The health effects of air pollution: time to act

Tuesday 13 March, 2018

"This paper on the health effects of air pollution from Policy Connect comes at a significant time. We are beginning to understand the full effects of air pollution on a whole range of health conditions from lung and heart disease to cancer, and urgent action is now needed by the Government to get emissions down, especially from highly polluting diesel vehicles. With an estimated 40,000 premature deaths in the UK caused by the effects of outdoor air pollution each year, the impact of air pollution on health and its cost to the economy is moving towards the 80,000 annual deaths linked to smoking."

Geraint Davies, Member of Parliament for Swansea West, and promoter of the Clean Air Bill (2017-19).

EXECUTIVE SUMMARY

The scale of the problem

1. European and global health leaders are increasingly concerned about the toll that air pollution is taking on human health. In the UK it is estimated that 40,000 - 50,000 premature deaths each year are linked to air pollution, while the EU estimates that air pollution is responsible for more than 500,000 premature deaths across Europe annually. Worldwide, the number of premature deaths due to outdoor air pollution is estimated to be three million by the World Health Organization. The Royal College of Physicians and Royal College of Paediatrics and Child Health concluded in 2016 that indoor and outdoor air pollution costs the UK economy around £20bn per year in terms of healthcare costs, premature illness and the impact on business.

2. The scale of cardiorespiratory morbidity and mortality caused by outdoor air pollution is now widely acknowledged to be considerable, with other diseases such as a range of cancers, now also being linked to air pollution.

3. This briefing focuses on outdoor air pollution - in particular, the impacts of nitrogen dioxide (NO_2) and particulates on human health. However other forms of air pollution, including heavy metals, can also have an impact on health at low levels. For some pollutants there are no safe limits.

What medical research is telling us about the wide range of health effects caused by air pollution

1. It has been known for many years that air pollution can affect the respiratory system, but it is also now implicated in more serious conditions such as cardiovascular disease and cancer; it has even been potentially linked to neurological disorders such as dementia and diabetes. People with existing respiratory or heart conditions are also far more susceptible to the effects of air pollution. The overall impact of air pollution on health is complex; most commonly it makes existing conditions worse. However, there is now some evidence that air pollution can: cause the onset of some conditions such as asthma; lead to poor lung development in the womb resulting in illness later in life; and, by complex vascular mechanisms, increase a person's risk of suffering from a stroke.

2. As early as the 1990s, researchers in the U.S. concluded that particulates should be considered as mutagenic carcinogens for which there is no safe level. The International Agency for Research on Cancer (IARC) has also classified outdoor air pollution as a carcinogen, concluding that it can cause lung cancer. For the UK it is estimated that 7.8% of lung cancer cases each year are attributable to PM2.5 air pollution exposure – or approximately 3,500 people out of a total of around 45,000 cases in the UK each year.

3. Young people, the elderly, and those with pre-existing, long-term conditions are particularly susceptible to the effects of air pollution. Evidence shows that exposure to pollution during pregnancy can have potential life-long impacts for the foetus including on the early development of the brain, and on psychological and behavioural impacts later in childhood. Some epidemiological studies also now point to a potential association between exposure to air pollution and cognitive impairment in older people, including vascular dementia and Alzheimer's disease, although further research is required to determine the exact nature of cause and effect.

What further medical research is needed?

1. Determining which pollutants trigger - or exacerbate - which particular health conditions is important- both in terms of (i) short-term and long-term exposure and (ii) for different populations, especially vulnerable groups.

2. It also needs to be determined whether existing and new EU air pollution limits, currently set out in UK legislation, are wholly adequate for protecting human health. This includes pollutants for which the health effects are less well understood (e.g. many gaseous pollutants) and/or can be less easily measured (e.g. smaller ultrafine particles for which no recommended limits currently exist).

3. The evidence for a link between air pollution and cardiovascular and respiratory disease is now well established and strong, in particular for sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter. However, further research is needed to better understand the biology behind these links as this will help scientists to determine more specific questions, such as which pollutants are the most harmful, who is especially at risk, and which technological/medical/policy interventions are likely to be the most successful in addressing the health problems associated with air pollution.

4. Further medical investigation is also needed to verify the emerging links between different types of air pollution and a much wider range of health conditions, including: cancers, diabetes, cognitive impairments in the young and old; vascular dementia; endocrine and immune disorders; and the effects of air pollution on the foetus during pregnancy. Other legitimate areas for investigation include possible links between air pollution and kidney disease, gastrointestinal conditions, liver disease, depression and the body's repair mechanisms.

5. Finally, further consideration should be given to the likely impact of climate change on air pollution and any subsequent effects that this might have on health.

Current air pollution limits and targets – what does the future hold post-Brexit?

