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EXPERT CONSENSUS DOCUMENTS, RECOMMENDATIONS, AND WHITE PAPERS

Air Pollution and Health – A Science-Policy Initiative

Academy of Science of South Africa*, Brazilian Academy of Sciences†, German National Academy of Sciences Leopoldina‡, U. S. National Academy of Medicine§ and U. S. National Academy of Sciences‖

Air pollution is a major, preventable and manageable threat to people's health, well-being and the fulfillment of sustainable development. Air pollution is estimated to contribute to at least 5 million premature deaths each year across the world. No one remains unaffected by dirty air, but the adverse impacts of air pollution fall most heavily upon vulnerable populations, such as children, women, and people living in poverty — groups to whom States have special obligations under international human rights law. The National Academies of Sciences and Medicine of South Africa, Brazil, Germany and the United States of America are calling upon government leaders, business and citizens to take urgent action on reducing air pollution throughout the world — to the benefit of human health and well-being, to the benefit of the environment and as a condition towards sustainable development. Air pollution is a cross-cutting aspect of many UN Sustainable Development Goals.

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Poor air quality threatens human life, population health, and the future prosperity of children. Air pollution also threatens the sustainability of the earth's environment, as clean air is as vital to life on earth as clean water.

The scientific evidence is unequivocal: air pollution can harm health across the entire lifespan. It causes disease, disability and death, and impairs everyone's quality of life. It damages lungs, hearts, brains, skin and other organs; it increases the risk of disease and disability, affecting virtually all systems in the human body.

The costs of air pollution to society and the economies of low- and middle-income countries are enormous. These economic losses are so significant that they can undercut sustainable development. Economic growth that accepts air pollution and ignores the public health and environmental impacts is unsustainable and unethical.

Combustion of fossil fuels and biomass is the most significant source of air pollution globally. These are also significant sources of short-lived climate pollutants such as black carbon, methane, ground-level ozone and the main sources of CO_2 emissions. Many of the solutions to air pollution issues will also have a positive impact on climate change mitigation and can make important contributions to meeting a 1.5°C climate target.

Public and private investments in tackling air pollution are insufficient and do not match the scale of the problem. Opportunities to create synergies between air pollution control, climate change mitigation and sustainable development are many, but have not been fully realized.

Air pollution is a preventable problem. But without renewed action, air pollution exposure will continue to be a significant contributor to global mortality. Coupled with ageing, population growth and urbanization, more people will suffer and die each year.

Air pollution can be cost-effectively controlled through a combination of policies, legislation, regulation, standards and enforcement coupled with implementing new technologies and increasing social awareness. Air pollution control fosters economic growth and benefits national economies by averting disease and preventing productivity losses.

The National Academies of Sciences and Medicine of South Africa, Brazil, Germany and the United States of America are calling upon government leaders, business and citizens to take urgent action on reducing air pollution throughout the world — to the benefit of human health and well-being, to the benefit of the environment and as a condition towards sustainable development. Air pollution is a cross-cutting aspect of many UN Sustainable Development Goals.

Our five National Academies of Sciences and Medicine propose the adoption of a global compact on air pollution to make air pollution control and reduction a priority for all.

* Academy of Science of South Africa, ZA

† Brazilian Academy of Sciences, BR

‡ German National Academy of Sciences Leopoldina, DE

§ U. S. National Academy of Medicine, US

‖ U. S. National Academy of Sciences, US

Corresponding academy: German National Academy of Sciences Leopoldina (kathrin.happe@leopoldina.org)

Air Pollution Affects the Health of Everyone

Clean air is essential for life and health. Air pollution is the largest environmental cause of disease and early death in the world today. It has been associated with at least 5 million premature deaths every year. While air pollution impacts everyone, the burden of disease is highest among the poor and the powerless, minorities and the marginalized.

Air pollution affects people from the beginning until the end of life, causing a wide range of acute and chronic diseases from the earliest stages of child development to extreme old age. Particularly sensitive populations include infants in the womb, children, the elderly, and people with pre-existing chronic diseases. Almost all organs, systems and processes in the human body may be impacted: the lungs, the heart, the brain, the vascular system, the metabolism, and reproduction.

Air pollution is a major cause of pneumonia, bronchitis and asthma in infants and children. It slows the growth of the developing lungs of children and adolescents. It contributes to heart disease including cardiac arrhythmias and acute myocardial infarction, stroke, cancer, asthma, chronic obstructive pulmonary disease, diabetes, allergies, eczema, and skin ageing. There is emerging and growing evidence that air pollution contributes to dementia in adults and impacts brain development in children.

Women in low-income countries are disproportionately affected by exposure to household air pollution from the use of solid fuels (coal and biomass) for cooking, and they bear the greatest burden of pollution-related disease. Women also bear the main burden of caring for other household members suffering from air pollution-related ill health.

The risks of air pollution vary across societies, with vulnerability varying among individuals. Factors that affect individual vulnerability include age, gender, education, socioeconomic status, location and residence, fuels used for cooking and heating, and occupation. Biological factors that increase individual vulnerability include genetic susceptibility and underlying diseases, such as asthma, heart disease or diabetes.

Diseases related to air pollution cause productivity losses that can reduce gross domestic product, cause work and school absenteeism, and perpetuate existing societal inequalities. These diseases also result in health care costs that in rapidly industrializing countries can consume as much as 7% of national health budgets.

The global economic burden of disease caused by air pollution (both outdoor and indoor) across 176 countries was estimated to be USD 3.8 trillion in 2015. The health and economic benefits of action against air pollution will generally far outweigh the costs of action.

There is an ethical imperative to work together to protect everyone against the health risks of air pollution, which are sustained by the population as an unpaid adverse consequence of actions by polluters.

