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Urban outdoor air quality

Overview

- Air pollution is the greatest UK environmental public health threat. It is responsible for 29,000-43,000 UK deaths annually (based on 2019 data) and multiple health effects. Between 2017 and 2025, the total estimated NHS and social care cost will be at least £1.6 billion in England.
- Particulate matter (PM), nitrogen dioxide (NO_2) and ozone (O_3) are the air pollutants of most human health concern in urban areas. No safe lower limit has been identified for these pollutants, which disproportionately affect vulnerable groups.
- In UK urban areas, average PM and NO_2 concentrations are decreasing over time while O_3 shows a slight increasing trend. However, some urban areas exceed the World Health Organization's Global Air Quality guidelines for PM and NO_2.
- The Government is setting two targets for reducing $PM_{2.5}$ to be met by 2040 including an annual mean concentration limit of 10 µg/m^3. Modelling suggests that most of England will be compliant with this by 2030.

Background

The impacts of air pollution were highlighted by the 2013 case of Ella Adoo-Kissi-Debrah, in which high levels caused a severe fatal asthma attack. Ella is the first person in the UK to have air pollution listed as an associated cause of death following the 2020 inquest, which highlighted several organisations with responsibility for action on air pollution.[1]

Air quality has been the subject of infringement proceedings by the European Commission against the UK and court cases brought against the Government by the environmental law charity ClientEarth.[2,3]

The Chief Medical Officer's 2022 Annual Report focused on air pollution, stating that "we can and should go further to reduce air pollution".[4]

Across the UK, concentrations of key air pollutants are uneven. Urban areas typically have poorer air quality,[5] particularly deprived neighbourhoods.[6,7]

Key pollutants

Particulate matter (PM)

PM is the broad term for microscopic particles suspended in air originating from a range of human-made and natural sources. PM is classified by size range, named according to upper-limit diameter in micrometres, and comprises coarse particles ($PM_{10-2.5}$), fine particles ($PM_{2.5}$) and ultrafine particles ($PM_{0.1}$).

PM is emitted directly through combustion or friction (such as braking) or formed through atmospheric chemical reactions between air pollutants (secondary PM, estimated to comprise 60% of urban background $PM_{2.5}$).[8] Ultrafine particles dominate the total number of particles (typically >90%)[9,10] but represent a relatively small proportion by mass.[9] PM composition varies by source, but the major components include metals, black and organic carbon, sulphate, nitrate, ammonium and sea salt.[11,12]

The main UK human-made PM_{10} emission sources (as a percentage of 2020 total PM_{10} emissions) are:[13]

- Industrial processing and solvent use (34%);
- Combustion in manufacturing and construction (16%);
- Domestic combustion (residential burning of fuels, e.g., wood burners,[4] 15%); and
- Road transport (12%).

The main UK human-made $PM_{2.5}$ emission sources (as a percentage of 2020 total $PM_{2.5}$ emissions) are:[13]

- Combustion in manufacturing and construction (27%);

- Domestic combustion (25%, of which 70% is from wood burning);
- Industrial processing and solvent use (14%); and
- Road transport (13%).

Combustion is the major $PM_{0.1}$ emission source, particularly residential wood burning and transport (road, air and shipping).[9]

Precursors of secondary PM include sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and non-methane volatile organic compounds (NMVOCs). SO_2 comes from coal and fuel oil combustion, but UK emission levels have fallen by 95% since 1990,[14] largely through replacement of coal-fired power stations.[15] NH_3 emissions mainly come from agricultural sources, particularly fertiliser use and livestock manures.[16,17] Most NMVOCs now originate from solvent and chemical use in industry and domestic products (previously vehicles).[18]

While PM_{10} generally remains airborne for hours to days, $PM_{2.5}$ can stay airborne for weeks and be transported long distances.[19] 21-30% of $PM_{2.5}$ is estimated to originate from non-UK sources (transboundary pollution), particularly continental Europe during Spring.[8,20†] Due to regional PM transport, rural $PM_{2.5}$ is estimated to account for 60-80% of background $PM_{2.5}$ concentrations in major urban areas of southern England.[8]

Nitrogen dioxide (NO_2)

NO_2 is one of a group of gases called nitrogen oxides (NO_x) but is the most harmful for human health. Nitric (NO) emissions produced from fossil fuel combustion react atmospherically to produce NO_2, which is also directly emitted.

The biggest UK sources of primary NO_x emissions are:

- Road transport (28%);
- Manufacturing industries and construction (21%);
- Energy industries (20%); and
- Non-road transport (13%).

NO_x has a short atmospheric lifespan of hours,[22] and is a precursor to ozone formation.[23]

Ozone (O_3)

O_3 gas is not directly emitted but formed in the air. Ground level (tropospheric) O_3 can be formed by photochemical reactions (driven by sunlight) of NO_x and NMVOCs

[†] In 2018, 3.1 μg/m^3 of the UK's population-weighted mean concentration (PWMC) of $PM_{2.5}$ came from natural sources, 1.3 μg/m^3 from Europe and 0.63 μg/m^3 from international shipping.[21]

from various natural and human-made sources. O_3 formation is heavily influenced by levels of sunlight; its concentrations commonly build up during hot summer days.

O_3 often forms at large distances from precursor emission sources, lasts for a few weeks in the atmosphere and can travel long distances (with ~45% of O_3 estimated to come from non-UK precursor emissions).[24] O_3 and NO can react chemically, reducing levels in urban areas with high NO_x concentrations,[25] so O_3 concentrations are typically higher in rural areas.

Health impacts of key air pollutants

Associated health conditions

PM, NO_2 and O_3 have legal limit values (see Air Quality legislation), but low concentrations can have health impacts[26] and no levels safe for human health have been identified.[27] Different pollutants are often emitted together and mix in the air, creating challenges in attributing health effects to individual pollutants.

