Chief Medical Officer's Annual Report 2022

Air pollution

Executive summary and recommendations

Front cover image: Emissions from Hope Cement Works, Hope Valley, Derbyshire, England
Source: Wesley Kristopher Photography.

Executive summary

Introduction

Air pollution affects us all. It is associated with impacts on lung development in children, heart disease, stroke, cancer, exacerbation of asthma and increased mortality, among other health effects. Except for air quality in our own homes, we have little control as individuals over the level of pollution that we and our families breathe – this must be seen as a societal problem to solve. Government has therefore had a central role in tackling air pollution in the UK going back at least to King Edward I in the 1280s, and does now. Many industries and sectors also have to be part of the solution.

Outdoor air quality in this country, and most high-income countries, has improved significantly since the 1980s. Some air pollutants such as sulphur dioxide from coal, and lead from petrol, are fractions of their previous levels.

As this report lays out, we can and should go further to reduce air pollution – and it is technically possible to do so. Improvements in engineering for transport and industry, modifications to agricultural practice and improvements in the built environment are examples that should, once a change is made, be self-sustaining and allow us to reap health benefits for the foreseeable future. Many of the changes to improve outdoor air pollution have significant co-benefits. For example, reducing the use of fossil fuels for energy reduces both air pollution and carbon emissions; improving active travel reduces air pollution emissions from vehicles and has direct health benefits to those who are walking, wheeling or cycling.

In particular, we need to concentrate on the places where people live, work and study; the same air pollution concentration in a densely populated area will lead to greater accumulated health effects than in a sparsely populated area as more people will be affected.

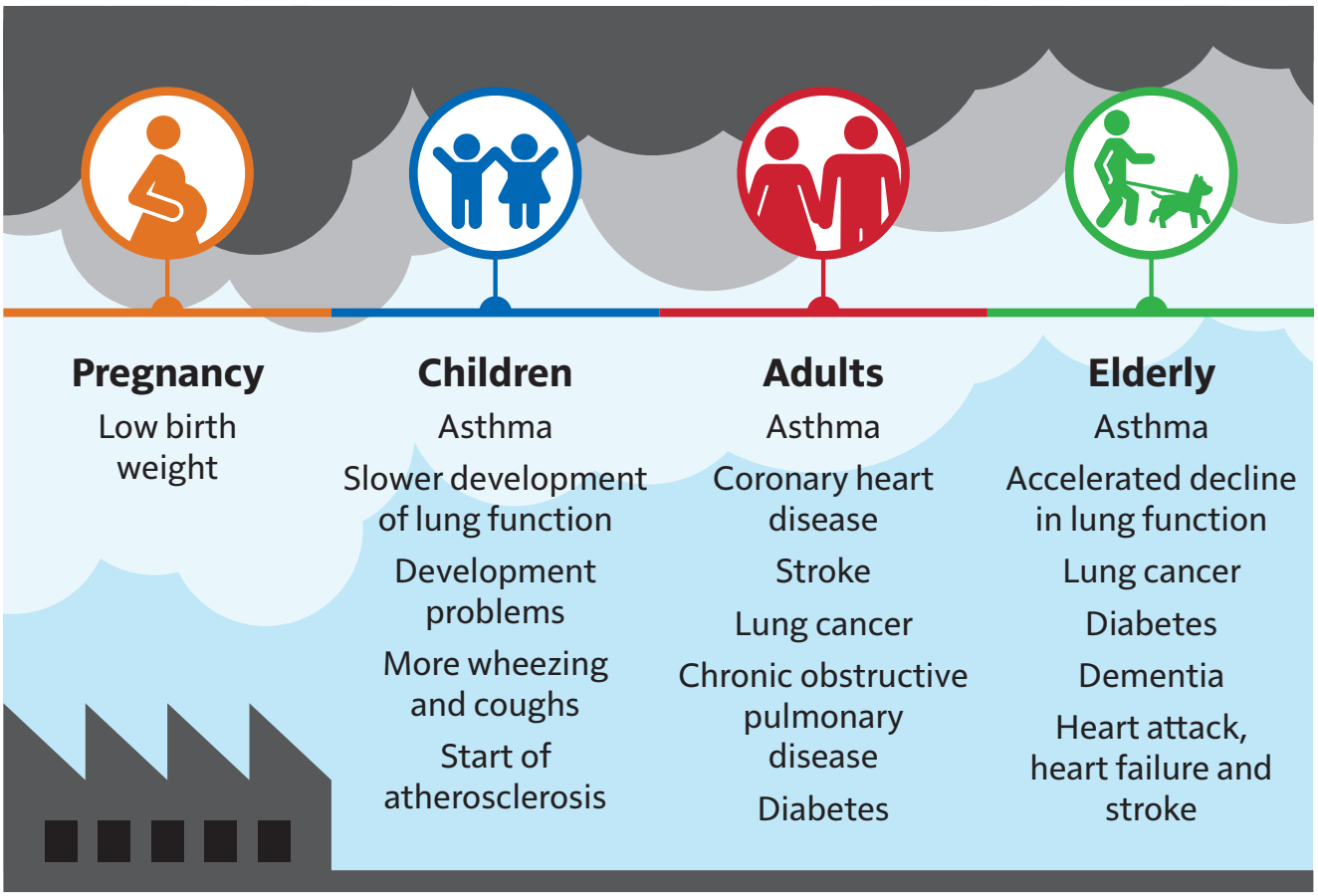
The path to better outdoor air quality is clear, and we now need to go down it. Indoor air pollution is becoming an increasing proportion of the problem as improvements in outdoor air pollution occur. Most of our days are spent indoors whether for work, study or leisure, yet indoor air quality has been studied much less than outdoors. While there are some spaces such as owner-occupied houses that are fully private, many indoor spaces are public, including health facilities, schools, other public buildings, and also shops and workplaces. As with outdoor spaces, people in public buildings are exposed to air pollution but can do little about it, so society needs to act. A better understanding of how we can prevent and reduce indoor air pollution should now be a priority.

This report is about air pollution and its solutions in England, but it is also an international problem. There is a lot we can learn from best international practice. Many air pollutants travel long distances, so emissions and air quality in continental Europe affect the UK and vice versa. It is important to acknowledge that the improvements in air quality we are seeing in high-income countries are yet to be felt in many middle-income countries, but many of the technologies and techniques will be transferable.

The first chapters of this report lay out the health problems of air pollution, but most of the report is about achievable solutions. Air pollution is everybody's problem, but it has improved, and will continue improving provided we are active in tackling it.

Chapter 1 – Air pollution and health

Chapter 1 covers the effects of air pollution on health, including inequalities. Air pollution has negative effects on health throughout the life course, from pre-birth to old age, summarised in Figure 1.