Combustion of Fossil Fuels and Biomass is the Main Source of Air Pollution

The air pollutants of greatest concern for human health are airborne particulate matter. The unfiltered emissions of combustion contain significant concentrations of ultrafine, fine and large particles, including black carbon, as well as harmful gases.

Air pollution is a complex mixture of different components. Levels of fine particles ($PM_{2.5}$ mass concentration) along with ozone serve as a robust indicator for regulatory purposes; with black carbon as a proxy for emissions from combustion.

The main sources of combustion-related air pollution are: A. stationary combustion facilities; B. household heating and cooking; C. controlled biomass burning and waste combustion; and D. mobile sources. The relative importance of these sources varies from country to country.

- A Stationary sources include power plants, manufacturing facilities and mining with limited emission controls. Facilities that burn coal or other poor quality fuels or that rely on diesel-powered generators due to a lack of grid reliability are generally the worst offenders.
- B Households are an important source of air pollution, especially in low-income countries that rely on biomass fuels for heating and cooking. They are also a place where people are greatly exposed.
- C Controlled biomass burning sources related to agricultural waste burning and to land and forest clearance are important sources of air pollution in developing countries. Additional uncontrolled biomass burning is related to residential and other waste combustion.
- D Mobile sources of air pollution include petroleum-powered cars, trucks, and buses; in both the private and public sectors. They are the main source of air pollution in cities. Old and poorly maintained vehicles that burn low-grade fuels are especially hazardous. Emissions from ships and aircraft are the major mobile sources of air pollution near ports and airports.

There are synergies between air pollution control and climate change mitigation as they share common sources and, to a large extent, solutions; while the majority of air pollutants also impact the climate. They also aggravate each other in multiple ways, e.g. greenhouse gases, such as methane, contribute to the formation of ground-level-ozone, and levels of ground-level ozone increase with rising temperatures and rising temperatures increase the frequency of wildfires; which in turn further elevate levels of particulate air pollution.

Black carbon from combustion impacts health but also regional temperatures, precipitation and extreme weather. The Arctic and glaciated regions such as the Himalayas are particularly vulnerable to melting as a result of deposited black carbon which heats the surface. Changing rain patterns from black carbon aerosol-cloud interactions can have far-reaching consequences for both ecosystems and human livelihoods, for example by disrupting monsoons, and droughts which are critical for agriculture in large parts of Asia and Africa.

Call to Action

The five National Academies of Sciences and Medicine of South Africa, Brazil, Germany and the United States of America are issuing a call to action to government leaders, business and citizens to reduce air pollution in all countries. This call is underpinned by unequivocal scientific evidence on the health impacts of air pollution.

Many existing agreements, resolutions, conventions and initiatives already address aspects of air pollution. These include the Montreal Protocol, the United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution, the WHO Framework Convention on Tobacco Control, and the World Health Assembly resolution on the health impact of air pollution.

Therefore, the Academies propose adoption of a global compact on air pollution. This would ensure sustained engagement at the highest level and make air pollution control and reduction a priority for all. It would also encourage policymakers and other key partners, including the private sector, to integrate emission control and reduction into national and local planning, development processes, and business and finance strategies. For such a process to be successful, there would need to be both political leadership and partnerships including working together with existing multinational structures.

The Academies recognize that no perfect solution fits all situations in all countries. Nevertheless, urgent action is needed in the following areas:

There are many policy and technological solutions to reduce harmful products of combustion. For stationary sources this includes implementation of emission controls for industry and power plants or changing to clean fuels. For households this includes provision of access to clean household fuels. For controlled biomass burning this includes enforcement of rules to eliminate garbage burning and new agricultural techniques to reduce crop burning. For mobile sources this includes promoting and investing in sustainable mass transport and urban infrastructures.

Effective policies and technologies need to be shared. Where applicable, these strategies should urgently be put into action in countries at every level of economic development across the world. Some solutions enjoy a high degree of consensus. Where that consensus is lacking or where the policy choice depends importantly on context (given the heterogeneity in legal systems, geography, economic development stage, sources of pollution), tailoring of policies is needed, although there are universal actions that are needed in many parts of the world.

There is a need to collect the success stories in controlling air pollution from cities and countries and to extract lessons from those stories and share those lessons with countries now beginning to grapple with the issue.

Population exposure is directly related to population density, pollutant concentration and duration of exposure. In optimizing the costs and benefits of actions taken to improve air quality priority should be given to the pollution sources where population exposure can be reduced cost-effectively, and to reducing exposures to the poorest members of society, recognizing that these two metrics may at times conflict.

Sufficient monitoring of key pollution metrics, especially $PM_{2.5}$ concentrations and population exposures, is a critical need in all countries. An additional need is for follow-on statistical analyses that can be used to assess the success of policy actions.

Co-benefits amongst policy instruments need to be identified. Priority should be given to policies that maximize synergies across multiple development goals, including climate change mitigation and food security. Energy efficiency improvements provide reductions in both CO_2 and harmful products of combustion, as do many other strategies to mitigate climate change such as greater reliance on renewable energy and electrification of transport.

Efforts need to be made to devise strategies for the implementation of solutions. These strategies may include building institutional capacity, improving governance, and fostering mechanisms for cross-agency collaborations and enforcement. Using the tools of risk assessment and cost-benefit analysis will help in choosing policy designs and targets. Air pollution control policies should be designed to deliver cost-effective reductions in exposures. Ideally, they should also deliver benefits in other areas, such as climate, or other sectors, such as agriculture. Polluters could be incentivized to find the cheapest ways of reducing pollution and thereby exposures.

This call for action requires mobilizing finance and substantial investment in opportunities to reduce air pollution. Increased funding is also needed for research, pollution monitoring, infrastructure, management and control, and stakeholder interaction.