$PM_{2.5}$ is the PM fraction widely considered of most human health concern as the particles are small enough to travel deep into the lungs.[28] Studies are limited but available evidence suggests that the $PM_{0.1}$ subset may be more harmful as these are retained longer in the lungs[29] and have higher surface area per unit of mass than $PM_{2.5}$.[30,31]

Evidence suggests that black carbon PM (BC, PN 480), produced through fossil fuel combustion, may be more closely associated with adverse health effects than $PM_{2.5}$ generally.[32,33] Recent work confirmed that BC crosses the placenta into the human fetus.[34] However, health effects are difficult to attribute to BC and other PM chemical components individually due to lack of human exposure data.

Air pollution is linked to loss of life expectancy and various acute and chronic effects that disproportionately affect certain groups (Box 1). The health effects of air pollution have implications throughout life.[35] Short-term exposure is typically associated with acute health outcomes, such as worsening existing conditions, while long-term exposure is a contributing factor in development and progression of chronic conditions.[36]

The acute effects with strong supporting evidence include:

- Worsening of asthma and chronic obstructive pulmonary disease (COPD);[37–39]
- Coughing, wheezing and shortness of breath;[40] and
- Acute cardiovascular effects including heart attacks and strokes.[41,42]

The chronic effects with strong supporting evidence include:

- Development of cardiovascular diseases;[43,44]
- Development of lung diseases, including lung cancer;[45,46] and
- Dementia and cognitive decline.[47]

Other health outcomes have emerging evidence with causal associations yet to be established, including:

- Development of respiratory conditions such as asthma;[48–50]
- Pregnancy loss, low birth weight and other adverse birth outcomes[51–53] (currently under review by the UK advisory Committee on the Medical Effects of Air Pollutants (COMEAP));[54]
- Type II diabetes;[55]
- Infertility;[56]
- Some cancers (such as kidney, bladder);[57,58]
- Increased Covid-19 severity[59] (under review by COMEAP);[60] and
- Cognitive performance.[61,62]

Box 1: Inequalities in air quality impact

Certain groups are disproportionately affected by air pollution health impacts. Those more vulnerable include children; or people who have pre-existing medical conditions, are older or are pregnant (including their fetuses).[35] In urban areas, people from deprived neighbourhoods and those from ethnic minority backgrounds are more likely to be exposed to poor air quality where they live.[6,7,63] Socioeconomically disadvantaged people are more likely to have pre-existing medical conditions, increasing their vulnerability,[64] and are often also subjected to higher concentration levels indoors.[4]

Households in the poorest areas produce lower air pollutant emissions,[7] raising environmental justice concerns.[7,65,66] For example, an NGO analysis has suggested those living in highly polluted neighbourhoods are three times less likely to own a car.[67]

Trends in urban air quality

Past trends

UK PM_{10} and $PM_{2.5}$ concentrations have been decreasing over time at urban background and traffic sites (Box 2) but remained relatively stable between 2015 and 2019.[68]

For both PM_{10} and $PM_{2.5}$, all zones[‡] were compliant with existing annual limit values (40 µg/m^3 and 20 µg/m^3 respectively) in 2021. A number of sites exceeded the recently updated World Health Organization (WHO) targets for PM_{10} and $PM_{2.5}$ (15

[‡] The UK is divided into 43 geographical zones for assessing air quality. Maximum concentration limits for PM are defined as annual mean values.

μg/m^3 and 5 μg/m^3 respectively) and several exceeded the new Environment Act target for $PM_{2.5}$, which is to be met by 2040[69] (see Air Quality legislation).

Overall, average annual UK NO_2 concentrations have been decreasing at urban background and traffic sites since the 1990s.[70] In 2021 ten zones exceeded the annual legal limit for NO_2 (40 μg/m^3), nine of which were large urban areas. Roadside monitoring sites have significantly higher annual mean concentrations than urban and rural background sites.[70] The latest WHO guidelines recommend a maximum annual value of 10 μg/m^3 for NO_2.[71]

Annual average O_3 concentrations have shown an increasing trend since 1992 at urban background sites,[72] potentially due to NO_x emission reductions. The UK has a target value for O_3 based on a maximum daily 8-hour mean, with which all zones were compliant in 2021,[73] and a long-term objective for protection of human health with which four zones were compliant.[73]

The Office for Environmental Protection has stated that overall they "assess progress towards achievement of the six pollutant[§] limit values to be off track".[74]

Box 2: Monitoring and modelling

Monitoring sites can be near a pollutant source (traffic/roadside or industrial sites) or at locations representing background pollutant levels (background sites).

The National Atmospheric Emissions Inventory compiles estimates of primary pollutant emissions, while Defra's monitoring networks (managed by the Environment Agency) measure ambient PM, NO_2, NO, selected NMVOCs, O_3, and other air pollutant concentrations. Additional monitoring is undertaken by local authorities.[75] The Particle Numbers and Concentrations Network has three UK sites measuring $PM_{0.1}$,[9] resulting in limited data on its spatial distribution.[9] Hourly PM composition measurements are currently taken at four sites for inorganic PM and two sites for organic PM. Regulatory monitoring is supported by modelling to produce air quality forecasts, including for future policy scenarios, target setting, and concentration estimates in locations without monitoring. Defra is expanding the monitoring networks used for compliance reporting. The UK Urban NO_2 Network provides NO_2 measurements at 300 roadside sites. Investment into $PM_{2.5}$ monitoring will double the existing network by the end of 2025.[76]

The NERC OSCA supersites in London, Birmingham and Manchester collect detailed urban air pollution data (including further PM composition measurements).[77]

Low-cost sensors may be suitable for providing supplementary monitoring data on pollution exposure if standards are met,[78,79] and are being trialled in several UK locations.[80–82] Their reliability and accuracy can vary as they have yet to undergo regulatory validation.[83–85] Within research, satellite measurements are increasingly used to assess air quality, which may be useful for regulators as they are developed.[86]