1. WHO target levels and EU air pollution legal limits differ for different pollutants, with WHO target levels, generally, being more stringent than EU legal limits. After Brexit, the UK Government needs to decide whether: it will continue to apply existing and future EU pollution limits; it will relax EU pollution limits; or whether it will make legal limits more stringent than EU values to protect human health.

2. A guiding principle for the Government should be whether present EU pollution targets, as set out in UK legislation, and any future limit values, are adequate for the protection of human health. In this context, it is important to determine the health impacts of short-term spikes in local particulate, NO_2 emissions and ozone, and the effects on health where pollution levels consistently exceed legal limits. In addition, the Government needs to take into account the fact that there are currently no recommended legal limits or target values for ultrafine particles, now being linked to a wide range of disorders including strokes.

3. In the short term, it is clear that urgent action is needed to tackle air pollution from vehicles, including through developing a comprehensive strategy to reduce the UK's heavy reliance on diesel fuel, given that it is a major source of ultrafine combustion-derived particles and NO_2. The UK's high relatively death rate linked to air pollution, compared to similar European countries, could be potentially linked to the UK's heavy reliance on diesel.

The need for a national air pollution monitoring strategy

1. In the UK, a national air pollution monitoring strategy is needed, as there is currently no uniformity of methods for collecting air pollution data across the country. There is also, currently, no duty on local authorities to monitor air pollution, and no specific funding stream to support this.

2. Given the above, at the national and local level, the responsible authorities should put in place robust monitoring networks, supported by dedicated funding streams, to be better able to acquire the high-quality data needed to support preventative and remedial action in order to deliver on existing, and future, air quality targets.

Determining the full financial implications of air pollution for the healthcare system and the wider economy

The Government should undertake an in-depth analysis of the total financial burden associated with air pollution across the UK, to expand upon the work already done for London by King's College London; this should look at both the total healthcare costs associated with short-term, and long-term exposure to different pollutants, and the consequent impact on the economy and society of the ill-health and excess deaths caused. This would provide a much-needed impetus for key stakeholders to take the practical action needed to address both the short-term and irreversible health effects of air pollution.

The need for improved public health information

Given the threats to health posed by air pollution, improved information should be made available to the public, schools, colleges and employers on minimising personal risk through taking 'cleaner' routes to work, differential risks associated with taking different forms of transport, and other relevant health information. Health advice should be made available in much the same way as advice was provided on the risks associated with passive smoking in public places.

The urgent need to phase out diesel fuel

In the early 2000s, financial incentives were provided to consumers to switch to diesel fuel in order to protect the environment from the greenhouse gases associated with climate change. This has clearly had serious health implications for all sections of the population – particularly (i) those people already suffering from health conditions such as respiratory and heart disease, and (ii) populations living in highly urbanised areas, who often experience other heath inequalities. There is now an urgent imperative to reverse that policy decision in order to protect public health.

INTRODUCTION

Outdoor air pollution (also known as ambient air pollution) is a global problem, particularly associated with industrialised countries whose economies, transport and heating systems are heavily reliant on fossil fuels. There is now growing concern worldwide about the impact of outdoor air pollution on health, particularly on vulnerable groups, such as children, the elderly and those with pre-existing health conditions. Indoor air pollution can also have serious effects on health although in this briefing we shall only be looking at outdoor air pollution.

The Health Group at Policy Connect has produced this briefing on the major health effects associated with outdoor air pollution that are documented in the medical literature, including some very recent research developments. A report by the Royal College of Physicians and the Royal College of Paediatrics and Child Health in 2016, estimated that the number of deaths in the UK brought forward by the effects of air pollution is around 40,000 a year [1]. We will examine the data around excess deaths linked to air pollution later in this briefing.

The 1952 London Smog: the beginning of UK air quality legislation

Air quality in the UK has improved significantly since the first Clean Air Act came into force in 1956 [2] after the great London smog of December 1952, when people living in the city burned large quantities of coal in their homes because of particularly cold weather conditions at the time. Around 4,000 people are known to have died as a direct result of this weather event and the associated increased burning of coal, and an additional 100,000 people were affected by the impact which the smog had on their respiratory systems, accentuated by the calm meteorological conditions at the time [3]. More recent research suggests that the total number of deaths was even greater - possibly up to 12,000 - due to an overestimation of the number of deaths attributable to influenza that year [4]. This event illustrates that, at its worst, air pollution can kill, and that its effects can be influenced by one factor beyond our control - local weather conditions.

The Clean Air Act 1956, which aimed to control domestic sources of pollution by introducing zones where only smokeless fuels could be burnt, was successful in reducing pollution from smoke and sulphur dioxide. This legislation was followed by the Clean Air Act 1968 [5] which specified that only tall chimneys could be used for the industrial burning of coal, liquid or gaseous fuels, in order to improve the dispersal of air pollution. The subsequent Clean Air Act 1993 [6] prohibited dark smoke from domestic, industrial and trade premises, and required that new furnaces should, so far as practicable, be smokeless, with further limits on emissions of grit, dust, smoke and fumes from industrial sources.