Source: Adapted from Public Health England (2018)[1]

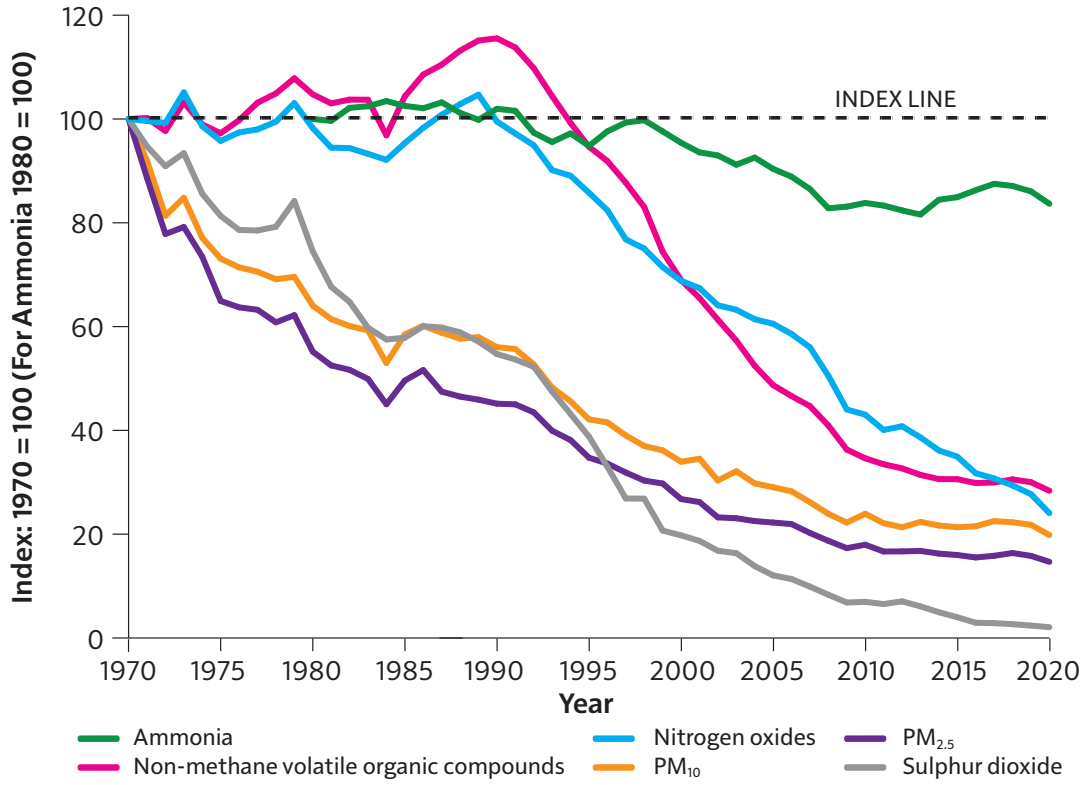
Figure 1: Health effects of air pollution throughout life

Some individuals such as those with pre-existing respiratory or cardiovascular disease are particularly susceptible, but the effects of air pollution can be seen across the population. The mortality burden of air pollution in England is estimated to be between 26,000 and 38,000 a year, but in addition many people suffer avoidable chronic ill health as a result of it. Improvements in air quality have been associated with improved health outcomes – for example, reductions in air pollution in London have led to reduced childhood asthma hospital admissions. Further reductions in air pollution will lead to significant reductions in coronary heart disease, stroke and lung cancer, among others.

The chapter discusses and summarises evidence for the short- and long-term health effects of the main outdoor air pollutants, including particulate matter (PM) especially fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and others. It then considers additional indoor air pollutants such as volatile organic compounds (VOCs). Air pollution does not affect everyone equally and the chapter has a further section on disparities in air pollution including by age, socio-economic gradient and ethnicity. These disparities are both by air pollution exposure and by vulnerability – for example pregnant women, children and those with health conditions are more vulnerable to harm, even if their exposure is the same as other population groups.

Chapter 2 – Outdoor air pollution emissions and recent trends

Chapter 2 considers recent trends in outdoor air pollution emissions. There has been a steady decline in emissions of most outdoor air pollutants, with some dropping substantially, such as SO_2. Others such as ammonia (NH_3) have been largely static, as shown in Figure 2. In the last decade improvements in $PM_{2.5}$ have stalled, and these especially need attention.



Note: The figure shows trends in annual emissions of particulate matter (PM_{10} and $PM_{2.5}$), nitrogen oxides, ammonia, non-methane volatile organic compounds, and sulphur dioxide, 1970 to 2020, expressed as a percentage change from the base year of 1970 (for ammonia the base year is 1980).

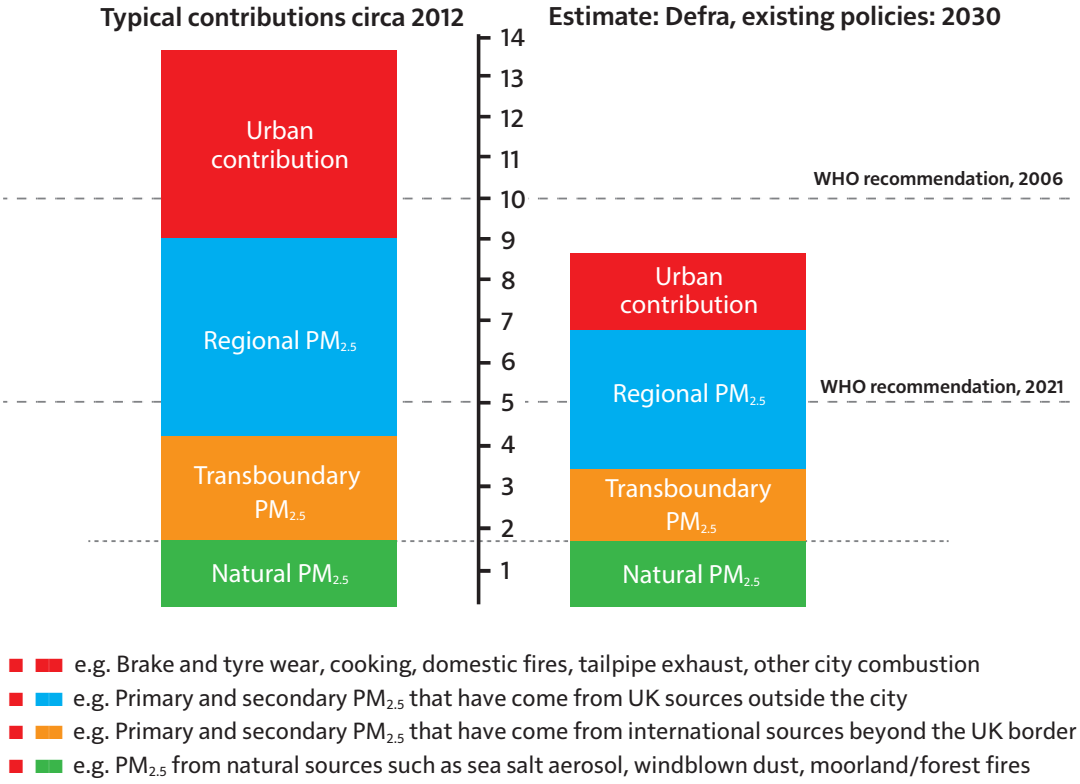
Source: Ricardo Energy & Environment. Defra (2022)[2]

Figure 2: Trends in UK emissions of air pollutants 1970 to 2020

Chapter 3 – How air pollution is changing

Chapter 3 explains how air pollution is changing and how it is expected to change in the future. It considers UK and international trends that will affect the UK, and likely changes in population-weighted exposure to outdoor air pollution. It also considers some of the interactions between air pollution and climate change, and the implications of net zero policies.