[§] "The Secretary of State [for Environment, Food and Rural Affairs] must ensure that levels of sulphur dioxide, nitrogen dioxide, benzene, carbon monoxide, lead and particulate matter do not exceed the limit values set out in Schedule 2 of The Air Quality Regulations 2010"[74]

Air quality during Covid-19 restrictions

Research on air quality during lockdown measures found reductions in NO_2 concentrations and increases in O_3 concentrations at urban background and roadside locations, but mixed results for $PM_{2.5}$.[87–91] For NO_2, the average roadside concentration in 2021 increased by 8% when lockdown ended, compared to 2020.[70]

Future trends

Non-exhaust emissions (NEE)

NEE originate from tyre, brake and road wear, and road dust resuspension. As electric vehicle usage increases (Box 3), reducing exhaust emissions, NEE represents a larger proportion of road transport emissions (currently 60% of $PM_{2.5}$ and 73% of PM_{10} emissions from road transport).[92] Studies suggest some NEE components may be associated with adverse lung effects, detrimental acute and chronic cardiovascular outcomes and reduced birth weight.[93,94] However, the health implications of NEE and their relative hazard are not well-understood.

Box 3: Electric vehicles (EVs)

In 2020, the government announced that sales of new petrol and diesel cars will end by 2030 and all new cars and vans will be fully zero emission (at the tailpipe) by 2035.[95]

The increased weight of EVs compared to internal combustion engine vehicles will increase NEE, but EV technologies that reduce friction braking (regenerative braking) may lower emissions from brake wear. Potential net changes in PM emissions are affected by road type and driving mode,[92] but modelling has estimated net $PM_{2.5}$ reductions on all road types with regenerative braking use.[96] Research estimates reductions in NO_x and PM of 35.0–37.9% and 44.3–48.3% respectively on urban roads.[97] Potential NEE mitigation methods could include particle trapping before emission and/or regulation of tyre and brake pad formulations.[92]

Net Zero policies

Existing and future Net Zero policies will have implications for air quality[98] with overall improvements in air quality expected:[98–100]

- Increased uptake of active travel and EV usage would reduce transport emissions of NO_x and likely PM, but this decrease in NO_x is predicted to initially increase O_3 levels due to their chemical interactions.
- Fuel switching may have air quality implications, such as reduced NO_x emissions from heating electrification, potentially increased NO_x production as a by-product of hydrogen use (PN 645), NH_3 slippage from its use as a hydrogen carrier (PN 665), and increased PM production from biomass burning (PN 690).

Indoor air quality

People spend an estimated 80-90% of time indoors.[101] As outdoor air quality is improved, indoor air quality (PN 366) will represent a larger proportion of individuals' exposure, but indoor pollutant concentrations are less well understood.[101] Indoor air quality concerns include NMVOCs from household products and PM from solid fuel burners, cookers and boilers.[101] Some commentators call for greater consideration of people's overall exposure from outdoor and indoor sources.[102] No systematic long-term monitoring data is available for UK indoor air pollution.[4]

Air quality legislation

Air quality legislation is outlined in a House of Commons Library briefing (CBP-9600). The Air Quality Standards Regulations 2010[103] set requirements for annual reporting of ambient air quality data (Box 2) in England and set limit values (legally binding parameters that must not be exceeded) and target values (to be attained where possible) for pollutants. Responsibility for meeting limit values is devolved, with Wales, Scotland and Northern Ireland having equivalent regulations.

Scotland currently has stricter levels for PM, and the Scottish Government has committed to applying EU air pollutant standards and principles.[104] UK-wide emissions reduction commitments of some air pollutants are regulated under the National Emission Ceilings Regulations (NECR) 2018.[105]

The Environment Act 2021[106] requires the Government to introduce targets for air quality in England. The Government is setting two targets for $PM_{2.5}$ only: an annual mean concentration limit of 10 $\mu g/m^3$ and a population exposure reduction target of 35%, both to be met by 2040.

Several organisations advocate for the 10 $\mu g/m^3$ limit value to be met by 2030.[107–109] Modelling by Imperial College, UKCEH and Defra has shown that most of England will be compliant with this target by 2030.[21,110] The 10 $\mu g/m^3$ $PM_{2.5}$ target value is above WHO's latest recommendation (5 $\mu g/m^3$).

A recent Private Members' Bill proposes aligning government targets with these,[111] but the Government has stated that meeting this would be impossible in many locations due to natural and imported $PM_{2.5}$.[112]

Interventions to improve air quality

Challenges of addressing poor air quality

Key measures suggested by stakeholders to improve air quality are summarised below, focusing on England. Many local air quality measures are funded by the Government's Air quality grant scheme.[113]

Evidence demonstrating effectiveness of measures is limited, as attributing outcomes to particular interventions is difficult[114] due to confounding factors (such as weather conditions, seasonality and impacts of other interventions) and the health effects long-term.

Practical challenges with regulating air quality at a local authority level include resource limitations, lack of relevant expertise, and communication between environmental health and transport authorities.[115] The contribution of regional and international pollution allows limited control at the local level.

Policy interventions have implications across sectors, suggesting a systems approach may be required (Box 4).

Box 4: Systems approach

Considering air pollution in a wider policy context requires a joined-up approach across government,[116–118] as highlighted in the 2019 Clean Air Strategy.[119] Defra is the lead department for outdoor air quality, but works across government on the issue, including through the Defra/DfT Joint Air Quality Unit. Organisations highlight the need for coordination between the nations of the UK,[120,121] which is managed through Common Frameworks for Air Quality and Integrated Pollution and Prevention Control: Best Available Techniques.[122,123]

Air quality has implications across policy areas and vice versa, including health, environment, climate, transport, urban planning and social inequalities. These connections can represent co-benefits such as health benefits of active transport and green spaces and economic benefits of reducing the health and social burden of poor air quality.