Finally, there needs to be advocacy for action where citizens are informed and inspired to reduce their air pollution footprint and advocate for bold commitments from the public and private sectors.

Note

This statement has first been published in June 2019. It is available in all official UN-languages and in German and Portuguese on www.air-pollution.health.

Author Information

Academies Working Group

Maria de Fatima Andrade, Professor of Meteorology and Atmospheric Sciences, University of São Paulo, São Paulo, Brazil.

Paulo Artaxo, Professor of Environmental Physics, University of São Paulo, São Paulo, Brazil.

Simone Georges El Khouri Miraglia, Associate Professor and Leader of the Laboratory of Economics, Health and Environmental Pollution (LESPA), Federal University of São Paulo, São Paulo, Brazil.

Nelson Gouveia, Associate Professor of Epidemiology, University of São Paulo, São Paulo, Brazil.

Alan J. Krupnick, Senior Fellow, Resources for the Future, Washington, DC, U.S.A.

Jean Krutmann, Scientific Director, IUF — Leibniz Research Institute for Environmental Medicine, Düsseldorf, Germany.

Philip J. Landrigan, Professor of Biology and Director, Program in Global Public Health and the Common Good, Boston College, Boston, U.S.A.
Kristy Langerman, Senior Lecturer, University of Johannesburg, Johannesburg, South Africa.
Tafadzwa Makonese, Senior Researcher and Lab Manager, University of Johannesburg, Johannesburg, South Africa.
Angela Mathee, Director MRC Environment & Health Research Unit, South African Medical Research Council (SAMRC), Johannesburg, South Africa.
Stuart Piketh, Professor of Environmental Science, North-West University, Potchefstroom, South Africa.
Beate Ritz, Professor of Epidemiology and Environmental Health Sciences, University of California, Los Angeles, U.S.A.
Paulo H. N. Saldiva, Director, Institute of Advanced Studies, University of São Paulo, São Paulo, Brazil.
Jonathan Samet, Dean, Colorado School of Public Health, Aurora, U.S.A.
Tamara Schikowski, Head of Research Group "Environmental epidemiology of lung, brain and skin aging", IUF — Leibniz Research Institute for Environmental Medicine, Düsseldorf, Germany.
Alexandra Schneider, Head of Research Group "Environmental Risks", Institute of Epidemiology, Helmholtz Zentrum München — German Research Center for Environmental Health, Neuherberg, Germany.
Kirk R. Smith, Professor of Global Environmental Health, University of California, Berkeley, U.S.A. and Director, Collaborative Clean Air Policy Centre, Delhi, India.
Claudia Traidl-Hoffmann, Chair and Institute of Environmental Medicine, UNIKA-T, Technical University of Munich and Helmholtz Zentrum München — German Research Center for Environmental Health, Augsburg, Germany.
Alfred Wiedensohler, Head of Department for Experimental Aerosol and Cloud Microphysics, Leibniz Institute for Tropospheric Research, Leipzig, Germany.
Caradee Wright, Specialist Scientist, South African Medical Research Council (SAMRC), Parktown, South Africa.

Invited External Experts

David Richard Boyd, United Nations Special Rapporteur on Human Rights and the Environment, Office of the United Nations High Commissioner for Human Rights (OHCHR), Geneva, Switzerland.
Valentin Foltescu, Senior Science and Programme Officer, Climate and Clean Air Coalition Secretariat, United Nations Environment, New Delhi, India.
Richard Fuller, Lancet Commission on Pollution and Health Co-Chair, Pure Earth and Global Alliance on Health and Pollution, New York, U.S.A.
Dorota Jarosińska, Programme Manager, World Health Organization, European Centre for Environment and Health, Bonn, Germany.
Jacqueline Myriam McGlade Former Chief Scientist, United Nations Environment, Nairobi, Kenya.
Drew Shindell, Duke University Durham, NC, U.S.A. and Chair of the Scientific Advisory Panel, Climate and Clean Air Coalition, Paris, France.

Secretariat

Marcos Cortesao Barnsley Scheuenstuhl, Executive Director of International Affairs, Brazilian Academy of Sciences (ABC), Rio de Janeiro, Brazil.
John P. Boright, Director of International Affairs, U.S. National Academy of Sciences (NAS), Washington, DC, U.S.A.
Siyavuya Bulani, Senior Liaison Officer, Academy of Science of South Africa (ASSAf), Pretoria, South Africa.
Margaret Hamburg, Foreign Secretary, U.S. National Academy of Medicine (NAM), Washington, DC, U.S.A.
Kathrin Happe, Deputy Head of Department of Science — Policy — Society, German National Academy of Sciences Leopoldina, Halle (Saale), Germany.
Jan Nissen, Senior Officer, Department of International Relations, German National Academy of Sciences Leopoldina, Halle (Saale), Germany.
Isabel Scheer, Assistant, Department of International Relations, German National Academy of Sciences Leopoldina, Halle (Saale), Germany.

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Competing Interests

The authors have no competing interests to declare.

Further Readings

Integrated Assessments

1. **European Environment Agency.** Air Quality in Europe — 2018. *EEA Report*. DOI: https://doi.org/10.2800/777411
2. **International Energy Agency.** Energy and Air Pollution. *World Energy Outlook Special Report*. Paris; 2016. https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlookSpecialReport2016EnergyandAirPollution.pdf (accessed 21 Nov 2018).
3. **Landrigan PJ, Fuller R, Acosta NJR,** et al. The Lancet Commission on pollution and health. *The Lancet*. 2018; 391: 462–512. DOI: https://doi.org/10.1016/S0140-6736(17)32345-0
4. **United Nations Environment Programme.** Healthy Environment, Healthy People. Thematic Report, Ministerial Policy Review Session. 2016 UNEA 2 Inf. Doc 5. https://wedocs.unep.org/bitstream/handle/20.500.11822/17602/K1602727%20INF%205%20Eng.pdf?sequence=1&isAllowed=y (accessed 10 May 2019).
5. **World Health Organization.** Burden of disease from the joint effects of household and ambient Air pollution for 2016. Geneva; 2018. https://www.who.int/airpollution/data/AP_joint_effect_BoD_results_May2018.pdf (accessed 9 Nov 2018).