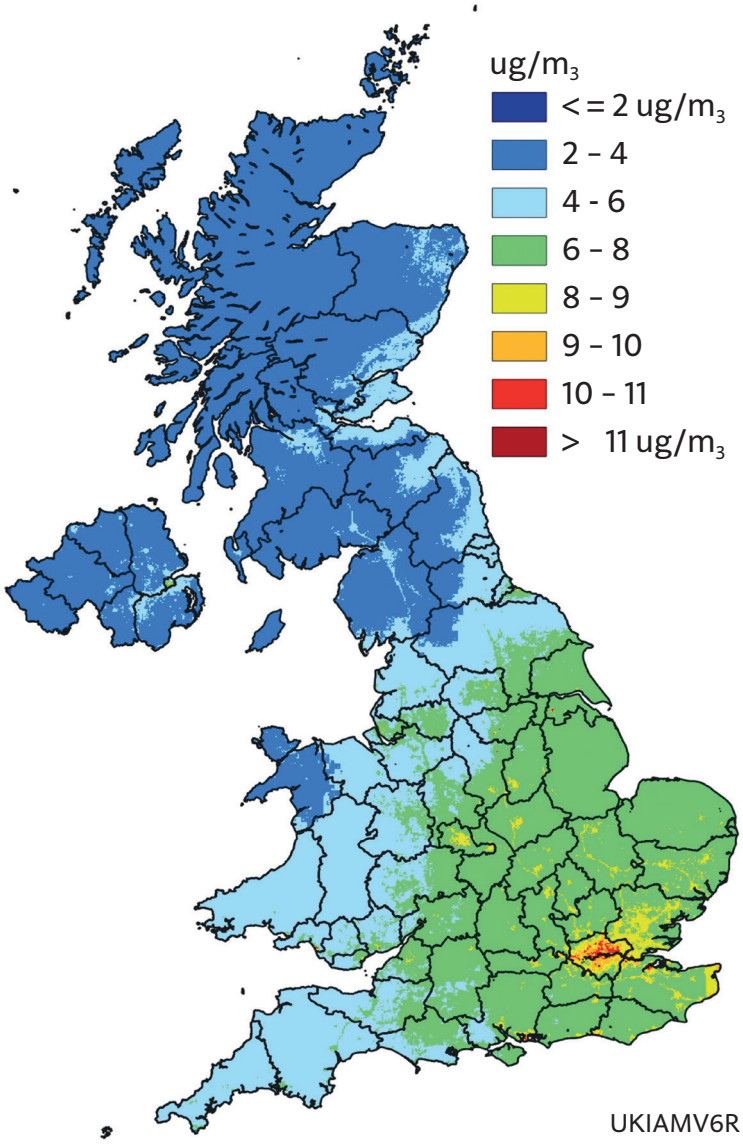
Outdoor $PM_{2.5}$ is changing in its nature, and to address it we need to differentiate between primary $PM_{2.5}$ (emitted direct from source) and secondary $PM_{2.5}$ (formed by combining chemicals in the atmosphere). For example, NH_3 from agriculture contributes to secondary $PM_{2.5}$ in cities as well as having negative effects on rural ecosystems. Air pollutants vary in how long they persist in the atmosphere, and this has implications on how far away from source they can have an effect on health. The relative importance of these sources will vary over the next decade, and Figure 3 shows estimates of the contributions to $PM_{2.5}$ for an urban background location circa 2012 and estimated for 2030.



Left: the period circa 2012 (based on materials in reference 3). Right: contributing sources that might be anticipated in 2030 based on the author's evaluation of impacts arising from likely emissions reduction by 2030. Y-axis is atmospheric concentration in units of µg/m³.
Source: AQEG (2015)[3] and ApSimon et al. (2022)[4]

Figure 3: A qualitative representation of the different contributing sources to $PM_{2.5}$ that might be experienced in a typical urban centre (England)

The chapter also shows how, with existing policies, outdoor air quality will have improved right across the UK by 2030, however some areas will still experience annual average concentrations of $PM_{2.5}$ higher than the government's target of 10 micrograms/m^3, particularly in South-East England, as shown in Figure 4. It then goes on to consider changes, or lack of them, in indoor air pollution in the future. Changes to behaviour, such as more working from home, may have an important impact on people's exposures.



Source: Air Quality $PM_{2.5}$ Targets: Detailed Evidence Report. Department for Environment, Food & Rural Affairs, 2022[5]

Figure 4: Modelled annual average concentrations of $PM_{2.5}$ in 2030 based on a 'baseline' (existing agreed government policies) emission reduction scenario[6]

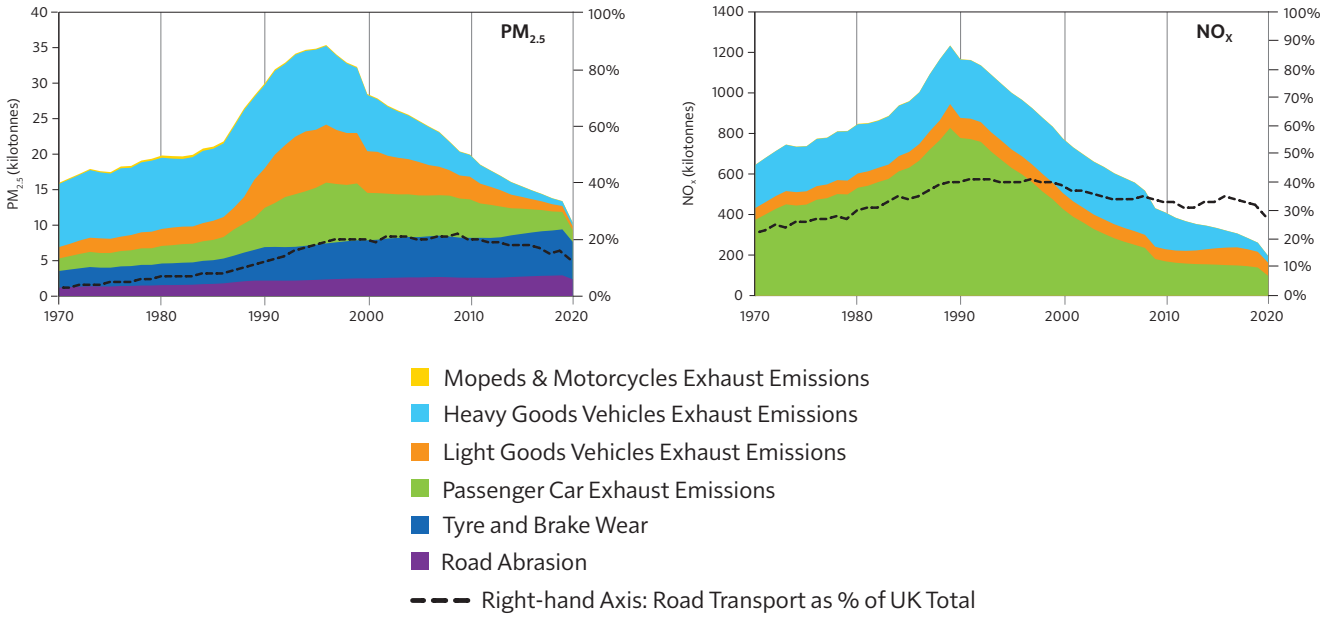
Chapter 4 – Outdoor and indoor air pollution solutions

Chapter 4 is the largest chapter of the report, and it covers major sectors that emit outdoor air pollution and what can be done to reduce these emissions. The sections within the chapter cover areas including transport, urban planning, industry, agriculture and a specific section on the NHS. Chapter 4 also discusses indoor air quality.