Interventions may also cause unintended consequences in related policy areas, if not considered as a whole.[124] Methods for exploring unintended consequences include engaging stakeholders through participatory systems approaches, trialling interventions, and modelling policy scenarios.[125]

Specific interventions

Road transport

Charging schemes

Some local authorities have implemented Clean Air Zones (CAZ) to reduce NO_2 concentrations, which charge owners of vehicles not meeting minimum emissions standards. In England, CAZ have been implemented in Birmingham, Bath, Bradford, Portsmouth and Bristol; more cities plan to implement them despite controversies.[126] In 2022, Oxford launched a pilot Zero Emission Zone.[127] London's 2019 Ultra Low Emission Zone (ULEZ), expanded in 2021 and due for expansion in 2023,[128] similarly charges owners of non-compliant vehicles. This operates in conjunction with the Low Emission Zone (LEZ, CBP-7374, CDP-2021-0047), which applies to large and heavy vehicles and has reduced PM and NO_x emissions.[129]

Greater Manchester plans for a charging CAZ are under review, with local authorities now proposing a non-charging Clean Air Plan.[130] Final proposals remain to be approved by the Government. Results from the London ULEZ and the CAZ in Birmingham and Bath show improvements in recorded NO_2 levels within the intervention area, by direct analysis[131–134] and new approaches that disentangle confounding effects such as weather and Covid-19 restrictions.[135]

Some organisations raise concerns that CAZ may lead to pollutant displacement to surrounding areas,[116,136] but progress reports have identified no or minimal impact on traffic displacement.[132,133,137] The Government stated that if equally effective measures can be identified and the local authority can demonstrate that they will deliver compliance as quickly, or more quickly than a charging CAZ, those are preferred.[138]

Encouraging less polluting transport modes

Both personal and public transport are important contributors to air pollution in urban areas.

Increased uptake of less polluting transport modes may reduce air pollution, such as electric vehicles (Box 3) or active transport (walking and cycling, CBP-8615). Measures promoting active transport include expanded walking/cycling networks,[139] green spaces,[140] 15-minute cities,[141] bike share schemes[142] and reduced parking availability,[143] which all require behaviour change (Box 5).

Transport hubs also represent a potential target for interventions.[144] Low-traffic neighbourhoods (LTN) that restrict access to motor traffic passing through, and School Streets that limit traffic at pick-up and drop-off times, can be established but evidence on air quality benefits for these and other active transport measures is lacking.[145,146]

Evidence suggests that pollutant exposure overall within vehicles is higher than for active transport but that active commuters have a higher inhalation dose.[147]

Box 5: Behaviour change

Combining behavioural and policy/infrastructure-based interventions is highlighted as having the highest potential to improve air quality and public health outcomes.[148]

Recent recommendations made by the House of Lords Environment and Climate Change Committee on behaviour change for climate and environmental goals include:[149] making adoption of new technologies easier; changing consumption patterns; and, shifting travel modes. Their report stated that awareness-raising measures are insufficient and that the public wants clear leadership and a coordinated approach from Government to understand the required actions and scale of change.

Witnesses to the Committee's enquiry highlighted the importance of positive messaging and emphasising the co-benefits of environmental measures for communication.

Domestic combustion

Interventions for domestic combustion require behaviour change and enforcement (Box 5).

Smoke Control Areas (SCAs) are in place across the UK, which place restrictions on fuels used and smoke released by households, but research has identified several obstacles to enforcement.[150] Restrictions will limit sales of coal and wet wood in small quantities in England, and sale of coal for use in domestic premises is prohibited from May 2023.[151]

Defra has published guidance on good practice for open fires and wood burners.[152] A warning system that recommends limiting burner use when air pollution is high is being trialled by researchers.[153]

Further possible interventions regarding solid fuel are outlined in the Chief Medical Officer's annual report.[4] Gas boilers are a key NO_x emissions source and lower-emission alternatives include electric boilers and heat pumps (PN 632).

Industry

Industrial emissions have reduced substantially since the 1990s due to tightened emissions standards and fuel changes. Reductions are ongoing but biomass use (and its emissions) has increased (PN 690). Increased use of electric boilers, electric arc or induction furnaces, and large-scale industrial heat pumps, is likely to reduce NO_x emissions, along with progressively tighter standards and use of best available techniques, such as selective catalytic reduction (increasingly used to limit NO_x emissions from combustion plants).

Green infrastructure

Trees and hedges have been promoted as improving air quality in close proximity to pollutant sources (e.g., roadside), primarily by acting as partial barriers to alter air flow patterns and pollutant dispersion.[154–156]

Green infrastructure alone has a modest impact on ambient air quality,[157] but some researchers suggest they are a valuable secondary complement to emission reductions. In the wrong locations, it can increase trapping of air pollution at street level.[158,159] As certain leaf traits can increase pollutant deposition on leaves,[160] and NMVOC emissions vary between species,[161] deliberate species selection during planning is needed (PB 26). The need to select species with low NMVOC emission potentials is also relevant to carbon sequestration and land-management towards Net Zero (PN 636).

