Air pollution and health: recent advances in air pollution epidemiology to inform the European Green Deal: a joint workshop report of ERS, WHO, ISEE and HEI

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Current European air pollution levels, which are in most places well below air quality limit values, still have deleterious health effects. The report discusses ways to move forward with air quality legislation to improve public health. https://bit.ly/3kFRHHf

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Introduction

Ambient air pollutants can adversely affect population health in multiple ways, such as through respiratory, cardiovascular, metabolic, neurological and birth-related outcomes [1–3]. These health effects lead to a substantial burden of disease and economic impact. In response, air quality policies have been put into place across the globe. The European Union has developed an extensive body of legislation which establishes health-based standards for several air pollutants [4–6]. Despite sizable successes of pollution control over the past decades, air pollution-related disease burden among Europeans remains high, leading the European Commission to conclude that the current legislation has only been partially successful in protecting the health of Europeans [7]. Recent evidence from large research programmes and

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comprehensive reviews supports this view and points towards important aspects to consider in striving to reduce air pollution-related burden of disease.

The Health Effects Institute, the European Respiratory Society, the World Health Organization (WHO), and the International Society for Environmental Epidemiology were pleased to organise a joint meeting in Brussels, Belgium, on 21–22 January 2020. The event was also supported by the European Commission. The aim of the meeting was to review the latest science on major pollutants, focusing on particulate matter 2.5 µm or less in diameter ($PM_{2.5}$) and nitrogen dioxide, to help evaluate the need for updating Europe's air quality policies and in support of the European Green Deal. A number of important scientific and policy questions about the causal links between air pollution and health, its effects at low levels of exposure, the relative contributions of different sources or constituents, and ultimately the question of how to achieve the most health benefits most cost-effectively were presented and discussed. This workshop report summarises the key findings of the meeting.

European Air Quality Regulation

The Fitness Check has found that EU regulations have contributed to improved air quality, but substantial health burden remains.

The EU has the overarching goal to protect European citizens and susceptible subpopulations from the adverse effects of major ambient air pollutants by both regulating emissions of air pollutants at the source (*i.e.* National Emission Ceilings Directive and source-specific standards), and by monitoring and limiting population exposure according to a harmonised monitoring scheme throughout the European Union (Ambient Air Quality Directive). In 2019, the European Commission conducted a retrospective analysis of whether these EU air quality actions are actually fit for this purpose (*i.e.* the "fitness check" [7]). It concluded that the actions have been partially successful by contributing to a downward trend in air pollution, but that air pollution remains a major health and environmental concern, leading to more than 400 000 premature deaths [8] and total health-related external costs in the range of EUR 330–940 billion per year [9]. Moreover, the Commission noted that the current air quality standards are less ambitious than scientific health-based guidelines from the WHO and those of non-European high income countries and has proposed revising the air quality standards to bring them into closer alignment with WHO guidelines [7, 10].

The European Green Deal is a comprehensive road map striving to make the EU more resource-efficient and sustainable, which was brought forward by the European Commission in 2019 [11]. The Green Deal has the overarching aim of reducing sources of carbon dioxide sufficiently to make Europe climate neutral by 2050. It also aims for a zero emission strategy of air pollutants and foresees a revision of the European Air Quality Directive in the current legislative period [12]. The European Green Deal coincides with the United Nations' Sustainable Development Goals call for major reductions in exposure to air pollution by 2030 [13]. Now, it also plays an important role in the climate-friendly rebuilding of the European economy after the coronavirus disease 2019 (COVID-19) pandemic.

Recent reviews regarding the health effects of ambient air pollution: what do they tell us?

EU regulations need to be updated to reflect the latest scientific evidence on air pollution and health.

Regular synthesis of the scientific evidence to assess the strength of causal relationships between air pollution and health are crucial steps for policy makers. This process relies on interdisciplinary teams of scientists to assess potential biases, limitations and strengths of the individual epidemiological, experimental and mechanistic studies and ultimately develops an integrated assessment about causality and characteristics of the exposure-response-relationship.

While the US Environmental Protection Agency is mandated by law to conduct such comprehensive reviews on individual pollutants on a regular basis, Europe relies on the WHO Air Quality Guidelines development process for the rigorous evaluation of the scientific evidence and guidelines to protect public health across European countries. However, since the European Union Air Quality Directive was published in 2008, a sizable gap exists between the EU limit value for annual average $PM_{2.5}$ concentration of 25 $\mu g \cdot m^{-3}$ and the WHO health-based guideline of 10 $\mu g \cdot m^{-3}$ established in 2005 [10]. In addition, a large body of evidence has accumulated specifically for $PM_{2.5}$ since the last revision of the WHO Air Quality Guidelines in 2005. As a consequence of this strengthened evidence, in 2012, the US National Ambient Air Quality Standard for $PM_{2.5}$ was reduced from 15 to 12 $\mu g \cdot m^{-3}$. Other countries' air quality standards are also in better alignment with WHO Air Quality Guidelines [14] than the EU limit values. Currently, WHO is updating the global Air Quality Guidelines to better reflect recent evidence [15]. The updated

WHO global Air Quality Guidelines, expected to be ready in early 2021, will provide important input for the Commission's ambition to align legal standards of $PM_{2.5}$ with health-based recommendations.