While outdoor air pollution from industrial sources has fallen dramatically over the past three decades, largely due to the above-mentioned legislation and the decline of heavy and polluting industries in the UK, air pollution linked to road transport has become of far greater concern. Increasing recognition of the harmful impacts of air pollution on health has also led to a developing body of EU air quality legislation, which we will look at below.

Almost all forms of air pollution in the UK have actually been declining relatively steadily over the past three decades according to official data, as shown in Fig. 1 [7]. Fine particulates and nitrogen oxide emissions, for example, are about one quarter of what they were in 1970. Of course, this is not the situation in many other countries around the world such as China and India, where pollution levels have been rising steadily due to rapid industrialisation, with major implications for human health.

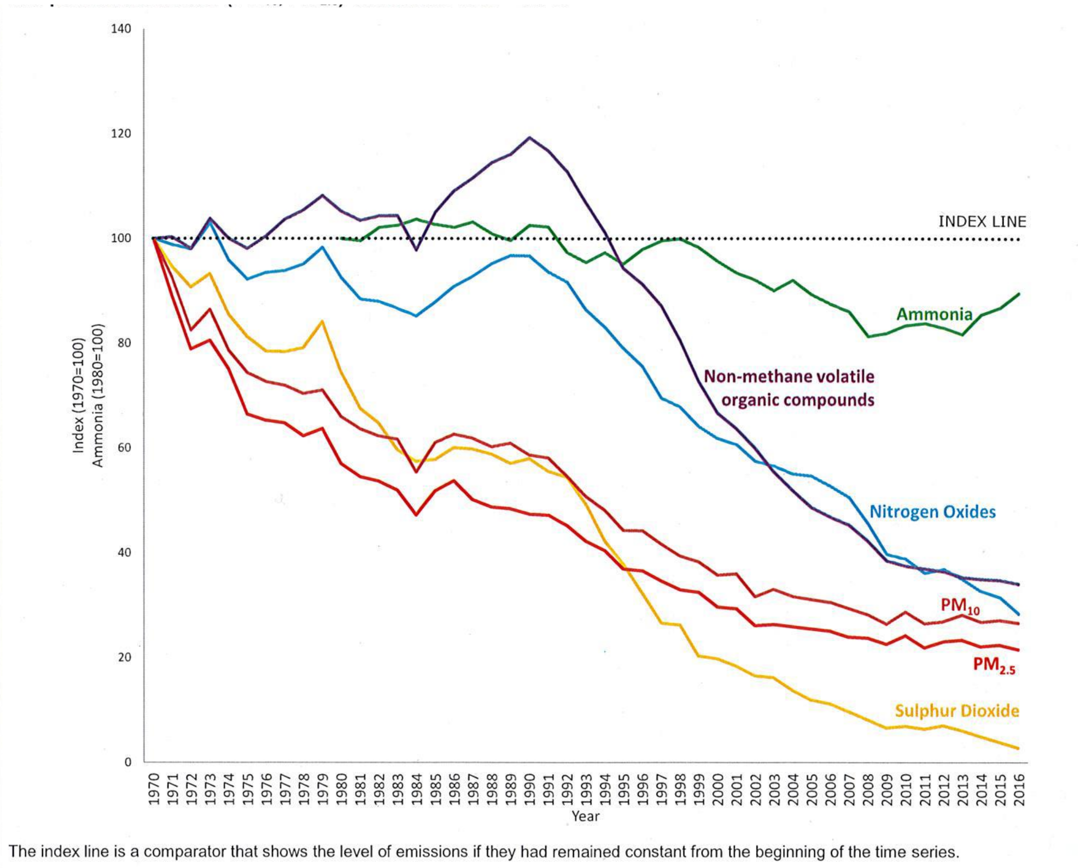

Fig.1: Trends in UK sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia and particulate matter (PM10, PM2.5) emissions 1970 – 2016 (Source, Defra, 2018)[7]

Nonetheless, it should not be forgotten that while in rapidly industrialising countries, heavily dependent on fossil fuels, outdoor air pollution is *generally* far worse than in the UK, on a rare number of days, London air pollution levels have matched those in Beijing, including in January 2017, when the combination of cold, calm and settled weather conditions and pollution from both traffic and domestic wood burning stoves, caused parts of London to be put on red and black air quality alerts[8].

In summary, while outdoor air pollution levels have declined overall in the UK, it is the negative impact of air pollution on health that is now becoming much more widely understood, raising concerns globally about the problem.