Agricultural technologies

Agriculture is the biggest source of NH_3 emissions and reducing these would decrease secondary PM formation. Defra has good practice guidelines for reducing agricultural ammonia emissions and stated that wide adoption would achieve the NECR target of a 16% emissions reduction by 2030.[162]

These include guidelines for low-emission spreading and storing organic manure, spreading fertilisers, and livestock diets and housing. Other European countries have achieved even higher reductions using similar methods.[163]

References

1. Barlow, P. (2021). Regulation 28: Report to Prevent Future Deaths.
2. UK Government loses third air pollution case as judge rules air pollution plans 'unlawful' | ClientEarth.
3. Publications Office of the European Union (2021). Case C-664/18: Judgment of the Court (Seventh Chamber) of 4 March 2021 — European Commission v United Kingdom of Great Britain and Northern Ireland. Publications Office of the European Union.
4. Department of Health and Social Care (2022). Chief Medical Officer's annual report 2022: air pollution.
5. National Audit Office (2022). Tackling local breaches of air quality.
6. Fecht, D. *et al.* (2015). Associations between air pollution and socioeconomic characteristics, ethnicity and age profile of neighbourhoods in England and the Netherlands. *Environ. Pollut.*, Vol 198, 201–210.
7. Barnes, J. H. *et al.* (2019). Emissions vs exposure: Increasing injustice from road traffic-related air pollution in the United Kingdom. *Transp. Res. Part Transp. Environ.*, Vol 73, 56–66.
8. Air Quality Expert Group (2012). Fine Particulate Matter (PM2.5) in the United Kingdom.
9. Air Quality Expert Group (2018). Ultrafine Particles (UFP) in the UK.
10. Vu, T. V. *et al.* (2015). Review: Particle number size distributions from seven major sources and implications for source apportionment studies. *Atmos. Environ.*, Vol 122, 114–132.
11. Air Quality Expert Group (2005). Particulate Matter in the United Kingdom: Summary.
12. Adams, K. *et al.* (2015). Particulate matter components, sources, and health: Systematic approaches to testing effects. *J. Air Waste Manag. Assoc.*, Vol 65, 544–558. Taylor & Francis.
13. Department For Environment, Food & Rural Affairs Emissions of air pollutants in the UK – Particulate matter (PM10 and PM2.5). *GOV.UK*.
14. Department for Environment Food and Rural Affairs Pollutant Information: Sulphur Dioxide. Department for Environment, Food and Rural Affairs (Defra), Nobel House, 17 Smith Square, London SW1P 3JR helpline@defra.gsi.gov.uk.
15. Department For Environment, Food & Rural Affairs Emissions of air pollutants in the UK – Sulphur dioxide (SO2). *GOV.UK*.
16. Department For Environment, Food & Rural Affairs Emissions of air pollutants in the UK – Ammonia (NH3). *GOV.UK*.
17. Misselbrook, T. H. *et al.* (2021). Inventory of Ammonia Emissions from UK Agriculture 2019.
18. Air Quality Expert Group (2020). Non-methane Volatile Organic Compounds in the UK.
19. World Health Organization. Regional Office for Europe *et al.* (2006). Health risks of particulate matter from long-range transboundary air pollution. WHO Regional Office for Europe.
20. Air Quality Expert Group (2013). Mitigation of United Kingdom PM2.5 Concentrations.
21. Department For Environment, Food & Rural Affairs (2022). Air quality PM2.5 targets: Detailed Evidence report.
22. Lorente, A. *et al.* (2019). Quantification of nitrogen oxides emissions from build-up of pollution over Paris with TROPOMI. *Sci. Rep.*, Vol 9, 20033. Nature Publishing Group.
23. Hidy, G. M. (2022). Urban Air Chemistry in Changing Times.

Atmosphere, Vol 13, 327. Multidisciplinary Digital Publishing Institute.
24. Air Quality Expert Group (2021). Ozone in the UK - Recent Trends and Future Projections.
25. Miyazaki, K. *et al.* (2021). Global tropospheric ozone responses to reduced NOx emissions linked to the COVID-19 worldwide lockdowns. *Sci. Adv.*, Vol 7, eabf7460. American Association for the Advancement of Science.
26. Strak, M. *et al.* (2021). Long term exposure to low level air pollution and mortality in eight European cohorts within the ELAPSE project: pooled analysis. *BMJ*, Vol 374, n1904. British Medical Journal Publishing Group.
27. Committee on the Medical Effects of Air Pollutants (COMEAP) (2018). Associations of long-term average concentrations of nitrogen dioxide with mortality. 152.
28. Xing, Y.-F. *et al.* (2016). The impact of PM2.5 on the human respiratory system. *J. Thorac. Dis.*, Vol 8, E69–E74.
29. Schraufnagel, D. E. (2020). The health effects of ultrafine particles. *Exp. Mol. Med.*, Vol 52, 311–317. Nature Publishing Group.
30. Morawska, L. *et al.* (2019). *Ambient ultrafine particles: evidence for policy makers. A report prepared by the 'Thinking outside the box' team.*
31. Kwon, H.-S. *et al.* (2020). Ultrafine particles: unique physicochemical properties relevant to health and disease. *Exp. Mol. Med.*, Vol 52, 318–328. Nature Publishing Group.
32. WHO Regional Office for Europe (2012). Health Effects of Black Carbon. 96.
33. Committee on the Medical Effects of Air Pollutants Statement on the differential toxicity of particulate matter according to source or constituents. *GOV.UK*.
34. Bongaerts, E. *et al.* (2022). Maternal exposure to ambient black carbon particles and their presence in maternal and fetal circulation and organs: an analysis of two independent population-based observational studies. *Lancet Planet. Health*, Vol 6, e804–e811. Elsevier.
35. Royal College of Physicians (2016). Every breath we take: the lifelong impact of air pollution.
36. World Health Organization. Regional Office for Europe (2013). Review of evidence on health aspects of air pollution: REVIHAAP project: technical report. World Health Organization. Regional Office for Europe.
37. Orellano, P. *et al.* (2017). Effect of outdoor air pollution on asthma exacerbations in children and adults: Systematic review and multilevel meta-analysis. *PLoS ONE*, Vol 12, e0174050.
38. Hoffmann, C. *et al.* (2022). Asthma and COPD exacerbation in relation to outdoor air pollution in the metropolitan area of Berlin, Germany. *Respir. Res.*, Vol 23, 64.
39. Li, J. *et al.* (2016). Major air pollutants and risk of COPD exacerbations: a systematic review and meta-analysis. *Int. J. Chron. Obstruct. Pulmon. Dis.*, Vol 11, 3079–3091.
40. Kelly, F. J. *et al.* (2011). Air pollution and airway disease. *Clin. Exp. Allergy*, Vol 41, 1059–1071.
41. Bourdrel, T. *et al.* (2017). Cardiovascular effects of air pollution. *Arch. Cardiovasc. Dis.*, Vol 110, 634–642.
42. World Health Organization (2016). Ambient air pollution: A global assessment of exposure and burden of disease.
43. Brook, R. D. *et al.* (2010). Particulate Matter Air Pollution and Cardiovascular Disease. *Circulation*, Vol 121, 2331–2378. American Heart Association.
44. Committee on the Medical Effects of Air Pollutants (COMEAP) (2010). The