The workshop also reviewed recent evidence on NO_2, which plays a central role in European air pollution policy, as traffic-related emissions have remained high and many member states have violated long-term limit values for NO_2 concentrations. While NO_2 has been less studied than $PM_{2.5}$, evidence for an independent effect of NO_2 on mortality and potentially on the development of asthma in children is growing [16, 17]. Nonetheless, there is more certainty about the health benefits of interventions that reduce both $PM_{2.5}$ and NO_2 than those that target NO_2 alone [16].

Growing concern has been raised regarding ultrafine particles (UFP), because of their potential for travelling deeper into the lungs, into the bloodstream and into the brain. Because exposures to UFPs vary highly in space and time and co-occur with other pollutants, assessment of their independent health effects has been difficult. Despite these challenges, recent reviews conclude that the evidence, from studies of short-term exposures particularly, suggests that UFPs contribute to respiratory, cardiovascular and nervous system health effects [18–21]. More definitive conclusions have been limited by lack of comprehensive monitoring and studies on effects of long-term exposures, so this area will need to be re-evaluated as new evidence becomes available. Nevertheless, while specific guidelines cannot be recommended yet, the available evidence supports the need for reductions in UFP emissions and human exposure.

How low should we go? New health research on low-level ambient air pollution

New studies have reported strong associations of health effects with air pollution at levels below current standards, with no observable thresholds.

Air pollution levels and the air pollution-attributable burden of disease are declining in most European countries. Nonetheless, new studies report strong associations with health effects at levels below current legal standards in the general population, with no observable thresholds [22, 23]. Two of the largest new studies undertaken to examine adverse health effects of low levels of ambient air pollution in USA and Canada were published recently by the Health Effects Institute [24, 25]. Results from the third study in the HEI programme, focused on Europe, are expected later this year [26]. Each study uses state-of-the-art exposure assessment methods and very large populations, and put special emphasis on clarifying the exposure–response relationship at low levels of exposure.

Di *et al.* [27] used Medicare insurance data for 61 million Americans, aged 65 years and older and enrolled between 2000 and 2012. By combining air monitoring, satellite, atmospheric transport models and land use regression models, the investigators developed hybrid models for the continental USA to estimate $PM_{2.5}$ at 1 km×1 km grids. Brauer *et al.* [24] used a cohort of approximately 9 million Canadians, based on census and health survey data. They combined satellite data, ground-level measurements, atmospheric modelling data, and land-use covariates to estimate $PM_{2.5}$ exposures at a fine resolution across North America from 1981 to 2016. Brunekreef *et al.* [26] used pooled data from the well-characterized ESCAPE cohorts (European Study of Cohorts for Air Pollution Effects) and large administrative cohorts resulting in a study population of about 35 million persons across Europe. They developed hybrid Europe-wide exposure models that utilise land use information, dispersion modelling, satellite data, and monitoring data for $PM_{2.5}$ and other pollutants to estimate long-term pollutant concentrations at residential address for the cohort members.

All three studies report associations between mortality and $PM_{2.5}$ concentrations at levels as low as 5 $\mu g \cdot m^{-3}$, well below the current EU limit values, the US National Ambient Air Quality Standards and even below the 2005 WHO air quality guideline value of 10 $\mu g \cdot m^{-3}$. The European study also investigated traffic-related exposures to NO_2 and black carbon and found robust associations of the exposure with mortality and incidence of cardiovascular and respiratory disease also for these pollutants. The associations were very stable in multi-exposure models and were observed well below the European annual limit value of 40 $\mu g \cdot m^{-3}$ for NO_2 and even below the WHO recommended value for health impact assessment of 20 $\mu g \cdot m^{-3}$. For both $PM_{2.5}$ and NO_2, associations tended to have steeper slopes at low exposures with no indication of a threshold.

The lack of a threshold together with robust associations at low levels of air pollution underscores the large potential for health benefits by lowering the average exposure of the population, even though most of the population in the USA, Canada and Europe are currently exposed to levels below the respective legal limit values and standards. For example in the EU, while only 8% of the urban population was exposed to concentrations exceeding the annual EU limit value of 25 $\mu g \cdot m^{-3}$ in 2017 [28], 77% exceeded the annual WHO air quality guideline for $PM_{2.5}$ of 10 $\mu g \cdot m^{-3}$.

Implications for future health impact assessment and regulation

Burden of disease calculations, health impact assessment, and accountability studies are powerful tools to shape policy. Abatement measures see significant success.

Various burden assessments, including from the European Environment Agency, WHO and the Global Burden of Disease consortium, have played a key role in identifying the overall and relative importance of air pollution compared to other risk factors, showing that ambient air pollution is currently ranked fifth among the leading risk factors for mortality in the EU [7, 29, 30].