Health Effects

6. **Atkinson RW, Kang S, Anderson HR,** et al. Epidemiological time series studies of $PM_{2.5}$ and daily mortality and hospital admissions: A

systematic review and meta-analysis. *Thorax*. 2014; 69: 660–5. DOI: https://doi.org/10.1136/thoraxjnl-2013-204492

7. **Balakrishnan K, Dey S, Gupta T,** et al. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The Global Burden of Disease Study 2017. *The Lancet Planetary Health*. 2019; 3: e26–39. DOI: https://doi.org/10.1016/S2542-5196(18)30261-4
8. **Bowe B, Xie Y, Li T,** et al. The 2016 global and national burden of diabetes mellitus attributable to $PM_{2.5}$ air pollution. *The Lancet Planetary Health*. 2018; 2: e301–12. DOI: https://doi.org/10.1016/S2542-5196(18)30140-2
9. **Brook RD, Rajagopalan S, Pope CA,** et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation*. 2010; 121: 2331–78. DOI: https://doi.org/10.1161/CIR.0b013e3181dbece1
10. **Burke KE.** Mechanisms of aging and development — A new understanding of environmental damage to the skin and prevention with topical antioxidants. *Mechanisms of Ageing and Development*. 2018; 172: 123–30. DOI: https://doi.org/10.1016/j.mad.2017.12.003
11. **Calderón-Garcidueñas L, Calderón-Garcidueñas A, Torres-Jardón R,** et al. Air pollution and your brain: What do you need to know right now. *Primary Health Care Research & Development*. 2015; 16: 329–45. DOI: https://doi.org/10.1017/S146342361400036X
12. **Chen H, Kwong JC, Copes R,** et al. Exposure to ambient air pollution and the incidence of dementia: A population-based cohort study. *Environment International*. 2017; 108: 271–7. DOI: https://doi.org/10.1016/j.envint.2017.08.020
13. **Cohen AJ, Brauer M, Burnett R,** et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. *The Lancet*. 2017; 389: 1907–18. DOI: https://doi.org/10.1016/S0140-6736(17)30505-6
14. **Contreras ZA, Heck JE, Lee PC,** et al. Prenatal air pollution exposure, smoking, and uterine vascular resistance. *Environ Epidemiol*. 2018; 2. DOI: https://doi.org/10.1097/EE9.0000000000000017
15. **Dadvand P, Figueras F, Basagaña X,** et al. Ambient Air Pollution and Preeclampsia: A Spatiotemporal Analysis. *Environ Health Perspect*. 2013; 121: 1365–71. DOI: https://doi.org/10.1289/ehp.1206430
16. **Dimakakou E, Johnston H, Streftaris G,** et al. Exposure to Environmental and Occupational Particulate Air Pollution as a Potential Contributor to Neurodegeneration and Diabetes: A Systematic Review of Epidemiological Research. *International Journal of Environmental Research and Public Health*. 2018; 15: 1704. DOI: https://doi.org/10.3390/ijerph15081704
17. **Ding A, Yang Y, Zhao Z,** et al. Indoor $PM_{2.5}$ exposure affects skin aging manifestation in a Chinese population. *Sci Rep*. 2017; 7: 15329. DOI: https://doi.org/10.1038/s41598-017-15295-8
18. **Di Q, Wang Y, Zanobetti A,** et al. Air Pollution and Mortality in the Medicare Population. *New England Journal of Medicine*. 2017; 376: 2513–22. DOI: https://doi.org/10.1056/NEJMoa1702747
19. **Eze IC, Hemkens LG, Bucher HC,** et al. Association between Ambient Air Pollution and Diabetes Mellitus in Europe and North America: Systematic Review and Meta-Analysis. *Environ Health Perspect*. 2015; 123: 381–9. DOI: https://doi.org/10.1289/ehp.1307823
20. **Gauderman WJ, Urman R, Avol E,** et al. Association of Improved Air Quality with Lung Development in Children. *New England Journal of Medicine*. 2015; 372: 905–913. DOI: https://doi.org/10.1056/NEJMoa1414123
21. **Guxens M, Garcia-Esteban R, Giorgis-Allemand L,** et al. Air Pollution During Pregnancy and Childhood Cognitive and Psychomotor Development. *Epidemiology*. 2014; 25: 636–47. DOI: https://doi.org/10.1097/EDE.0000000000000133
22. **Health Effects Institute.** State of Global Air 2019. Boston, MA. https://www.stateofglobalair.org/ (accessed 18 Apr 2019).
23. **Hoek G, Krishnan RM, Beelen R,** et al. Long-term air pollution exposure and cardio-respiratory mortality: a review. *Environmental Health*. 2013; 12: 43. DOI: https://doi.org/10.1186/1476-069X-12-43
24. **International Agency for Research on Cancer (IARC).** Outdoor air pollution; 2016. http://www.ncbi.nlm.nih.gov/books/NBK368024/ (accessed 5 Oct 2018).
25. **Kaufman JD, Adar SD, Barr RG,** et al. Association between air pollution and coronary artery calcification within six metropolitan areas in the U.S.A. (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. *The Lancet*. 2016; 388: 696–704. DOI: https://doi.org/10.1016/S0140-6736(16)00378-0
26. **Kirrane EF, Bowman C, Davis JA,** et al. Associations of ozone and $PM_{2.5}$ concentrations with Parkinson's disease among participants in the Agricultural Health Study. *J Occup Environ Med*. 2015; 57: 509–17. DOI: https://doi.org/10.1097/JOM.0000000000000451
27. **Krutmann J, Bouloc A, Sore G,** et al. The skin aging exposome. *Journal of Dermatological Science*. 2017; 85: 152–61. DOI: https://doi.org/10.1016/j.jdermsci.2016.09.015
28. **Landrigan PJ.** Air pollution and health. *The Lancet Public Health*. 2017; 2: e4–5. DOI: https://doi.org/10.1016/S2468-2667(16)30023-8
29. **Lee P-C, Liu L-L, Sun Y,** et al. Traffic-related air pollution increased the risk of Parkinson's disease in Taiwan: A nationwide study. *Environment International*. 2016; 96: 75–81. DOI: https://doi.org/10.1016/j.envint.2016.08.017

