

Bringing air pollution reduction policies and climate change mitigation and adaptation policies together is essential to reduce death and disease from air pollution and heat and protect people from their interactive effects.



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Heat and high levels of air pollution have an interactive effect on health, particularly for vulnerable people

- There is an increased risk of cardiovascular (CVD) and respiratory disease and death associated with heat exposure, with the strongest heat effect on respiratory diseases.
- An elevated risk for heat-related mortality and morbidity was shown for the older age groups, as well as for people living in densely populated or less green areas. In the south of Europe, the health effects of heat were stronger in socioeconomically deprived areas.
- In the warm season, high levels of air pollution (PM_{2.5} and ozone) increase the heat-related risk for heart- and lung diseases in Europe (data from cities in 15 European countries). Again, the effect is strongest for respiratory diseases.
- Significantly higher health effects of heat together with high concentrations of air pollutants were observed, for example, in Portugal, Spain, the UK, Germany, and Switzerland, with effects being most prominent in the south of Europe. In contrast, inconsistent patterns were found for northern European countries, e.g., Norway and Sweden.
- Bringing air pollution and climate mitigation and adaptation policies together will enhance the health co-benefits and reduce heat-related mortality and morbidity.



The research has demonstrated a range of important new insights:

Environmental factors do not affect humans in isolation; instead, populations are exposed to a combination of environmental factors. Therefore, it is essential to investigate the interplay of these factors.

Reducing air pollution leads not only to an immediate improvement in health and prevention but also the heat effects on health will be lower – preventing deaths and diseases related to heat.

Our results not only confirm the health effects of heat but provide additional information on heat-related risks and on vulnerability factors in non-urban areas:

Climate change is interacting with individual-level and area-level characteristics, so that, for example, greater heat vulnerability is observed for the older age groups and in areas with high population density, high degree of urbanization, low green coverage, and high levels of PM_{2.5}.



Key policy recommendations

The EU's Ambient Air Quality Directive and the updating of guidance for heat-health action plans at the European level, and their adaptation and implementation on a national level are policy instruments for which the research results are relevant. Generally, a comprehensive view on multi-exposures is essential.

- The role of air pollution on days with high temperatures or during heatwaves needs to be considered in the context of climate change adaptation, such as in heat-health action plans, especially addressing vulnerable groups and areas at risk.
- Potential co-exposure to air pollution (including air pollution from wildfires) should be considered in the updating of guidance for developing and implementing national, regional and local heat-health action plans, according to their specific context.

- Climate change mitigation strategies and measures that reduce emissions will, at the same time, address the interactive effects of high air pollution levels and heat as so-called health co-benefits.
- The established interactive effects of heat stress and air quality need to be reflected in the context of the EU Ambient Air Quality Directive. The alignment of new air pollution limit values with the latest WHO Air Quality Guidelines will significantly help mitigate and adapt to climate change.
- New knowledge on the health effects of high temperatures and heatwaves, interactions between temperature and air pollution and implications for specific vulnerable population groups needs to be integrated into the education and training of medical professionals.

Overall, there is a high potential for beneficial effects on health and prevention of diseases by reducing air pollution and in considering air pollution in heat health prevention and protection. Even if the relative risks of air temperature and air pollution for our health might be small compared to other individual or lifestyle risk factors, the entire population is affected; therefore, there is a high number of attributable cases.