Using burden of disease and health impact assessment approaches, the outcome of various policy options for different scenarios can be predicted. The outcomes can be expressed both in terms of number of deaths or illnesses avoided, or in economic terms, by putting monetary value on health outcomes. Studies show that the estimated health benefits outweigh by far the implementation costs of air quality actions [9, 31]. More specifically, a recent evaluation of various policy options for air pollution standards concluded that an approach aiming for the reduction of average long-term exposures of the European population would have a better cost–benefit ratio than a strategy aimed only at reducing peak exposures with fixed limit values [32]. Likewise, even though current evidence does not clearly identify differences in the toxicity of $PM_{2.5}$ from different sources [33, 34], cost–benefit analyses allow for identification of the most cost-effective targets of emission reduction measures from various sources. It is also important to calculate the co-benefits of air quality improvements associated with specific climate change actions as they are inexorably linked, as demonstrated, for example, by the benefits of reducing coal extraction and combustion [35]. An integrated approach to climate change and air pollution can therefore lead to significant co-benefits, as well as to reducing the risk of introducing climate change measures with significant negative impacts on air quality [36–38].

To date, such assessments have not been extensively validated by comparison with results of "real world" studies of regulatory programmes and interventions using actual health outcome data. Accountability studies designed to assess whether such actions lead to the expected health benefits have emerged to fulfil that role [39]. In some cases, such studies have provided evidence for the benefits of specific actions and policies, but in other cases their evidence has been weaker than had been originally anticipated. Some of the first, and classic, examples of accountability studies are those documenting air quality and health improvements associated with temporary factory closures of a steel mill and copper smelters in the USA [40, 41]. Another early well-known example is the study in Dublin, Ireland, which reported substantial air quality improvements and decreases in respiratory mortality after the introduction of a city-wide ban on the sale of coal [42, 43]. The experience from these accountability studies has been recently reviewed and recommendations have been offered for the design and conduct of future studies [44–47]. A review of practical interventions to reduce outdoor air pollution at the local level was recently published [48], though it remains clear that air quality actions are needed at all levels (international, national, local) and across all sectors (*e.g.* transport, energy, agriculture) to bring significant health benefits [49].

The evidence base highlights the challenges related to establishing the effectiveness of specific air pollution interventions on outcomes. It also points to the need for improved study design and analysis methods, including use of causal inference approaches [50–52]. Though challenging, intervention studies are appealing and are the closest epidemiological equivalent to controlled experimental studies, thereby contributing to the causality debate. The prospective planning of evaluations and an evaluation component built into the design and implementation of large interventions may be particularly beneficial.

Air pollution research priorities and policy implications

Despite the remarkable growth in knowledge about air pollution and health, a range of issues warrant additional research. As governments act to reduce air pollution, there is a continuing need for research to shed more light on disease risk at very low levels of air pollution, identify the air pollution sources and pollutants most responsible for disease burden, identify subgroups of the population at most risk, and assess the public health effectiveness of actions taken to improve air quality. Specifically for vulnerable subpopulations, better communication of the risks of air pollution, advising on how to reduce exposure at the community (local) level and to reduce individual health risks, and involvement of healthcare professionals in providing this information need to be strengthened; with several activities being under way [53–55].

Despite existing research needs, the strength of the evidence is overwhelming and provides a sufficient basis for policy decisions. Growing scientific evidence for effects at levels below current air quality standards and the large overall estimates of the air pollution-attributable burden of disease, as well as the need to reduce greenhouse gases, imply that more stringent air quality standards and guidelines should be considered in the future to improve public health even further. To maximise health benefits, it is

important to implement measures that will reduce peak exposures in specific hotspots, the average exposure of all EU citizens, and inequalities in air pollution risk. To tackle the health effects of air pollution, bold, readily available, and cost-effective air quality actions are needed at all levels (international, national, local) and across all sectors (*e.g.* transport, energy, agriculture). The estimated health benefits outweigh by far the implementation costs of air quality actions. Co-benefits in other policy areas such as climate change and urban structure need to be considered as well.

The current COVID-19 pandemic has profoundly impacted the world, and air pollution may increase susceptibility to mortality and morbidity from COVID-19 [56, 57]. The European Green deal must be central to a resilient and healthy recovery from the COVID-19 pandemic. Such efforts must be further amplified and multiplied in countries across the globe, including the USA, to limit global warming and improve air quality for the sake of planetary and human health. Green and healthy recovery from COVID-19 is also at heart of a WHO Manifesto [58], with strong emphasis on reducing pollution, protecting nature, promoting healthy energy transition, sustainable food systems and healthy and liveable cities.

A coordinated and systemic approach, which also takes equity issues into account, will be needed to make Europe the first climate-neutral and zero-emission continent by 2050. The European Green Deal and the Commission's pollution action plan for air, water and soil, to be adopted by 2021, can provide a unique opportunity to operationalise the fundamental changes that are necessary and build upon the synergies between air quality and climate actions.

We dedicate this to the memory of Kirk R. Smith, Professor at the University of California, Berkeley, who never ceased to raise his voice for the poor and the planet, and to Professor Martin Williams, Imperial College London, who has been a leader of research and policy development to solve the problems of poor air quality in the UK and more widely in Europe throughout the past four decades.

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