30. **Leiser CL, Hanson HA, Sawyer K,** et al. Acute effects of air pollutants on spontaneous pregnancy loss: a case-crossover study. *Fertility and Sterility*. 2019; 111(2): 341–347. DOI: https://doi.org/10.1016/j.fertnstert.2018.10.028
31. **Lelieveld J, Evans JS, Fnais M,** et al. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*. 2015; 525: 367–71. DOI: https://doi.org/10.1038/nature15371
32. **Li T, Zhang Y, Wang J,** et al. All-cause mortality risk associated with long-term exposure to ambient $PM_{2.5}$ in China: a cohort study. *The Lancet Public Health*. 2018; 3: e470–7. DOI: https://doi.org/10.1016/S2468-2667(18)30144-0
33. **Malley CS, Kuylenstierna JCI, Vallack HW,** et al. Preterm birth associated with maternal fine particulate matter exposure: A global, regional and national assessment. *Environment International*. 2017; 101: 173–82. DOI: https://doi.org/10.1016/j.envint.2017.01.023
34. **McConnell R, Berhane K, Gilliland F,** et al. Prospective study of air pollution and bronchitic symptoms in children with asthma. *Am J Respir Crit Care Med*. 2003; 168: 790–7. DOI: https://doi.org/10.1164/rccm.200304-466OC
35. **Newby DE, Mannucci PM, Tell GS,** et al. Expert position paper on air pollution and cardiovascular disease. *Eur Heart J*. 2015; 36: 83–93. DOI: https://doi.org/10.1093/eurheartj/ehu458
36. **Ngoc L, Park D, Lee Y,** et al. Systematic Review and Meta-Analysis of Human Skin Diseases Due to Particulate Matter. *International Journal of Environmental Research and Public Health*. 2017; 14: 1458. DOI: https://doi.org/10.3390/ijerph14121458
37. **Paul KC, Haan M, Mayeda ER,** et al. Ambient Air Pollution, Noise, and Late-Life Cognitive Decline and Dementia Risk. *Annual Review of Public Health*. 2019; 40: 203–20. DOI: https://doi.org/10.1146/annurev-publhealth-040218-044058
38. **Pedersen M, Giorgis-Allemand L, Bernard C,** et al. Ambient air pollution and low birthweight: a European cohort study (ESCAPE). *The Lancet Respiratory Medicine*. 2013; 1: 695–704. DOI: https://doi.org/10.1016/S2213-2600(13)70192-9
39. **Pedersen M, Stayner L, Slama R,** et al. Ambient air pollution and pregnancy-induced hypertensive disorders: A systematic review and meta-analysis. *Hypertension*. 2014; 64: 494–500. DOI: https://doi.org/10.1161/HYPERTENSIONAHA.114.03545
40. **Pope III CA** and **Dockery DW.** Health Effects of Fine Particulate Air Pollution: Lines that Connect. *Journal of the Air & Waste Management Association*. 2006; 56: 709–42. DOI: https://doi.org/10.1080/10473289.2006.10464485
41. **Power MC, Adar SD, Yanosky JD,** et al. Exposure to air pollution as a potential contributor to cognitive function, cognitive decline, brain imaging, and dementia: A systematic review of epidemiologic research. *NeuroToxicology*. 2016; 56: 235–53. DOI: https://doi.org/10.1016/j.neuro.2016.06.004
42. **Puri P, Nandar SK, Kathuria S,** et al. Effects of air pollution on the skin: A review. *Indian Journal of Dermatology, Venereology, and Leprology*. 2017; 83: 415. DOI: https://doi.org/10.4103/0378-6323.199579
43. **Lee KK, Miller MR** and **Shah ASV.** Air Pollution and Stroke. *Journal of Stroke*. 2018; 20: 2–11. DOI: https://doi.org/10.5853/jos.2017.02894
44. **Raaschou-Nielsen O, Andersen ZJ, Beelen R,** et al. Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). *The Lancet Oncology*. 2013; 14: 813–22. DOI: https://doi.org/10.1016/S1470-2045(13)70279-1
45. **World Health Organization.** Resolution WHA68.8: Health and the environment: Addressing the health impact of air pollution. *World Health Organization*; 2015. http://apps.who.int/gb/ebwha/pdf_files/wha68/a68_r8-en.pdf (accessed 8 Nov 2018).
46. **Ritz B, Lee P-C, Hansen J,** et al. Traffic-Related Air Pollution and Parkinson's Disease in Denmark: A Case-Control Study. *Environ Health Perspect*. 2016; 124: 351–6. DOI: https://doi.org/10.1289/ehp.1409313
47. **Ritz B, Liew Z, Yan Q,** et al. Air pollution and autism in Denmark. *Environmental Epidemiology*. 2018; 2: e028. DOI: https://doi.org/10.1097/EE9.0000000000000028
48. **Rückerl R, Schneider A, Breitner S,** et al. Health effects of particulate air pollution: A review of epidemiological evidence. *Inhalation Toxicology*. 2011; 23: 555–92. DOI: https://doi.org/10.3109/08958378.2011.593587
49. **Samoli E, Stergiopoulou A, Santana P,** et al. Spatial variability in air pollution exposure in relation to socioeconomic indicators in nine European metropolitan areas: A study on environmental inequality. *Environmental Pollution*. 2019; 249: 345–53. DOI: https://doi.org/10.1016/j.envpol.2019.03.050
50. **Shah ASV, Lee KK, McAllister DA,** et al. Short term exposure to air pollution and stroke: Systematic review and meta-analysis. *BMJ*. 2015; 350: h1295. DOI: https://doi.org/10.1136/bmj.h1295
51. **Shindell D, Faluvegi G, Seltzer K,** et al. Quantified, localized health benefits of accelerated carbon dioxide emissions reductions. *Nature Climate Change*. 2018; 8: 291–5. DOI: https://doi.org/10.1038/s41558-018-0108-y
52. **Shiraiwa M, Ueda K, Pozzer A,** et al. Aerosol Health Effects from Molecular to Global Scales. *Environ Sci Technol*. 2017; 51: 13545–67. DOI: https://doi.org/10.1021/acs.est.7b04417
53. **Stanek LW, Brown JS, Stanek J,** et al. Air Pollution Toxicology—A Brief Review of the Role of the Science in Shaping the Current Understanding of Air Pollution Health Risks. *Toxicol Sci*. 2011; 120: S8–27. DOI: https://doi.org/10.1093/toxsci/kfq367
54. **Stieb DM, Chen L, Eshoul M,** et al. Ambient air pollution, birth weight and preterm birth: A systematic review and meta-analysis. *Environmental Research*.