4.1 Transport

Road vehicles

Road vehicles have been sources of some of the most important air pollutants, especially $PM_{2.5}$ and NO_2, which are of health concern, particularly in urban areas where there is large population exposure. NO_2 is a gas that is produced along with nitric oxide (NO) by combustion processes, and together they are often referred to as nitrogen oxides (NO_x). There have been considerable reductions in road vehicle emissions, as successive tightening of regulations on Euro engineering standards for road vehicles have been met, as shown in Figure 5.



Note: The dashed black line indicates the contribution of road transport to the overall emissions on the right-hand axis .
Source: National Atmospheric Emissions Inventory[7] analysed by Air Quality Consultants Ltd

Figure 5: $PM_{2.5}$ and NO_x emissions from road vehicle sources since 1970

Tailpipe emissions from petrol and diesel engines are now much lower than they were two decades ago, and they are expected to fall further as zero tailpipe emission electric vehicles are adopted. Maintaining or accelerating this switch is important for air pollution. $PM_{2.5}$ emissions from brakes are also likely to fall, but not to zero, as the regenerative braking in electric vehicles takes over. This will leave tyre wear emissions and resuspension of road dust – novel low emission tyre materials and methods for capturing these particles, without reducing road safety, will become increasingly important. The section considers the relative merits of petrol, diesel, electric and hydrogen vehicles for air pollution reduction. The move to electric vehicles will take longer for heavy goods

vehicles and may provide a need for other engineering solutions, and there may be some interim solutions. Some specific vehicle types are also considered, for example refrigerated vehicles can currently emit significant air pollution from diesel refrigeration units.

Rail

In many areas, rail transport has moved from fossil fuel combustion to electrification as its main power source, and this can lead to reduced air pollution emissions, which is of particular importance in urban areas and enclosed spaces such as train stations. While further electrification is the ideal, there are several technical solutions that would improve air quality as an interim or permanent solution to air pollution, including power by bi-mode (with the option of diesel or electric), battery and hydrogen fuel cells. There are air pollution emissions from other rail sources including friction from brakes, the interface between the wheel and rail, and pantographs. Air pollution in stations is a particular problem and should be a priority.

Underground railways and metros often have significant $PM_{2.5}$ due to limited ventilation, with the London Underground having the highest measured concentrations in European subway systems. Improvements in braking, ventilation and/or filtration are possible solutions.

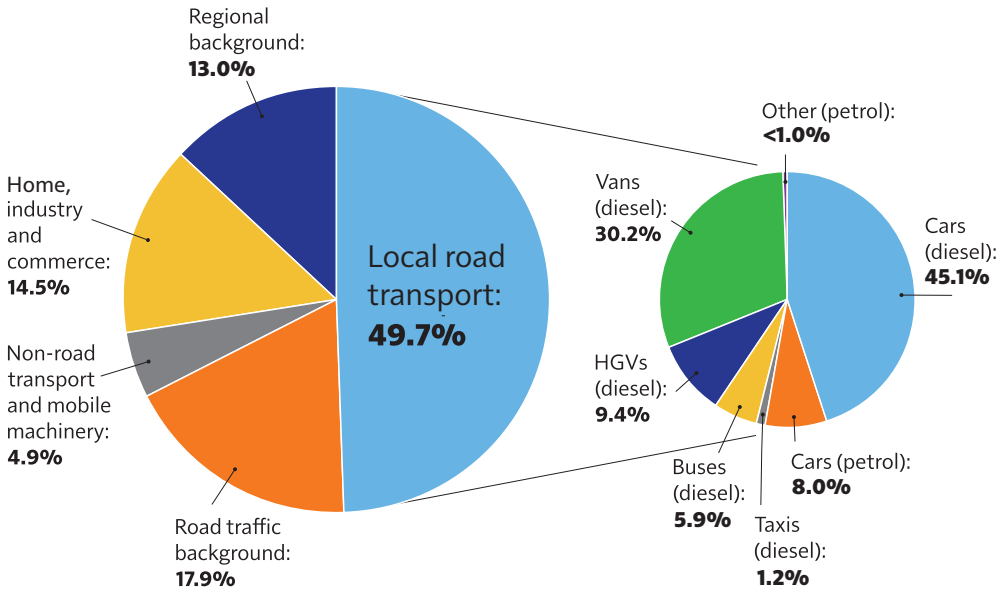
Aviation and shipping

Both aviation and shipping emit substantial air pollution that can affect the population, especially around ports and airports. While fuels for road transport have progressively reduced their sulphur content, jet fuel and bunker fuel for ships both still contain appreciable amounts of sulphur containing compounds, which leads to SO_2 emissions on combustion. Further reducing the sulphur content of ship and aviation fuels will reduce air pollution.

Using electrical power and tugs while aircraft are on the ground in airports would reduce some of the local air quality effects of aircraft engines, along with low or zero combustion airport vehicle fleets. For ships, more use of shore electricity and electrification of cranes and harbour craft would lead to improvements in air quality.

4.2 Reducing roadside NO_2 – an example of central and local government action

For all vehicle types, government action can have a significant impact on air pollution. Central and local government can both change local air pollution, including through regulation and the purchasing of cleaner vehicles for public transport, and the effect on NO_x can be substantial. Figure 6 shows the UK average NO_x roadside concentrations, by different sources.



