemophilous pollen while being less "interesting" for bees and wasps than wild varieties.

In this way, urban reforestation pursues the dual objective of protecting respiratory health (reducing allergens dispersed by the wind) and the physical safety of citizens, without sacrificing the ecosystem services offered by pollinating insects.

Climate change

The experience of the 2003 heatwave has sparked an increase in awareness of the risks associated with these exposures and the urgency of implementing prevention measures. According to the WHO, a plan for the prevention of the effects of heat must be based on an early warning system of the risks associated with high temperatures, prevention plans targeted at the most vulnerable population and modulated on the basis of alert levels and communication campaigns to the population and training for social and health workers [188].

Italy was one of the first countries in Europe to activate a national program of interventions for the prediction and prevention of the effects of heat waves on health: the "National Operational Plan for the Prevention of the Effects of Heat on Health" of the Ministry of Health [189]. The National Plan is based both on alarm systems for the prevention of the effects of heat on health, called Heat Health Watch Warning Systems (HHWWS), operating in the summer in 27 cities, and on health and social prevention interventions specifically oriented to susceptible population subgroups and modulated on the risk levels of alarm systems. In some cities, the plan provides for the identification of the elderly population susceptible to the effects of heat (registry of susceptible elderly).

In Italy, there are still no specific national plans for the prevention of health and respiratory effects for other types of exposure associated with climate change, such as drought or the transport of desert dust. However, some measures already in place for heat-related risks could be reshaped and extended to these exposures as well: the National Plan for the prevention of the effects of heat on health provides for alert systems, health monitoring and risk communication, useful tools also in the event of other climate-sensitive events that can affect health. Climate adaptation policies and civil protection plans include information and awareness-raising actions that can be extended to all exposures to extreme weather events. Prior communication by weather networks and local health authorities, if active locally, is in fact the only active measure to reduce the exposure of the population to these exposures, in particular of subjects with respiratory diseases [190].

The Ministry of Health has included in its programs the promotion of knowledge on environmental risks and climate change, with attention to asthma, COPD and allergies. The PNP includes the environment, climate and health among the macro-objectives of the plan. Regional climate adaptation policies can strengthen water resource management, improve air quality, and provide information for vulnerable citizens.

Occupational exposure

Recommendation for clinicians

Specialists in allergology and pulmonology play a fundamental role in the management of work-related respiratory allergies:

- They can perceive the presence of a potential occupational risk factor capable of causing, co-causing, or aggravating the allergy they have diagnosed. Their relationship of trust with the patient can make it possible to overcome his fear of reporting elements that could have possible repercussions on the judgment of suitability;
- They can intervene in the management of patients with work-related respiratory allergies, notoriously characterized by a more labile control of the disease, dedicating special attention to them, personalizing the periodicity of check-ups and optimizing drug treatment;
- They must report any occupational allergies and prepare any certifications of occupational disease to INAIL at the time of diagnosis;
- Can provide the patient with counseling in the pre-employment phase and collaborate with the competent doctor to improve the interaction between the work environment and the worker/patient;
- They can play a social role in disseminating information to the general population, institutional stakeholders, and other specialists in the field on the effects of exposures to risk factors in the workplace.

For this reason, it is necessary to provide tools that facilitate this type of intervention, first of all adequate training during the course of study in medicine and surgery and during specialization schools and then during professional activity in the form of continuing education in medicine.

Recommendations for patients/workers

A patient suffering from respiratory allergy who has noticed the appearance of symptoms or a worsening of the same related to work should immediately communicate it to his general practitioner, the competent doctor, and the allergy/pulmonologist specialist who is following him, with a view to preventing a possible worsening of the clinical picture and to bring out an exposure that could also represent a risk for other workers. In the event that the clinical picture is very complex or the patient perceives that he or she has not been adequately managed, he or she can ask his or her general practitioner to be sent to one of the public occupational health clinics, generally activated within public health facilities, for treatment and further investigation of the case.

The patient/worker must be adequately informed by the employer about the risk factors present in the company and the behaviors to be avoided to reduce the risk of undue exposure; if this is not the case, the patient/worker can contact his or her workers' safety representative so that this information and training course is carried out appropriately and effectively. The patient will also receive information in terms of health promotion to avoid those behaviors, for example smoking, which could have an additional negative effect on his health status and pathology.

The electronic health record: possible research applications

The EHR is established by law for all Italian citizens: in accordance with the provisions of article 11 of Legislative Decree 34/2020, it is automatically fed with present and past clinical data and documents. From 2022, the EHR is automatically fed with health data, unless the citizen opposes it (blackout option). The Health Record 2.0 is the updated and enhanced version of the EHR: a personal digital medical record, i.e., an evolution desired by the Ministry of Health for the National Health Service, an engine towards personalized and data-based healthcare.

State bodies or research bodies can access pseudonymized or anonymized data for health planning, evaluation of the quality of care, scientific and statistical research in the medical and epidemiological fields, subject to the authorization process (paragraph 2, article 34—Legislative Decree of 19 May 2020).