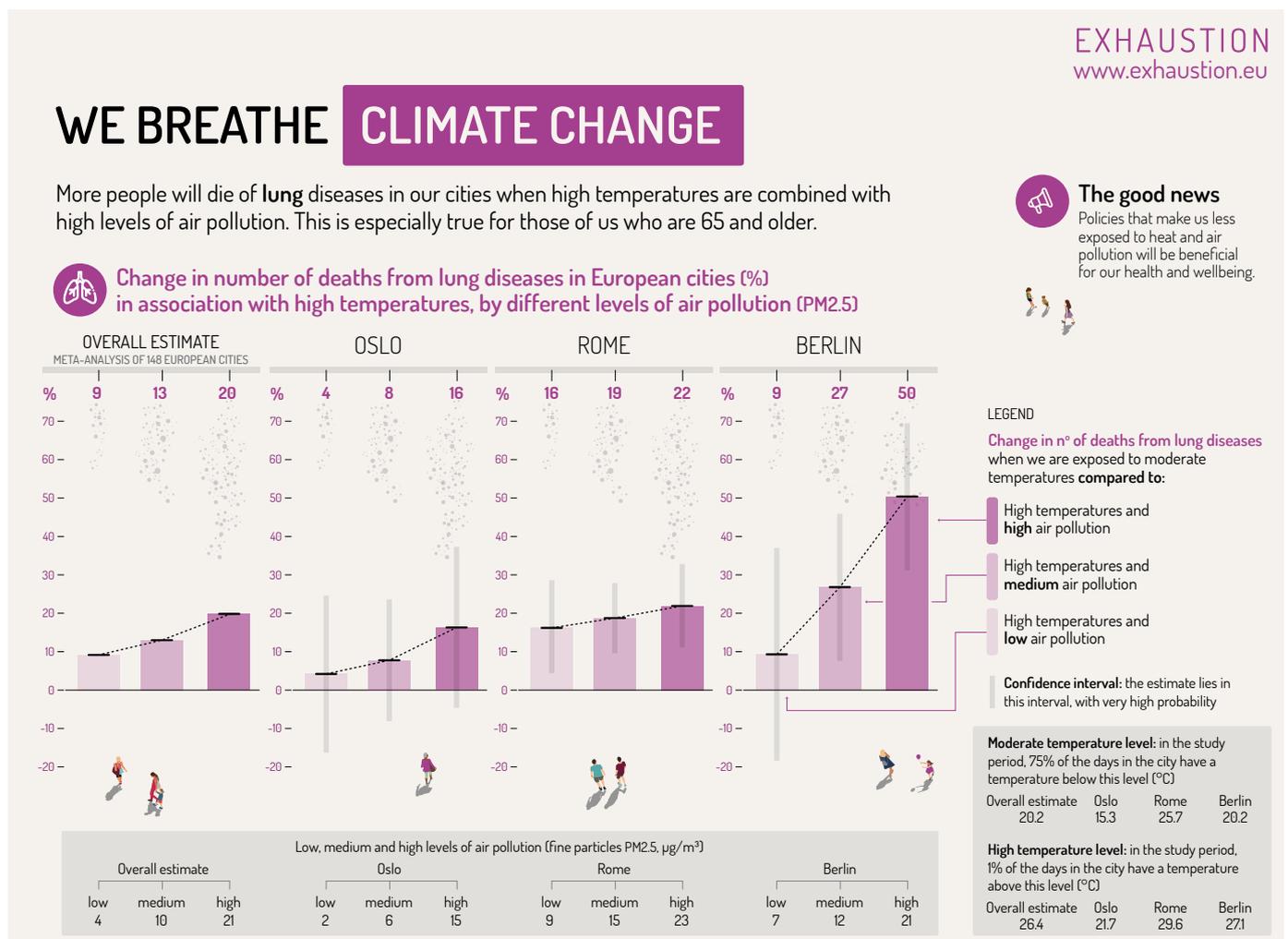


Figure 1: The visualisation shows the health impact of simultaneous exposure to high temperatures and particulate air pollution (PM_{2.5}). It explains the percent change in the number of deaths from lung diseases when the temperature increases from medium to high levels, given low, medium or high air pollution levels.



Key research recommendations

Based on the project results, some specific research gaps were identified that need to be addressed to inform further stakeholders and decision-makers as well as climate change mitigation and adaptation processes:

- Investigate the interplay of air temperature exposure with other environmental factors (e.g., green space or biodiversity) as well as with social factors (“environmental justice”).
- Deepen insight into adaptation processes (behavioural and physiological).
- Describe the pathophysiological mechanisms for the impact of temperature on health.
- Examine the interplay of outdoor and indoor temperatures.
- Establish exposure-response functions for temperature and more detailed cause-specific cardiovascular mortality and hospital admissions.
- Assess changes over time in the exposure-response relationship and the role of adaptation and heat vulnerability factors.
- Investigate long-term health impacts of non-optimal temperatures (and their interplay with air pollution).

Policy makers, decision-makers and stakeholders identified the following opportunities and needs at the EXHAUSTION policy conference on 15 November 2023:

Air pollution reduction measures are a success story. The project research results show the importance of connecting the air and climate agenda. Especially in the European “heat hot-spots” (especially in cities), people suffer from the double climate penalty - heat and air pollution - and the most vulnerable populations suffer the most.