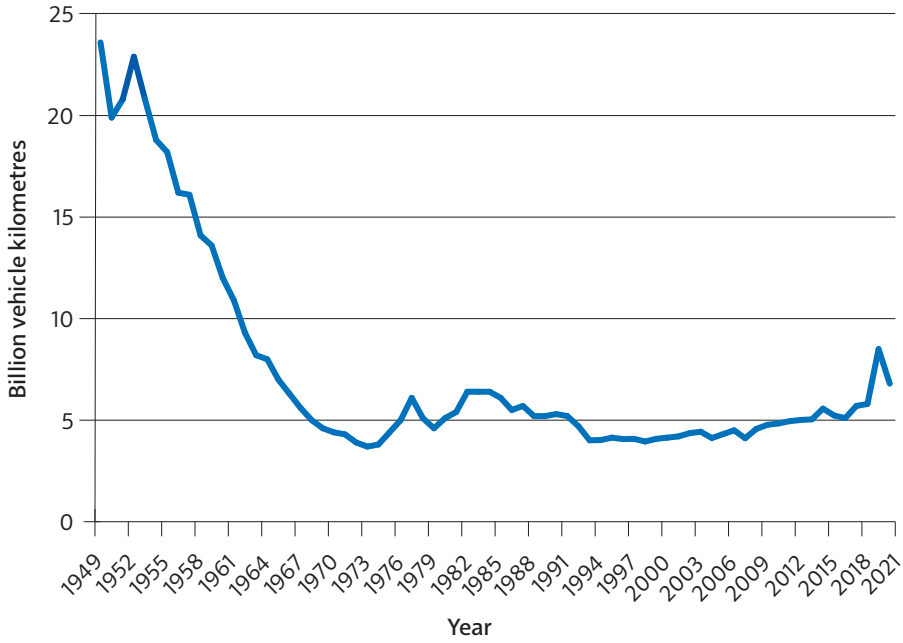
Note: NO_x is the sum of nitrogen dioxide (NO_2) and nitric oxide (NO).
Source: Defra (2021)[8]

Figure 6: UK national average NO_x roadside concentration apportioned by source of NO_x emissions, 2020

Clean air zones are, if well designed, potentially a way of reducing tailpipe air pollution, although they can have a mixed reception from the public. Clean air zones are designated in areas with high air pollution concentrations and high population density, and mainly target older vehicles with higher tailpipe emissions in areas of high risk and population vulnerability.

4.3 Urban planning and 4.4 Active travel

Urban planning can have a major impact on how much people use active forms of transport, compared to transport that emits air pollution. It can also influence the concentration of pollutants in areas of high building density and the impact of urban greening. Active travel, walking, wheeling and cycling has fallen a long way since the 1950s, and Figure 7 shows kilometres travelled by bicycle in Great Britain from 1949 to 2021. Reversing this decline would have substantial additional health benefits due to physical activity being built into the normal day, in addition to reductions in air pollution. Improving the infrastructure for active travel is a necessary, although not sufficient, step towards more active trips taken safely by all ages.

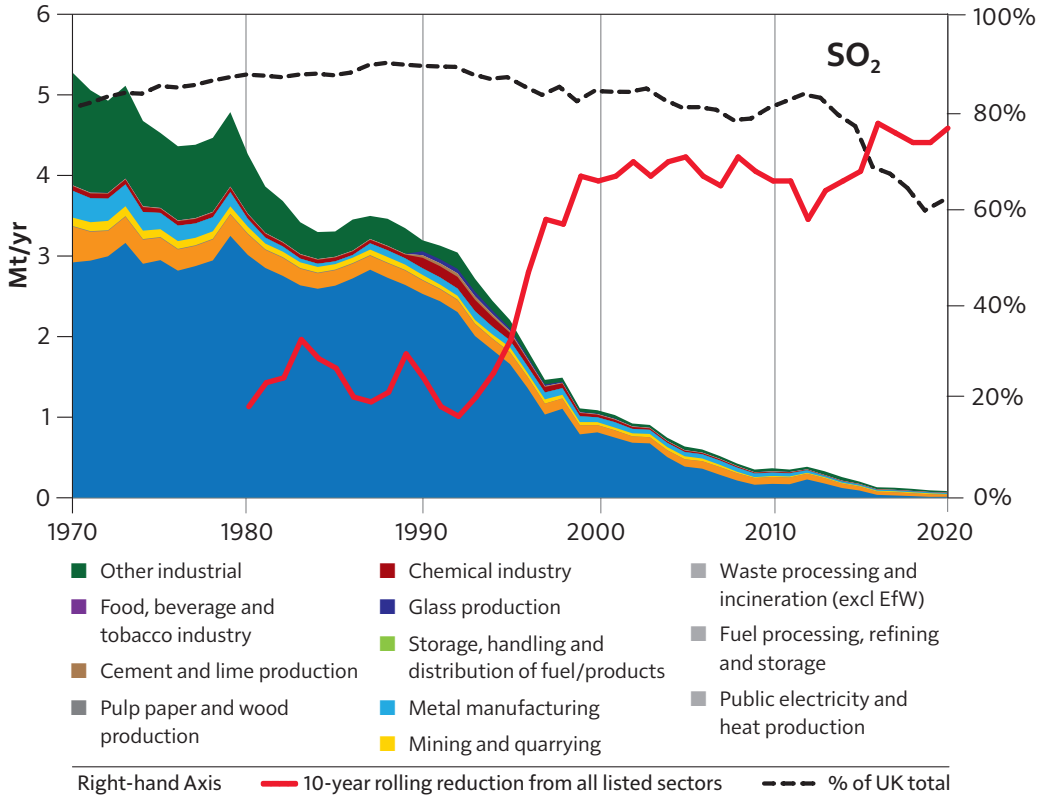


Source: Department for Transport (2022)[9]

Figure 7: Kilometres travelled by bicycle in Great Britain from 1949 to 2021

4.5.1 – 4.5.3 Industry

Many types of industry have reduced their emissions of air pollutants very substantially over recent decades. The major improvement in SO_2 is the most striking success, with the move away from coal and engineered solutions. $PM_{2.5}$ and NO_2 have also been reduced, or where they cannot be reduced, moved away from areas of high population density. Figures 8a, b, and c show the changes in total emissions from industrial processes of SO_2, NO_x and $PM_{2.5}$ from 1970 to 2020. Reductions in emissions or mitigations for many chemicals which can cause harm through air pollution have been achieved in multiple sectors.



Notes: Also showing the contribution of these sectors to the total reported UK emissions (black dashed line). Red line shows the % change over the preceding 10 years.

Source: National Atmospheric Emissions Inventory[10]

Figure 8a: Total UK emissions of SO_2 from industrial sectors reported in the NAEI