The data contained in the EHR could hopefully be the subject of epidemiological studies related to outdoor pollution and/or climate change (emerging infectious diseases, clinical consequences of heat waves, increase in allergic respiratory diseases). By cross-referencing, through geolocation, the data recorded in the EHR with those on air quality, climate, pollen, it would be possible to track new cases, increase in prescriptions for certain drugs and/or their consumption, admissions to the emergency room (or hospitalizations). The ultimate goal would be to collect useful data for the citizen for prevention, surveillance, clinical care. It could be better understood when, where and in whom asthma or COPD exacerbations increase by cross-referencing data by geographical area, average temperatures, peaks and duration of heat waves, pollutant levels, pollen counts. There would be an effective and rapid monitoring of health needs, a "clustering" of clinical risk, for primary and secondary preventive purposes.

Furthermore, subject to the explicit consent of the patient, an individualized alert system could be activated in the event of events (exceeding pollutant thresholds, pollen peaks, fires) capable of exacerbating recorded respiratory diseases, such as asthma or COPD, with a call to intensify therapies or limit environmental exposure.

Finally, in the context of the recording of sensitive patient data, it would be desirable to fill in, but not mandatory, some fields capable of further extending the investigation to the effects of indoor pollution, such as (1) the presence of humidity/mold in the home (yes/no), (2) the type of domestic heating (methane gas/wood/pellets/electricity). Therefore, the EHR integrated with environmental variables could be a useful research tool in the disciplines dealt with by the scientific societies belonging to this Task Force, which is available for their interpretation.

The epidemiological approach applied to the study of the effects of environmental exposures on health

The study of the possible health effects of environmental exposures requires a rigorous epidemiological method to compare the occurrence of a health outcome in an exposed and unexposed group or for different levels of exposure [191].

Exposure in these cases cannot be assigned experimentally by the researcher (i.e., experimental studies, such as randomized controlled trials) but is observed, as it is in the population (i.e., observational studies). The choice of groups comparing exposed and non-exposed, the measurement of exposure and disease must be valid or free of systematic errors, using standardized and objective methods in the measures.

In many cases, exposure is assessed at the area level (e.g., air pollution monitoring stations) as a proxy for individual exposure. Not measuring actual exposure at the individual level can introduce misclassification (i.e., misclassification of data, individuals, or variables, e.g., exposed/unexposed), but the more the accuracy of the measurement is increased (e.g., models with higher spatial resolution), the more the resulting bias is reduced.

The association is usually estimated as RR, calculated as the ratio between the incidence of disease in the population group exposed to the risk factor and that in the non-exposed group:

- If the incidence in exposed people is greater than the incidence in non-exposed people, the RR is greater than the unit value and suggests an adverse effect of exposure on disease risk, i.e., it increases the risk of developing disease in those exposed.
- If the incidence in the exposed is lower than the incidence in the non-exposed, RR is less than the unit value ($0 < RR < 1$) and suggests a protective effect of exposure on the risk of disease, i.e., it decreases the risk of developing the disease in the exposed.

In many cases, the RR is expressed in terms of the percentage increase (or decrease) that measures, assuming the risk of the non-exposed is 100, how, in percentage terms, the risk in the exposed group is greater (or less) than the risk of the non-exposed.

To obtain a valid estimate of the association between environmental exposure and health, it is crucial to check for potential confounding factors, i.e., variables associated with both exposure and outcome, which could lead to over- or under-estimation of the observed effect.

When is an environmental risk factor called a cause of disease?

According to Rothman and Greenland [192], a cause of disease is an event, condition, or characteristic that precedes the disease and that, if it had not occurred, the disease would not have occurred at that time or at all, net of all other factors.

To determine the causality of a relationship between risk factor and disease, Hill's principles [193] are applied: temporality, i.e., the risk factor must precede disease; the dose-response relationship, i.e., greater exposure to the factor leads to a higher risk; biological plausibility, i.e., that there must be a biological mechanism that supports the association; and other criteria such as strength, consistency, specificity and experimental evidence and consistency of association in different populations and at different times. The latter criterion is particularly relevant because it implies that from a single study it is not possible to conclude a causal association with the disease, but this can only derive from an analysis of the entire set of available evidence, critically evaluated, to take into account any limitations (random and systematic errors) of the studies.

Etiological epidemiological studies use advanced statistical methods to estimate whether differences in disease risk between exposed and unexposed are due to chance or whether they support the hypothesis of a causal relationship.

Study designs in environmental epidemiology

The most widely used approach to study the short-term effects (e.g., for heat) of an environmental exposure is the time-series approach. They are population studies that correlate the daily variation of an environmental factor (e.g., air pollution) to the daily variation in cases of disease.

These studies are based on pooled outcome data, with exposure measured for a certain geographical area (e.g., city) and therefore as the average value of the population, which estimates the effect as an RR of daily mortality (or other outcome) (as a daily number of events) associated with an increase in the daily concentration of the risk factor (estimation not at the individual level, but ecological) and allows the effect of exposure to be assessed days later (time delay or lag).