Effects of Long-Term Exposure to Ambient Air Pollution on Cardiovascular Morbidity: Mechanistic Evidence. 104.

45. Turner, M. C. *et al.* (2020). Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. *CA. Cancer J. Clin.*, Vol 70, 460–479.
46. Park, J. *et al.* (2021). Impact of long-term exposure to ambient air pollution on the incidence of chronic obstructive pulmonary disease: A systematic review and meta-analysis. *Environ. Res.*, Vol 194, 110703.
47. Committee on the Medical Effects of Air Pollutants (COMEAP) (2022). Cognitive decline, dementia and air pollution: A report by the Committee on the Medical Effects of Air Pollutants. 291.
48. Committee on the Medical Effects of Air Pollutants (COMEAP) (2016). Long-term Exposure to Air Pollution and Chronic Bronchitis. 100.
49. Khreis, H. *et al.* (2017). Exposure to traffic-related air pollution and risk of development of childhood asthma: A systematic review and meta-analysis. *Environ. Int.*, Vol 100, 1–31.
50. Thurston, G. D. *et al.* (2020). Outdoor Air Pollution and New-Onset Airway Disease. An Official American Thoracic Society Workshop Report. *Ann. Am. Thorac. Soc.*, Vol 17, 387–398.
51. Pedersen, M. *et al.* (2013). Ambient air pollution and low birthweight: a European cohort study (ESCAPE). *Lancet Respir. Med.*, Vol 1, 695–704. Elsevier.
52. Smith, R. B. *et al.* (2017). Impact of London's road traffic air and noise pollution on birth weight: retrospective population based cohort study. *BMJ*, Vol 359, j5299. British Medical Journal Publishing Group.
53. Nyadanu, S. D. *et al.* (2022). Prenatal exposure to ambient air pollution and adverse birth outcomes: An umbrella review of 36 systematic reviews and meta-analyses. *Environ. Pollut.*, Vol 306, 119465.
54. Committee on the Medical Effects of Air Pollutants (COMEAP) (2021). COMEAP Work Program.
55. Meo, S. A. *et al.* (2015). Effect of environmental air pollution on type 2 diabetes mellitus. *Eur. Rev. Med. Pharmacol. Sci.*, Vol 19, 123–128.
56. Carré, J. *et al.* (2017). Does air pollution play a role in infertility?: a systematic review. *Environ. Health*, Vol 16, 82.
57. Zare Sakhvidi, M. J. *et al.* (2020). Air pollution exposure and bladder, kidney and urinary tract cancer risk: A systematic review. *Environ. Pollut.*, Vol 267, 115328.
58. Turner, M. C. *et al.* (2017). Ambient Air Pollution and Cancer Mortality in the Cancer Prevention Study II. *Environ. Health Perspect.*, Vol 125, 087013. Environmental Health Perspectives.
59. Dutton, A. (2020). Air pollution and COVID-19 mortality rates in England - Office for National Statistics.
60. Hansell, A. (2022). Personal Communication.
61. Zhang, X. *et al.* (2018). The impact of exposure to air pollution on cognitive performance. *Proc. Natl. Acad. Sci.*, Vol 115, 9193–9197. National Academy of Sciences.
62. Laurent, J. G. C. *et al.* (2021). Associations between acute exposures to PM2.5 and carbon dioxide indoors and cognitive function in office workers: a multicountry longitudinal prospective observational study. *Environ. Res. Lett.*, Vol 16, 094047. IOP Publishing.
63. Friends of the Earth Which neighbourhoods have the worst air pollution? | Policy and insight.
64. Williams, M. L. *et al.* (2018). Impact of air pollution scenarios on inequalities. *Public health air pollution impacts of pathway options to meet the 2050 UK Climate Change*