There are additional points for future study designs, projects and policy implications at the heart of adaptation strategies and other measures to reduce adverse environmental exposures, such as:

- Consideration of mental health effects
- Provision and coordination of research data
- Recommendations on monitoring of compliance and evaluation of measures
- Vulnerability is not a choice: equity and justice need to be addressed in policies
- Costs of inaction are higher than costs of action for all scenarios



Ljubljana, Slovenia.



Key takeaways

Overall, understanding the effects of heat, particularly in socioeconomic deprived and less green areas, and the interaction with air pollution is critical to support the development of effective and equitable public health policies at European, national, and local levels. Concrete implications for policy development include:

- Policies reducing air pollution concentrations in Europe, such as the EU’s revised Ambient Air Quality Directive, will not only reduce the health effects of air pollution but also prevent death and disease from heat due to the interactive effects of air pollution and heat.
- The joint effects of air pollution and heat need to be considered in heat-health action plans as they are being developed across Europe. Combining air pollution and climate change policies is essential to avoid trade-offs and harvest health co-benefits.



Scientific methodology and research findings

The research in EXHAUSTION behind the findings presented above used a geographically very diverse database with spatially varying resolution; specifically, we:

- defined the methods to be applied in a rigorous and standardized way across all investigated urban, suburban, and rural locations to provide exposure-response functions and health effects estimates, including potential effect modifiers,
- established quantitative exposure-response functions for cardiopulmonary diseases in association with short- and long-term impacts of (extreme) air temperatures for European cities, small areas (e.g., municipalities, lower layer super output areas or administrative districts) or cohorts with individual participant data to estimate effects at the national level as well as in urban, suburban, and rural areas,
- assessed the interactive effects of high air temperature and air pollution, thereby providing insights into how the interplay of meteorology and air quality affects healthy living in urban and rural areas in Europe,
- assessed effects by susceptibility/risk factors such as having a pre-existing chronic disease, age and sex,
- identified epidemiological effect modifiers (e.g., urbanicity, population density, green areas, gross domestic product, unemployment rate, population above 65 years of age, type of landscape) that influence heat-related mortality and morbidity in urban and rural areas, respectively.

Publication date	First author	Last author	Title	Journal
10/10/2023	Massimo Stafoggia	Francesca de' Donato	Joint effect of heat and air pollution on mortality in 620 cities of 36 countries	Environment International
10/1/2023	Sofia Zafeiratou	Klea Katsouyanni	Assessing heat effects on respiratory mortality and location characteristics as modifiers of heat effects at a small area scale in Central-Northern Europe	Environmental Epidemiology
9/1/2023	Siqi Zhang	Alexandra Schneider	Assessment of short-term heat effects on cardiovascular mortality and vulnerability factors using small area data in Europe	Environment International
7/15/2023	Masna Rai	Alexandra Schneider	Temporal variation in the association between temperature and cause-specific mortality in 15 German cities	Environmental Research
4/1/2023	Pierre Masselot	Antonio Gasparrini	Excess mortality attributed to heat and cold: a health impact assessment study in 854 cities in Europe	The Lancet Planetary Health
4/1/2023	Masna Rai	Susanne Breitner	Heat-related cardiorespiratory mortality: Effect modification by air pollution across 482 cities from 24 countries	Environment International
12/16/2022	Masna Rai	Alexandra Schneider	Achievements and gaps in projection studies on the temperature-attributable health burden: Where should we be headed?	Frontiers in Epidemiology
7/6/2022	Siqi Zhang	Alexandra Schneider	Climate change and cardiovascular disease – the impact of heat and heat-health action plans	e-Journal of Cardiology Practice
6/10/2021	Sofia Zafeiratou	Klea Katsouyanni	A systematic review on the association between total and cardiopulmonary mortality/morbidity or cardiovascular risk factors with long-term exposure to increased or decreased ambient temperature	Science of the Total Environment
11/9/2020	Annette Peters	Alexandra Schneider	Cardiovascular risks of climate change	Nature Reviews Cardiology
3/26/2020	Siqi Zhang	Alexandra Schneider	Climate change and the projected burden of future health impacts–The Project EXHAUSTION	Public Health Forum