To assess the long-term effects of an environmental exposure, a commonly adopted study design is the cohort study involving a population sample, stratifying the sample according to the level of exposure to a certain environmental factor (e.g., air pollution) and following the population over time to estimate the incidence of disease in exposed and unexposed (or for different levels of exposure). The main problem with these studies is the possible dropout of participants from the study, which could be influenced by their risk of disease.

The cohort study also allows estimation of an RR by comparing the incidence of disease in exposed and non-exposed patients. Important are the cohort studies of newborns that enroll cohorts of children from birth to evaluate the effect of early exposures on early and/or subclinical outcomes (e.g., biomarkers and epigenetic modifications).

Another common etiological study in environmental epidemiology, especially in the case of rare diseases, is the case-control study that compares risk factors in individuals who develop the outcome and controls (sampled from the population that gave rise to the cases).

Another widely used study, but for descriptive and not causal purposes, is the cross-sectional study: which measures the prevalence of disease and simultaneously detects possible exposures, and for this reason does not allow us to establish whether the exposure occurred before the disease or vice versa, but suggests hypotheses to be tested in etiological studies.

Finally, to evaluate Hill's principle of consistency of association in different populations and at different times, a study design of extreme importance is the systematic review [194]. A systematic review relies on scientifically rigorous and reproducible methods to synthesize studies on a specific association between exposure (or intervention) and a disease, to understand whether evidence of association (or absence of association) is sufficient or further studies are needed.

The synthesis of the evidence must follow criteria of systematicity, transparency and reproducibility. Through these summaries, it is possible to give an overall assessment of the association between risk factor and disease, as is the case in the monographs of the International Agency for Research on Cancer (IARC), transparent and scientifically based. A rigorous method of synthesis, still little applied in the environmental field, is the GRADE method, which serves to transform epidemiological evidence into clinical recommendations, taking into account the quality of the available evidence and external validity [195].

Conclusions

Air pollution and climate change represent major and interconnected threats to respiratory health, contributing substantially to the burden of chronic respiratory and allergic diseases across the lifespan. Growing evidence demonstrates that outdoor, indoor, and occupational exposures are associated with the risk of developing respiratory or allergic conditions in the general population and adversely affect individuals with pre-existing diseases. Other vulnerable groups such as children and older adults are disproportionately impacted by domestic and ambient pollution and extreme weather events. All of them need to be protected through the lifetime by lowering anthropogenic emissions and controlling environmental pollution sources in all settings (home, school, work, etc.).

Although recent European legislation has introduced stricter AQG and launched the Green Deal to promote a green transition away from fossil fuels, further efforts are needed to transform policies into actions from the national to the local level. This process may be sustained by the large evidence for substantial health benefits that could be derived by aligning the European legislation with the WHO Global AQG 2021 and by mitigating greenhouse gas emissions through actions promoting healthy lifestyles. Strengthening integrated monitoring systems for air pollutants, aeroallergens, and climatic factors, together with implementing effective preventive measures and improving environmental health surveillance through EHRs, will be essential to reduce health risks and support evidence-based public health strategies in the context of ongoing climate crisis. In this context, respiratory and allergy clinicians have the fundamental role of advocating for clean air and climate change action. To pursue such an objective, it is also important for clinicians to strengthen a strategic alliance with epidemiologists, public health officials, and patient organizations.

At last, we believe that this expert position paper may be useful for the Ministry of Health, the Ministry of the Environment and Energy Security, and for the Regions, in order to strengthen policies for prevention, mitigation and protection of citizens' health.

Abbreviations

AQG: Air Quality Guidelines

ATS: American Thoracic Society

CI: confidence interval

CO_2: carbon dioxide

COPD: chronic obstructive pulmonary disease

EAACI: European Academy of Allergy and Clinical Immunology

EEA: European Environment Agency

EHR: electronic health record

ERS: European Respiratory Society

EU: European Union

NDVI: normalized difference vegetation index

NO_2: nitrogen dioxide

O_3: ozone

OR: odds ratio

PM: particulate matter

PM_{10}: atmospheric particulate matter with a diameter ≤ 10 μm

$PM_{2.5}$: atmospheric particulate matter with a diameter ≤ 2.5 μm

PNP: National Prevention Plan

RR: relative risk

SINPHONIE: Schools Indoor Pollution and Health Observatory Network in Europe

SO_2: sulphur dioxide

TRPV: transient receptor potential vanilloid

VOCs: volatile organic compounds

WHO: World Health Organization

YLD: years lived with disability

Supplementary materials

Supplementary materials for this article are available at: https://www.explorationpub.com/uploads/Article/file/1009135_sup_1.pdf.

Declarations

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Vincenzo Patella, who is the Editorial Board Member and Guest Editor of Exploration of Asthma & Allergy; Manlio Milanese, who is the Guest Editor of Exploration of Asthma & Allergy. The remaining authors declare that they have no conflicts of interest.

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