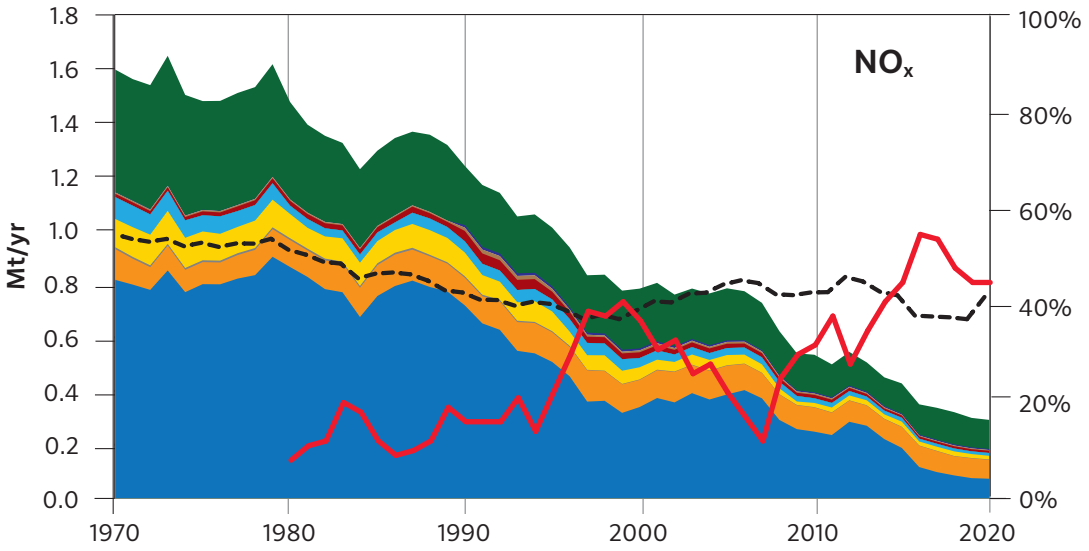
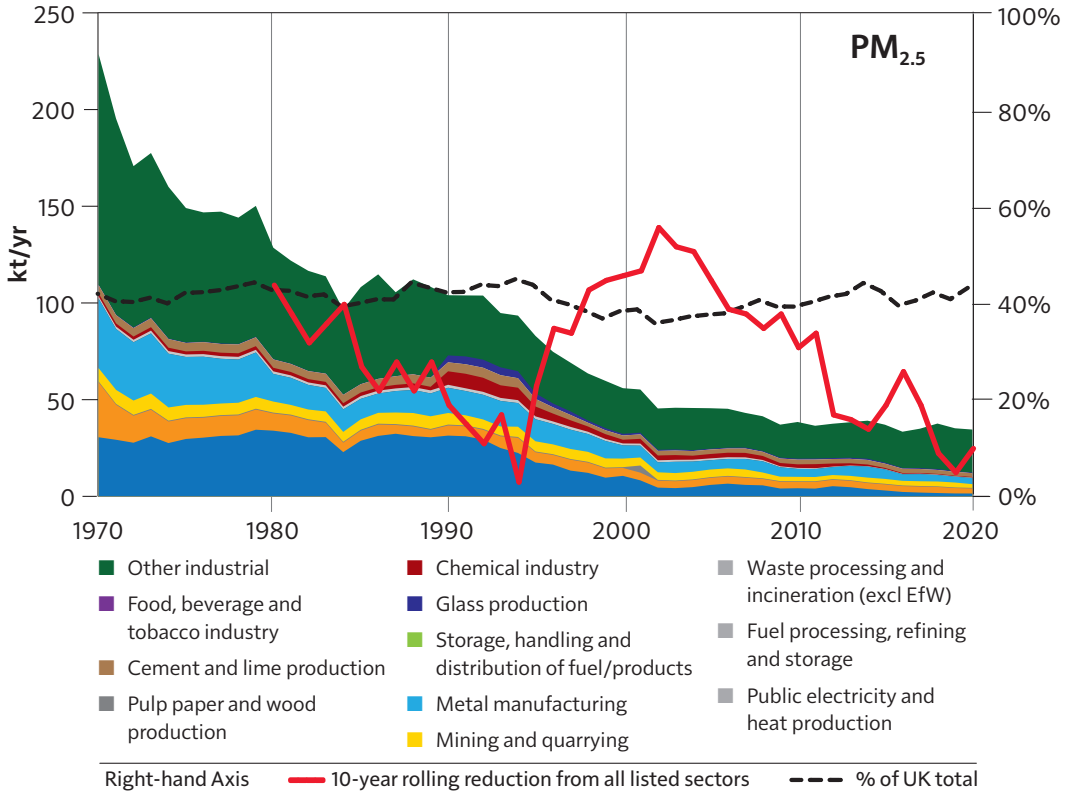


Figure 8b: Total UK emissions of NO_x from industrial sectors reported in the NAEI



Notes: Also showing the contribution of these sectors to the total reported UK emissions (black dashed line). Red line shows the % change over the preceding 10 years.

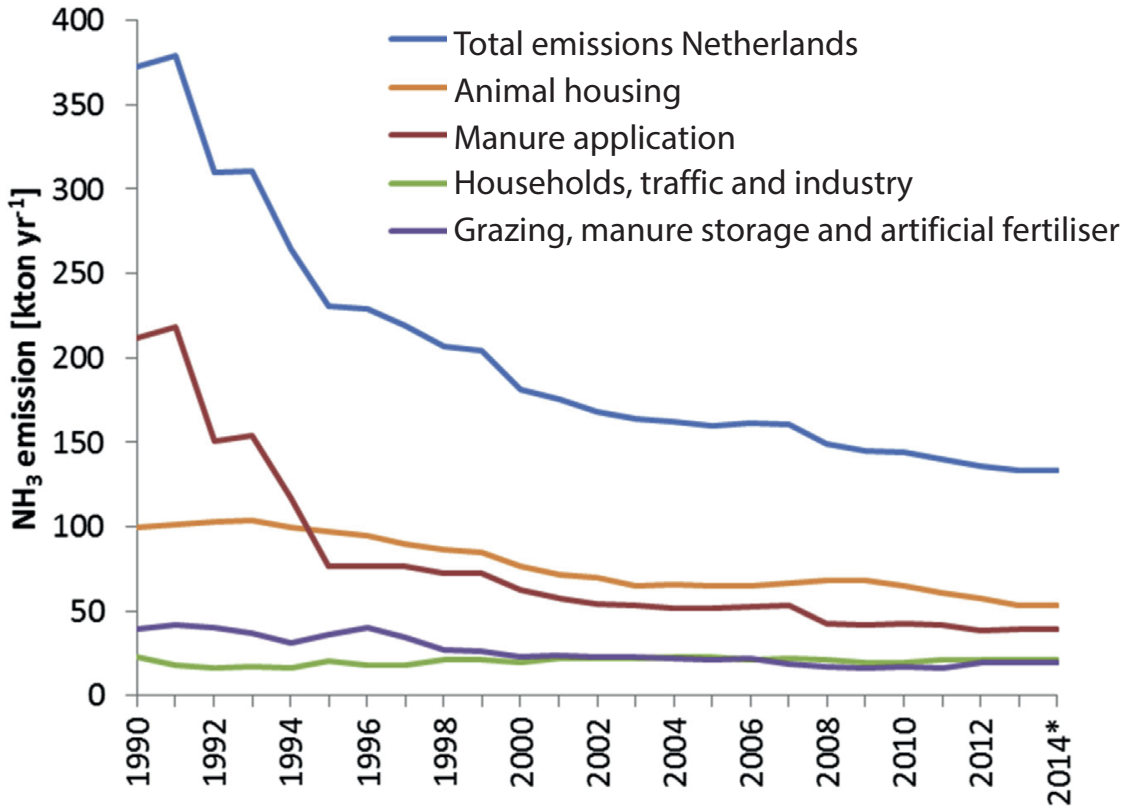
Source: National Atmospheric Emissions Inventory[10]

Figure 8c: Total UK emissions of $PM_{2.5}$ from industrial sectors reported in the NAEI

Regulations have supported a level playing field for industries and encouraged a transition away from processes which gave rise to significant air pollution emissions to those that were either intrinsically cleaner, or had much improved abatement. Some industries will inevitably cause particulate emissions and other air pollution in areas of human habitation, including the construction industry. However, even for these industries, air pollution emissions can be reduced substantially.