Act target: a modelling study. NIHR Journals Library.
65. Laurent, É. (2022). Air (ine)quality in the European Union. *Curr. Environ. Health Rep.*, Vol 9, 123–129.
66. Verbeek, T. *et al.* (2022). The 'just' management of urban air pollution? A geospatial analysis of low emission zones in Brussels and London. *Appl. Geogr.*, Vol 140, 102642.
67. People of colour far likelier to live in very high air pollution areas. *Friends of the Earth*.
68. Department For Environment, Food & Rural Affairs Concentrations of particulate matter (PM10 and PM2.5). *GOV.UK*.
69. Department For Environment, Food & Rural Affairs (2022). ENV02 - Air quality statistics. *GOV.UK*.
70. Department For Environment, Food & Rural Affairs Concentrations of nitrogen dioxide. *GOV.UK*.
71. World Health Organization (2021). WHO global air quality guidelines.
72. Department For Environment, Food & Rural Affairs Concentrations of ozone. *GOV.UK*.
73. Department For Environment, Food & Rural Affairs (2022). Air Pollution in the UK 2021 – Compliance Assessment Summary.
74. Office for Environmental Protection (2022). Progress in improving the natural environment in England, 2021/2022.
75. Department For Environment, Food & Rural Affairs (2022). Local Air Quality Management: Technical Guidance.
76. Department For Environment, Food & Rural Affairs (2022). Personal Communication.
77. UKRI Air quality supersite triplets (UK-AQST).
78. Bulot, F. M. J. *et al.* (2019). Long-term field comparison of multiple low-cost particulate matter sensors in an outdoor urban environment. *Sci. Rep.*, Vol 9, 7497. Nature Publishing Group.
79. (2022). Development and Supply of PAS4023 Document for Low-Cost Sensors for Air Quality.
80. Breathe London.
81. Air Quality Monitoring Pilot Study – Neath Port Talbot Council.
82. £3 million boost for innovative local air quality improvements. *GOV.UK*.
83. Castell, N. *et al.* (2017). Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates? *Environ. Int.*, Vol 99, 293–302.
84. Karagulian, F. *et al.* (2019). Review of the Performance of Low-Cost Sensors for Air Quality Monitoring. *Atmosphere*, Vol 10, 506. Multidisciplinary Digital Publishing Institute.
85. Department For Environment, Food & Rural Affairs AQEG advice on the use of 'low-cost' pollution sensors. Department for Environment, Food and Rural Affairs (Defra), Nobel House, 17 Smith Square, London SW1P 3JR helpline@defra.gsi.gov.uk.
86. Environment Agency (2021). Satellite measurements of air quality and greenhouse gases: application to regulatory activities.
87. Jephcote, C. *et al.* (2021). Changes in air quality during COVID-19 'lockdown' in the United Kingdom. *Environ. Pollut.*, Vol 272, 116011.
88. Singh, A. *et al.* (2022). Impacts of emergency health protection measures upon air quality, traffic and public health: evidence from Oxford, UK. *Environ. Pollut. Barking Essex 1987*, Vol 293, 118584.
89. Mohajeri, N. *et al.* (2021). Covid-19 mobility restrictions: impacts on urban air quality and health. *Build. Cities*, Vol 2, 759–778.
90. Air Quality Expert Group (2020). Estimation of changes in air pollution emissions, concentrations and exposure during the COVID-19 outbreak in the UK.
91. Shi, Z. *et al.* (2021). Abrupt but smaller than expected changes in surface air quality attributable to

COVID-19 lockdowns. *Sci. Adv.*, Vol 7, eabd6696. American Association for the Advancement of Science.

92. Air Quality Expert Group (2019). Non-Exhaust Emissions from Road Traffic.
93. Fussell, J. C. *et al.* (2022). A Review of Road Traffic-Derived Non-Exhaust Particles: Emissions, Physicochemical Characteristics, Health Risks, and Mitigation Measures. *Environ. Sci. Technol.*, Vol 56, 6813–6835. American Chemical Society.
94. Committee on the Medical Effects of Air Pollutants (2020). Statement on the evidence for health effects associated with exposure to non-exhaust particulate matter from road transport.
95. Outcome and response to ending the sale of new petrol, diesel and hybrid cars and vans. *GOV.UK*.
96. Beddows, D. C. S. *et al.* (2021). PM10 and PM2.5 emission factors for non-exhaust particles from road vehicles: Dependence upon vehicle mass and implications for battery electric vehicles. *Atmos. Environ.*, Vol 244, 117886.
97. Osei, L. K. *et al.* (2021). Real-World Contribution of Electrification and Replacement Scenarios to the Fleet Emissions in West Midland Boroughs, UK. *Atmosphere*, Vol 12, 332. Multidisciplinary Digital Publishing Institute.
98. The Royal Society (2021). Effects of Net Zero Policies and Climate Change on Air Quality summary. 16.
99. Department for Business, Energy & Industrial Strategy (2021). Impact Assessment for the sixth carbon budget.
100. Air Quality Expert Group (2020). Impacts of Net Zero pathways on future air quality in the UK.
101. Lewis, Alastair C *et al.* (2022). Indoor Air Quality.
102. Bartington, S. *et al.* (2022). Personal Communication.
103. The Air Quality Standards Regulations 2010. Queen's Printer of Acts of Parliament.
104. Scottish Government (2021). Cleaner Air For Scotland 2: Towards a Better Place for Everyone. 86.
105. The National Emission Ceilings Regulations 2018. Queen's Printer of Acts of Parliament.
106. HM Government (2021). Environment Act 2021.
107. Office for Environmental Protection (2022). OEP response to consultation on environmental targets. Office for Environmental Protection.
108. Royal College of Physicians (2022). RCP response to the government consultation on air quality targets under the Environment Act 2021. *RCP London*.
109. Healthy Air Campaign - The case for more ambitious clean air targets to reduce PM2.5 pollution to 10 µg/m3 by 2030 | ClientEarth.
110. Pathway to WHO: achieving clean air in the UK.
111. Haves, E. (2022). Clean Air (Human Rights) Bill [HL]: HL Bill 5 of 2022-23.
112. UK Parliament Air Pollution: Standards, Question for Department for Environment, Food and Rural Affairs.
113. Department For Environment, Food & Rural Affairs Air quality grant scheme. *GOV.UK*.
114. Air Quality Expert Group (2020). Assessing the Effectiveness of Interventions on Air Quality.
115. Barnes, J. H. *et al.* (2014). Air quality action planning: why do barriers to remediation in local air quality management remain? *J. Environ. Plan. Manag.*, Vol 57, 660–681. Routledge.
116. Environment, Food and Rural Affairs Committee *et al.* (2018). Improving air quality.