2012; 117: 100–11. DOI: https://doi.org/10.1016/j.envres.2012.05.007
55. **Suades-González E, Gascon M, Guxens M,** et al. Air Pollution and Neuropsychological Development: A Review of the Latest Evidence. *Endocrinology*. 2015; 156: 3473–82. DOI: https://doi.org/10.1210/en.2015-1403
56. **Taylor C, Golding J** and **Emond A.** Adverse effects of maternal lead levels on birth outcomes in the ALSPAC study: a prospective birth cohort study. *BJOG*. 2015; 122: 322–8. DOI: https://doi.org/10.1111/1471-0528.12756
57. **Thurston GD, Kipen H, Annesi-Maesano I,** et al. A joint ERS/ATS policy statement: What constitutes an adverse health effect of air pollution? An analytical framework. *Eur Respir J*. 2017; 49. DOI: https://doi.org/10.1183/13993003.00419-2016
58. **Vrijheid M, Casas M, Gascon M,** et al. Environmental pollutants and child health — A review of recent concerns. *International Journal of Hygiene and Environmental Health*. 2016; 219: 331–42. DOI: https://doi.org/10.1016/j.ijheh.2016.05.001
59. **Wang B, Xu D, Jing Z,** et al. Mechanisms in endocrinology: Effect of long-term exposure to air pollution on type 2 diabetes mellitus risk: a systemic review and meta-analysis of cohort studies. *European Journal of Endocrinology*. 2014; 171: R173–82. DOI: https://doi.org/10.1530/EJE-14-0365
60. **World Health Organization.** Fact sheet on household air pollution and health. 2018. https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health (accessed 18 Feb 2019).
61. **World Health Organization.** Fact sheet on ambient (outdoor) air quality and health. 2018. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (accessed 18 Feb 2019).
62. **Wu J, Ren C, Delfino RJ,** et al. Association between Local Traffic-Generated Air Pollution and Preeclampsia and Preterm Delivery in the South Coast Air Basin of California. *Environ Health Perspect*. 2009; 117: 1773–9. DOI: https://doi.org/10.1289/ehp.0800334
63. **Wu J, Laurent O, Li L**, et al. Adverse Reproductive Health Outcomes and Exposure to Gaseous and Particulate-Matter Air Pollution in Pregnant Women. *Research on Reproductive Health Effects Inst*. 2016; 1–58.