4.6 Agriculture

Agriculture is a sector that could, using existing technology, significantly reduce its contribution to air pollution. Ammonia (NH_3) is the most important air pollutant emitted from agriculture. NH_3 has negative effects on ecosystems, but importantly leads also to the creation of secondary $PM_{2.5}$ which can have an effect on health over wide areas. NH_3 emissions have changed very little over the last decades, in contrast to all other major outdoor pollutants. Some countries have demonstrated it is possible to significantly reduce NH_3 by a combination of liquid manure (slurry) covering and changing techniques to apply slurry to fields. Moving from broadcast (splash plate) slurry spreading, where much of the NH_3 ends up in the air, to more direct methods including narrow band spreading, trailing shoe or injection significantly reduces emissions, and can contribute to a reduced need for chemical fertiliser. The Netherlands is an example of where this has been successful, as shown in Figure 9.



Note: *The emissions in 2014 are assumed to be the same as in 2013 in this study as final numbers were not yet available

Source: Reproduced from Wichink-Kruit et al. 2017,[11] © 2017 The Authors. Published by Elsevier Ltd. Licensed under CC BY-NC-ND 4.0

Figure 9: Estimated contributions to the changes in NH_3 emissions from agriculture in the Netherlands, 1990 to 2014

4.7 The NHS

The health sector, and specifically the NHS, needs to contribute to the effort to improve outdoor air quality and is taking steps to do so. It has a large workforce and estate, and a substantial fleet of vehicles, second only to the Royal Mail nationally. Reducing the combustion of fossil fuels used to heat hospitals and other buildings reduces NO_x emissions. Electrification of the vehicle fleet and minimising unnecessary trips reduces NHS transport related air pollution emissions. The example of Great Ormond Street Hospital, working to improve local air quality is described in Section 4.7.2.

4.8 Indoor environments

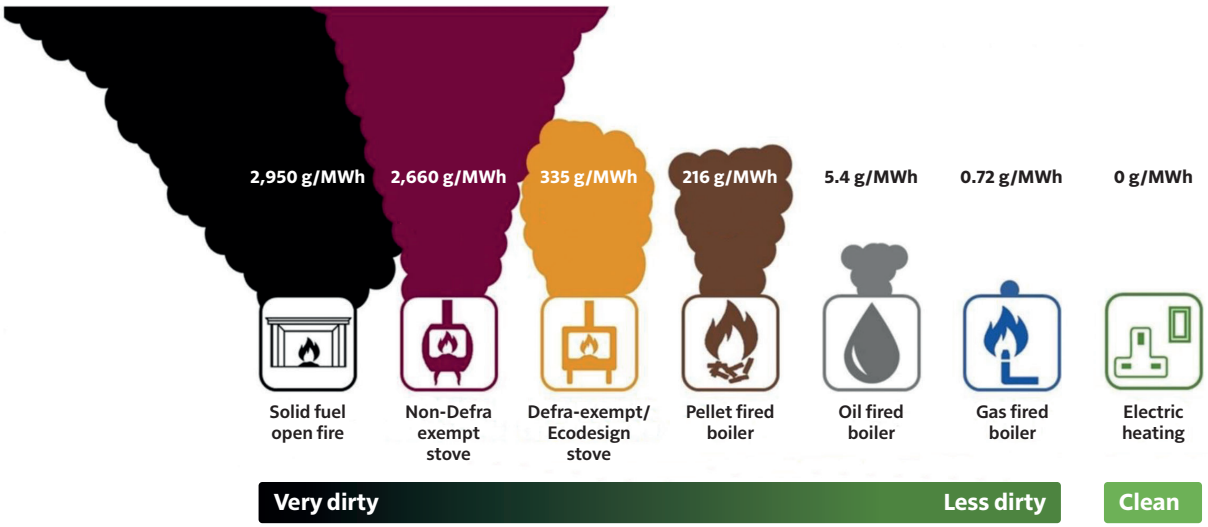
Indoor air pollution is important because over 80% of a typical adult day is spent indoors. Despite this we have much less knowledge about the sources and people's exposure to indoor air pollution, and a less well-developed plan for reducing it. As outdoor air pollution decreases in many environments, indoor air pollution will become the more important opportunity to improve health. Reducing emissions of health harming pollutants is clearly the best option.

Some pollutants may enter buildings from outdoors, and there are also indoor sources of PM and NO_x. Other pollutants such as volatile organic compounds and carbon monoxide are emitted indoors and tend to have higher concentrations indoors. Reducing emissions and concentrations of known pollutants and identifying other chemical indoor pollutants with significant health harms is important.

The role of ventilation is central to reducing unavoidable indoor air pollution, and this is an important difference from addressing outdoor air pollution. A critical engineering challenge is getting the best solution for maximising ventilation, while keeping buildings warm in winter and cool in summer, and minimising energy and therefore carbon use. This is likely to be different in large multi-occupier buildings compared to individual houses, and solutions may vary by season. The role of regulation may well be important in buildings which are public spaces, and in individual products and appliances that are used indoors.

4.9 Domestic space heating, including burning of solid fuels

The heating of buildings presents an important source of indoor as well as outdoor air pollution. Some historically important forms of indoor air pollution have largely gone, such as domestic coal burning. There is a substantial difference between the least and most polluting methods of domestic heating, as shown in Figure 10.



Note: The air pollution emissions will also depend on the age of the appliance, how it is maintained and used and the fuel burned (for example, dry or wet wood).

The following definitions were used: *Solid fuel open fire*: wood burned in an open fire. *Non-Defra-exempt stove*: wood in a conventional stove. *Defra-exempt/Ecodesign stove*: wood in an advanced/ecolabelled stove. *Pellet fired boiler*: wood in pellet stoves and boilers. *Oil fired boiler*: fuel oil in a medium (>50KWth <1MWth) boiler. *Gas fired boiler*: natural gas in a small (≤50kWth) boiler.

Source: Emission factors taken from EMEP 2019 Guidebook[12] (1A4 small combustion tables). Adapted from the Clean Air Strategy[13] with updated data

Figure 10: The relative $PM_{2.5}$ emissions from domestic heating methods

Solid fuels are by far the most polluting method of domestic heating, and wood burning has increased in popularity over recent years. Reasons for burning wood and other solid fuels vary, and include aesthetic as well as practical, ecological or economic reasons. For air pollution emissions, there is substantial difference between the different open fire and stove designs, the age of the appliance and how well maintained it is, and the moisture content of the wood, for those who want to burn wood. In urban areas, burning wood has the potential to worsen local air quality significantly.