117. Clean Air Fund (2021). Joined-up Action on Air Pollution and Climate Change.
118. Why policy on air quality and greenhouse gas emissions needs to be joined-up.
119. Department For Environment, Food & Rural Affairs Clean Air Strategy 2019: executive summary. *GOV.UK*.
120. UK Health Alliance on Climate Change (2016). A Breath of Fresh Air: Addressing Climate Change and Air Pollution Together for Health.
121. Royal College of Physicians (2017). Joint select committee inquiry: improving air quality.
122. Department For Environment, Food & Rural Affairs (2022). Air Quality Common Framework: Provisional Framework Outline Agreement and Concordat.
123. Department For Environment, Food & Rural Affairs (2022). Integrated Pollution Prevention and Control – The Developing and Setting of Best Available Techniques (BAT): Concordat and Provisional Framework Outline Agreement.
124. Penn, A. S. *et al.* (2022). Adopting a Whole Systems Approach to Transport Decarbonisation, Air Quality and Health: An Online Participatory Systems Mapping Case Study in the UK. *Atmosphere*, Vol 13, 492. Multidisciplinary Digital Publishing Institute.
125. Fang, D. *et al.* (2019). Clean air for some: Unintended spillover effects of regional air pollution policies. *Sci. Adv.*, Vol 5, eaav4707. American Association for the Advancement of Science.
126. Department For Environment, Food & Rural Affairs Clean air zones. *GOV.UK*.
127. Oxfordshire County Council, 01865 792422 About Oxford's zero emission zone (ZEZ) | Oxfordshire County Council. *http://www.oxfordshire.gov.uk*. Oxfordshire County Council, County Hall, New Road, Oxford, OX1 1ND; 01865 792422; online@oxfordshire.gov.uk.
128. Transport for London ULEZ Expansion 2023. *Transport for London*.
129. Mayor of London (2021). London Low Emission Zone - Six Month Report.
130. Greater Manchester Clean Air Plan | Clean Air Greater Manchester.
131. Bath & North East Somerset Council (2021). Bath's Clean Air Zone: Annual report summary 2021.
132. Brum Breathes (2022). Clean Air Zone Six Month Report | Brum Breathes.
133. Mayor of London (2022). Expanded Ultra Low Emission Zone Six Month Report.
134. Department For Environment, Food & Rural Affairs (2022). Evaluation of Local NO2 Plans - AQ0851.
135. Shi, Z. *et al.* (2022). Quantifying the impact of clean air policy interventions for air quality management. University of Birmingham.
136. British Lung Foundation (2016). Consultation response: DEFRA – Draft Clean Air Zone Framework for England.
137. Bath & North East Somerset Council (2022). Bath's Clean Air Zone: Appendix 2.
138. Department For Environment, Food & Rural Affairs (2017). UK plan for tackling roadside nitrogen dioxide concentrations: Detailed plan.
139. Mueller, N. *et al.* (2018). Health impact assessment of cycling network expansions in European cities. *Prev. Med.*, Vol 109, 62–70.
140. Public Health England (2020). Improving access to greenspace.
141. Allam, Z. *et al.* (2022). The 15-minute city offers a new framework for sustainability, liveability, and health. *Lancet Planet. Health*, Vol 6, e181–e183. Elsevier.

142. Woodcock, J. *et al.* (2014). Health effects of the London bicycle sharing system: health impact modelling study. *BMJ*, Vol 348, g425. British Medical Journal Publishing Group.
143. Vehicle Parking | LAQM.
144. TRANSITION Clean Air Network (2022). Air Quality in Transport Hubs.
145. Air Quality Consultants (2021). Air Quality Monitoring Study: London School Streets.
146. Bosetti, N. *et al.* Street Shift: The Future of Low-Traffic Neighbourhoods. 56.
147. Cepeda, M. *et al.* (2017). Levels of ambient air pollution according to mode of transport: a systematic review. *Lancet Public Health*, Vol 2, e23–e34. Elsevier.
148. Public Health England (2019). Improving outdoor air quality and health: review of interventions.
149. House of Lords Environment and Climate Change Committee (2022). In our hands: behaviour change for climate and environmental goals. 140.
150. Heydon, J. (in press). Between Ordinary Harm and Deviance: Evaluating the UK's Regulatory Regime for Controlling Air Pollution from Wood burning Stoves. *Br. J. Criminol.*,
151. Department For Environment, Food & Rural Affairs Selling coal for domestic use in England. *GOV.UK*.
152. Open fires and wood-burning stoves - a practical guide. 3.
153. Wood burner users needed to take part in new 'pollution alert' study.
154. Pearce, H. *et al.* (2021). Introducing the Green Infrastructure for Roadside Air Quality (GI4RAQ) Platform: Estimating Site-Specific Changes in the Dispersion of Vehicular Pollution Close to Source. *Forests*, Vol 12, 769. Multidisciplinary Digital Publishing Institute.
155. Mayor of London (2019). Using Green Infrastructure to Protect People from Air Pollution.
156. Department for Levelling Up, Housing and Communities *et al.* Air quality. *GOV.UK*.
157. Air Quality Expert Group (2018). Impacts of Vegetation on Urban Air Pollution.
158. Vos, P. E. J. *et al.* (2013). Improving local air quality in cities: To tree or not to tree? *Environ. Pollut.*, Vol 183, 113–122.
159. Grylls, T. *et al.* (2022). How trees affect urban air quality: It depends on the source. *Atmos. Environ.*, Vol 290, 119275.
160. Barwise, Y. *et al.* (2020). Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate plant species selection. *Npj Clim. Atmospheric Sci.*, Vol 3, 1–19. Nature Publishing Group.
161. Hewitt, C. N. *et al.* (2020). Using green infrastructure to improve urban air quality (GI4AQ). *Ambio*, Vol 49, 62–73.
162. Department For Environment, Food & Rural Affairs (2018). Code of good agricultural practice (COGAP) for reducing ammonia emissions. 30.
163. Air Quality Expert Group (2018). Air Pollution from Agriculture.

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