Emissions of Air Pollutants

64. **Apte JS, Messier KP, Gani S,** et al. High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data. *Environ Sci Technol*. 2017; 51: 6999–7008. DOI: https://doi.org/10.1021/acs.est.7b00891
65. **Beekmann M, Prévôt ASH, Drewnick J,** et al. In situ, satellite measurement and model evidence on the dominant regional contribution to fine particulate matter levels in the Paris megacity. *Atmospheric Chemistry and Physics*. 2015; 15: 9577–9591. DOI: https://doi.org/10.5194/acp-15-9577-2015
66. **Beelen R, Raaschou-Nielsen O, Stafoggia M,** et al. Effects of long-term exposure to air pollution on natural-cause mortality: An analysis of 22 European cohorts within the multicentre ESCAPE project. *The Lancet*. 2014; 383: 785–795. DOI: https://doi.org/10.1016/S0140-6736(13)62158-3
67. **Belis CA, Karagulian F, Larsen BR** and **Hopke PK.** Critical review and meta-analysis of ambient particulate matter source apportionment using receptor models in Europe. *Atmospheric Environment*. 2013; 69: 94–108. DOI: https://doi.org/10.1016/j.atmosenv.2012.11.009
68. **Bond TC, Bhardwaj E, Dong R,** et al. Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850–2000. *Global Biogeochemical Cycles*. 2007; 21. DOI: https://doi.org/10.1029/2006GB002840
69. **Braspenning Radu O, van den Berg M, Klimont Z,** et al. Exploring synergies between climate and air quality policies using long-term global and regional emission scenarios. *Atmospheric Environment*. 2016; 140: 577–91. DOI: https://doi.org/10.1016/j.atmosenv.2016.05.021
70. **Brook RD, Rajagopalan S, Pope CA 3rd,** et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation*. 2010; 121: 2331–2378. DOI: https://doi.org/10.1161/CIR.0b013e3181dbece1
71. **Brown JS.** Nitrogen dioxide exposure and airway responsiveness in individuals with asthma. *Inhalation Toxicology*. 2015; 27: 1–14. DOI: https://doi.org/10.3109/08958378.2014.979960
72. **Burnett R, Chen H, Szyszkowicz M,** et al. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *PNAS*. 2018; 115: 9592–9597. DOI: https://doi.org/10.1073/pnas.1803222115
73. **Butt EW, Rap A, Schmidt A,** et al. The impact of residential combustion emissions on atmospheric aerosol, human health, and climate. *Atmospheric Chemistry and Physics*. 2016; 16: 873–905. DOI: https://doi.org/10.5194/acp-16-873-2016
74. **Cesaroni G, Forastiere F, Stafoggia M,** et al. Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE Project. *BMJ*. 2014; 348: f7412. DOI: https://doi.org/10.1136/bmj.f7412
75. **Clifford A, Lang L, Chen R,** et al. Exposure to air pollution and cognitive functioning across the life course — A systematic literature review. *Environmental Research*. 2016; 147: 383–398. DOI: https://doi.org/10.1016/j.envres.2016.01.018
76. **Chen H, Huang Y, Shen H,** et al. Modeling temporal variations in global residential energy consumption

and pollutant emissions. *Applied Energy*. 2016; 184: 820–9. DOI: https://doi.org/10.1016/j.apenergy.2015.10.185

77. **Dave P, Bhushan M** and **Venkataraman C.** Aerosols cause intraseasonal short-term suppression of Indian monsoon rainfall. *Scientific Reports*. 2017; 7: 17347. DOI: https://doi.org/10.1038/s41598-017-17599-1
78. **Dawn Alas H, Müller T** and **Birmili W.** Spatial Characterization of Black Carbon Mass Concentration in the Atmosphere of a Southeast Asian Megacity: An Air Quality Case Study for Metro Manila, Philippines. *Aerosol and Air Quality Research*. 2018; 18: 2301–2317. DOI: https://doi.org/10.4209/aaqr.2017.08.0281
79. **Franklin BA, Brook R** and **Pope CA 3rd.** Air pollution and cardiovascular disease. *Current Problems in Cardiology*. 2015; 40: 207–38. DOI: https://doi.org/10.1016/j.cpcardiol.2015.01.003
80. **Gallardo L, Escribano J, Dawidowski L,** et al. Evaluation of vehicle emission inventories for carbon monoxide and nitrogen oxides for Bogotá, Buenos Aires, Santiago, and São Paulo. *Atmospheric Environment*. 2012; 47: 12–9. DOI: https://doi.org/10.1016/j.atmosenv.2011.11.051
81. **Gidden MJ, Riahi K, Smith SJ,** et al. Global emissions pathways under different socioeconomic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century. *Geoscientific Model Development*. 2019; 12: 1443–75. DOI: https://doi.org/10.5194/gmd-12-1443-2019
82. **Hassler B, McDonald BC, Frost GJ,** et al. Analysis of long-term observations of NOX and CO in megacities and application to constraining emissions inventories. *Geophysical Research Letters*. 2016; 43: 9920–30. DOI: https://doi.org/10.1002/2016GL069894
83. **Huang Y, Shen H, Chen Y,** et al. Global organic carbon emissions from primary sources from 1960 to 2009. *Atmospheric Environment*. 2015; 122: 505–512 DOI: https://doi.org/10.1016/j.atmosenv.2015.10.017
84. **Ibarra-Espinosa S, Ynoue R, O'Sullivan S,** et al. VEIN v0.2.2: An R package for bottom-up vehicular emissions inventories. *Geoscientific Model Development*. 2018; 11: 2209–2229. DOI: https://doi.org/10.5194/gmd-11-2209-2018
85. **Janssens-Maehout G, Crippa M** and **Guizarddi D,** et al. HTAP_v2.2: A mosaic of regional and global emission grid maps for 2008 and 2010 to study hemispheric transport of air pollution. *Atmospheric Chemistry and Physics*. 2015; 15: 11411–11432. DOI: https://doi.org/10.5194/acp-15-11411-2015
86. **Jimenez JL, Canagaratna MR, Donahue NM,** et al. Evolution of organic aerosols in the atmosphere. *Science*. 2009; 326: 1525–1529. DOI: https://doi.org/10.1126/science.1180353
87. **Klimont Z, Kupainen K, Heyes C,** et al. Global anthropogenic emissions of particulate matter including black carbon. *Atmospheric Chemistry and Physics*. 2017; 17: 8681–8723. DOI: https://doi.org/10.5194/acp-17-8681-2017
88. **Lamarque JF, Bond TC, Eyring V,** et al. Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: Methodology and application. *Atmospheric Chemistry and Physics*. 2010; 10: 7017–7039. DOI: https://doi.org/10.5194/acp-10-7017-2010
89. **Liu J, Mauzerall DL, Chen Q,** et al. Air pollutant emissions from Chinese households: A major and underappreciated ambient pollution source. *Proceedings of the National Academy of Sciences*. 2016; 113: 7756–7761. DOI: https://doi.org/10.1073/pnas.1604537113
90. **Madrazo J, Clappier A, Belalcazar LC,** et al. Screening differences between a local inventory and the Emissions Database for Global Atmospheric Research (EDGAR). *Science of The Total Environment*. 2018; 631–632: 934–941. DOI: https://doi.org/10.1016/j.scitotenv.2018.03.094
91. **van der Werf GR, Randerson, JT, Giglio L,** et al. Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmospheric Chemistry and Physics*. 2010; 10: 11707–11735. DOI: https://doi.org/10.5194/acp-10-11707-2010
92. **van Donkelaar A, Martin RV, Brauer M,** et al. Global Estimates of Fine Particulate Matter using a Combined Geophysical-Statistical Method with Information from Satellites, Models, and Monitors. *Environmental Science and Technology*. 2016; 50: 3762–3772. DOI: https://doi.org/10.1021/acs.est.5b05833