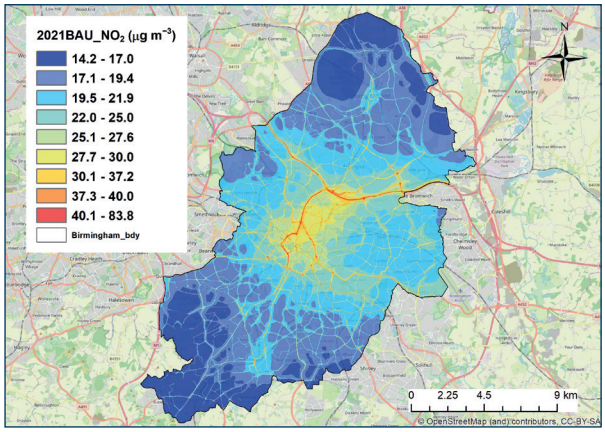
Chapter 5 – Air pollution chemistry, monitoring, forecasting and information

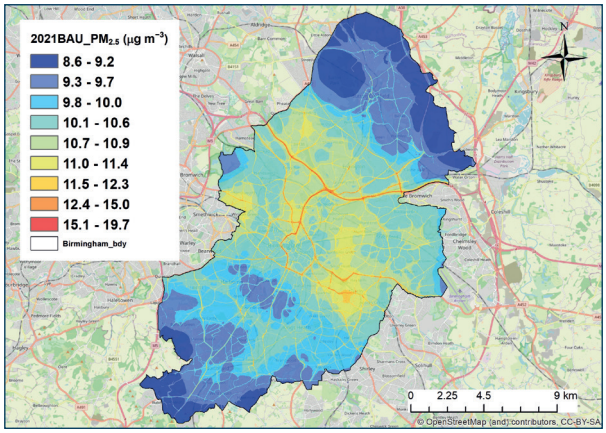
Section 5.1 covers a more detailed examination of where air pollution comes from, and where it goes to. This includes the transport of different pollutants, and how some can transform to secondary pollutants. Broadly the more persistent the pollutants are, the wider their effect geographically. Air pollution also varies by time of day and by season.

Section 5.2 turns to air pollution monitoring, forecasting and alerting – with alerting being particularly helpful for people who are medically vulnerable to harm from air pollution. Section 5.3 covers patient and public information about air pollution. This is especially useful when healthcare workers are giving simple, practical advice to potentially vulnerable children and adults.

Chapter 6 – City examples – work to reduce air pollution

Chapter 6 presents interventions to reduce outdoor air pollution at a city-wide level, considering the examples of Birmingham, Bradford and London. Each of these cities have had significant challenges around air pollution and have taken slightly different approaches to tackle it. These integrate actions including around transport, urban planning and design, reducing pollution around schools and monitoring at a city level. Figures 11 and 12 show maps of NO_2 and $PM_{2.5}$ air pollution across Birmingham.





Source: Zhong et al. (2019)[14] as part of the West Midlands Air Quality Improvement (WM-Air) programme[15]

Figure 11: Annual air quality map of mean NO_2 over Birmingham for 2021

Figure 12: Annual air quality map of mean $PM_{2.5}$ over Birmingham for 2021

Chapter 7 – Air pollution research and innovation

Chapter 7 turns to air pollution research and innovation. For some air pollutants, knowledge of sources, impacts and potential solutions already exists, and it should now be a matter of getting on and doing what we know works. There are however some significant research gaps, both in understanding how certain pollutants are generated, transformed and interact with the human body, and in designing countermeasures and mitigations. These include the health effects of different components of PM, a better understanding of indoor air pollution, and economic analyses of air pollution interventions. Countermeasures that need further development range from tyre design to research on energy-efficient and heat-retaining building ventilation.

Appendix

The report's Appendix lays out the range of publicly funded research on air pollution, currently being undertaken, funded by UK Research and Innovation, National Institute for Health and Care Research, government departments and some international research funded by the Wellcome Trust.

We hope that those reading this CMO Report will come away both with a sense of the scale of the challenge, but also the substantial progress that has been, and will be, made. Air pollution is an environmental risk to health that can, and should, be solved systematically.

Christopher Whitty, Chief Medical Officer for England

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Recommendations

Overall

Outdoor air pollution

1. Outdoor air pollution is falling and will fall further, provided we continue and accelerate the things we know work. This requires action in many sectors, but the interventions are all realistic. We need to focus on areas where people live, study, work and have leisure.

Indoor air pollution

2. As outdoor air pollution falls, indoor air pollution becomes a greater proportion of the problem. Ventilation and reducing emissions are important. Several interventions are highlighted in the report. However, the path to improvement is not as clear as for outdoors, and further research will be needed.

Specific recommendations

Transport

3. The electrification of light vehicles and public transport is important for reducing air pollution from vehicle tailpipes – momentum must be maintained, and accelerated wherever possible. Emissions from tyres and road wear will not be improved by electrification, and this is a key research and innovation need.

4. A greater range of options for reducing air pollution emissions from heavy vehicles is needed. Some specialised vehicles such as refrigerated units need to be addressed, especially in urban areas.

5. The electrification of railways can significantly reduce air pollution emissions from trains and improve air quality for travellers, staff and those living nearby. Where this is not possible, bi-mode or other low-pollution technologies should be used. Closed spaces are important, for example we should look to end diesel trains being left running in enclosed stations.

Urban planning

6. With national government, local authorities are central in the response to air pollution. Urban planning should support reducing air pollution concentrations locally – such as reducing air pollution near schools and healthcare settings. Shifting to active travel where possible has direct health wins as well as reducing air pollution from vehicles – planning should support this.

Industry

7. The substantial improvements from industrial processes over recent years are impressive. Wherever possible remaining industries that emit pollution should be sited away from densely populated areas. Where they cannot, such as construction, mitigations can significantly reduce the impact and they should be adhered to.

Agriculture

8. Ammonia emissions from agriculture contributes to secondary particulate matter air pollution, which can travel large distances and affect populated areas. Significant reductions in ammonia air pollution could be achieved by precision application of slurry to, or into soil, and covering slurry-stores. There would be capital costs, but these changes could be self-sustaining afterwards.

The NHS

9. The NHS is committing to halving its contribution to poor air quality within a decade while reducing health inequalities.

10. The training of healthcare staff should include the health effects of air pollution and how to minimise these, including communication with patients.

Indoor air pollution

11. People spend large periods of time indoors and many indoor places are public, where individuals have little control over the quality of air they breathe. These two factors should be recognised in the planning and development of public indoor spaces.

12. Effective ventilation, while minimising energy use and heat loss, is a priority for reducing air pollution, respiratory infections and achieving net zero. This is a major engineering challenge which needs solving.

13. While there is co-ordination across government, the ownership of indoor air quality policy within government needs to be clarified.

Wood stoves and other solid fuel heating

14. The use of wood stoves is increasing and can impact air quality significantly in urban areas. Air pollution emissions can be reduced, but not fully eliminated, by using modern, less polluting stoves and burning wood that is dry. In smoke control areas, the rules should be adhered to.

Research

15. Research priorities are highlighted in the research section. Indoor air pollution in particular needs greater research interest. Policies should be evaluated once implemented.

There are other recommendations in the different sections of the report.