Economic Costs and Benefits

93. **Amann M, Holland M, Maas R,** et al. Costs, benefits and economic impacts of the EU clean air strategy and their implications on innovation and competitiveness. *IIASA report*. Laxenburg; 2017. http://ec.europa.eu/environment/air/pdf/clean_air_outlook_economic_impact_report.pdf (accessed 10 May 2019).
94. **Roy R** and **Braathen NA.** The Rising Cost of Ambient Air Pollution thus far in the 21st Century — Results from the BRIICS and the OECD Countries. *OECD Environment Working Papers*; 2017. DOI: https://doi.org/10.1787/d1b2b844-en
95. **US Environmental Protection Agency Office of Air and Radiation.** The Benefits and Costs of the Clean Air Act from 1990 to 2020 — Summary Report. 2011. https://www.epa.gov/sites/production/files/2015-07/documents/summaryreport.pdf (accessed 16 Nov 2018).
96. **The World Bank.** The cost of air pollution: strengthening the economic case for action. *The World Bank*; 2016. http://documents.worldbank.org/curated/en/781521473177013155/pdf/108141-REVISED-Cost-of-PollutionWebCORRECTEDfile.pdf (accessed 10 May 2019).
97. **World Health Organization.** Health risks of air pollution in Europe — HRAPIE project.

Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide. *WHO Regional Office for Europe*. Copenhagen; 2013. http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_project.pdf (accessed 10 May 2019).

Policies and Actions

98. **Boyd DR.** Report of the Special Rapporteur on human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment. *Human Rights Council*; 2019. https://undocs.org/A/HRC/40/55 (accessed 28 May 2019).
99. **DeShazo J, Sheldon TL** and **Carson RT.** Designing policy incentives for cleaner technologies: Lessons from California's plug-in electric vehicle rebate program. *Journal of Environmental Economics Management*. 2017; 84: 18–43. DOI: https://doi.org/10.1016/j.jeem.2017.01.002
100. **Figueres C, Landrigan PJ** and **Fuller R.** Tackling air pollution, climate change, and NCDs: Time to pull together. *The Lancet*. 2018; 392: 1502–3. DOI: https://doi.org/10.1016/S0140-6736(18)32740-5
101. **Fuller R, Rahona E, Fisher S,** et al. Pollution and non-communicable disease: time to end the neglect. *The Lancet Planetary Health*. 2018; 2(3): e96–8. DOI: https://doi.org/10.1016/S2542-5196(18)30020-2
102. **Haines A** and **Landrigan PJ.** It's time to consider pollution in NCD prevention. *The Lancet*. 2018; 392: 1625–6. DOI: https://doi.org/10.1016/S0140-6736(18)32200-1
103. **Kutlar Joss M, Eeftens M, Gintowt E,** et al. Time to harmonize national ambient air quality standards. *International Journal of Public Health*. 2017; 62: 453–462. DOI: https://doi.org/10.1007/s00038-017-0952-y
104. **Samet JM** and **Gruskin S.** Air pollution, health, and human rights. *The Lancet Respiratory Medicine*. 2015; 3: 98–100. DOI: https://doi.org/10.1016/S2213-2600(14)70145-6
105. **United Nations Environment Programme.** Ministerial declaration of the United Nations Environment Assembly at its third session: Towards a pollution-free planet. UNEP/EA.3/L.19; 2017. https://papersmart.unon.org/resolution/ministerial-declaration (accessed 28 May 2019).
106. **Watts N, Amann M, Ayeb-Karlsson S,** et al. The Lancet Countdown on health and climate change: From 25 years of inaction to a global transformation for public health. *The Lancet*. 2018; 391: 581–630. DOI: https://doi.org/10.1016/S0140-6736(17)32464-9
107. **World Bank Group.** Independent Evaluation Group. Toward a clean world for all: An IEG evaluation of the World Bank Group's support for pollution management. Washington, DC: World Bank; 2017. http://ieg.worldbankgroup.org/evaluations/pollution (accessed 10 May 2019).
108. **World Health Organization.** Global action plan for the prevention and control of noncommunicable diseases 2013–2020. Geneva; 2013. https://www.who.int/nmh/events/ncd_action_plan/en/ (accessed 10 May 2019).
109. **World Health Organization.** Resolution WHA68.8: Health and the environment: Addressing the health impact of air pollution. Geneva; 2015. http://apps.who.int/gb/ebwha/pdf_files/wha68/a68_r8-en.pdf (accessed 8 Nov 2018).
110. **World Health Organization.** Air pollution and child health: prescribing clean air. Geneva; 2018. http://www.who.int/ceh/publications/air-pollution-child-health/en/ (accessed 31 Oct 2018).
111. **World Health Organization.** Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. *WHO Regional Office for Europe*. Copenhagen; 2006. http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide (accessed 10 May 2019).
112. **World Health Organization.** Review of evidence on health aspects of air pollution — REVIHAAP. *Technical Report. WHO Regional Office for Europe*. Copenhagen; 2013. http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf?ua=1 (accessed 28 May 2019).

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