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1. The developing body of EU legislation on air quality

The European Commission, through its developing air quality legislative programme[9] has identified pollutants in the air (either gaseous or particulate) which are potentially hazardous to human health at certain levels. These include:

- Sulphur dioxide (SO_2)
- Nitrogen oxides (NOx and NO_2)
- Fine particulates (PM2.5)
- Coarse particulates (PM10)

- Carbon monoxide (CO)
- Ozone (O_3)
- Benzene
- Lead (Pb)
- Arsenic (As)
- Cadmium (Cd)
- Nickel (Ni)
- Polycyclic Aromatic Hydrocarbons

Through a succession of Directives, the EU has set upper emission limits for these substances to protect the population from the negative health effects associated with high concentrations of these pollutants. EU limit values are currently legally binding parameters that must not be exceeded, and they have been translated into UK law. The impact of Brexit on the UK's adoption of any potentially tighter EU air quality standards after 2019 (or the subsequent two-year transitional exit period) remains open to question.

The two key pieces of legislation governing air quality in the EU, including the UK, at present, are:

Directive 2008/50/EC of 21/05/2008 on Ambient Air Quality and Cleaner Air for Europe – commonly known as the 'Air Quality Directive', applying to sulphur dioxide (SO2), nitrogen oxides (NOx) particulate matter (PM10 and PM2.5), lead, benzene, carbon monoxide and ozone [10]; and Directive 2004/107/EC of 15/12/2004, applying to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air – commonly known as the 'Fourth Daughter Directive' [11].

These two Directives set 'limit values', 'target values' and 'long-term objectives' for outdoor (ambient) concentrations of pollutants. Limit values are legally binding and must not be exceeded.

The UK is also currently bound by the updated National Emissions Ceilings (NEC) Directive (2016/2284/EU) [12], which entered into force in December 2016, and which sets upper national emission reduction commitments for all the Member States and the EU for five key air pollutants: nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), ammonia (NH_3) and fine particulate matter (PM2.5). The Directive sets national emission reduction commitments for these five pollutants for the period between 2020 and 2030, designed to reduce premature deaths across the EU caused by air pollution, estimated to be around 400,000 in the EU-28 for PM2.5 particulates alone in 2014[13].

Finally, emissions from specific industrial sources are covered by the EU's Industrial Emissions Directive [14] and our Clean Air 1993 [6] and the UK is also bound by the 1979 Gothenburg Protocol to the UNECE Convention on Long-range Transboundary Air [15], as updated, which covers the transmission of pollutants across international boundaries.

In the UK, the responsibility for meeting air quality limit values is devolved to the national administrations in Scotland, Wales and Northern Ireland. The Secretary of State for Environment, Food and Rural Affairs has responsibility for meeting the limit values in England and Defra co-ordinates assessment and air quality plans for the UK as a whole. The UK Government and the devolved administrations were required under the Environment Act 1995 to produce a comprehensive national air quality strategy. This was last reviewed and published in 2007[16], over a decade ago now. This strategy set out the UK's air quality objectives, recognising that action at the national, regional *and* local levels would be needed to tackle air quality problems, depending on the scale, source and nature of the pollutants.

In February 2017, a campaign was launched by a coalition of health organisations, charities and activists - including Greenpeace, the British Lung Foundation, the Royal College of Physicians and Sustrans - co-ordinated by the environmental law group, Client Earth, calling for a new Clean Air Act to protect the population's health [17]. Last year, in July 2017, Defra and the Department of Transport, following a short consultation period, published more limited guidance, specifically on tackling NO_2 air pollution[18]. A report published by the National Audit Office at the end of 2017, however, concluded that - despite overall improvements in the UK's air quality - it is not anticipated that the UK will fully meet even existing EU air quality targets before 2021[19].

In January 2018, tighter controls on air pollution from combustion plants and generators were approved by Parliament[20]. These regulations are expected to account for 43% of the reduction in sulphur dioxide (SO_2) emissions, 9% of the reduction in particulate matter, and 22% of the nitrogen oxides (NO_2) emissions reductions that are required to meet the UK's existing EU pollution targets for 2030. The new emission limits will come into force this year, implementing the EU's Medium Combustion Plant Directive (EU) 2015/2193[21].

However, in January 2018, the Welsh Government was a defendant alongside the UK Government, in a legal challenge over the claim that the Government's air quality plans still do not include measures which will bring the UK into compliance with current EU air pollution laws "as soon as possible"; this was ClientEarth's third judicial review against the UK Government [22]. On 21 February 2018, ClientEarth won their case. In a ruling handed down at the High Court in London, the judge declared the Government's failure to require action from 45 local authorities with illegal levels of air pollution in their areas to be unlawful, ordering Ministers to require local authorities to investigate and identify measures to tackle illegal levels of pollution in 33 towns and cities as soon as possible. The Welsh Government has now said that its Ministers will work with ClientEarth to develop a legally-binding air pollution agreement. The UK Government is also due to publish a draft Clean Air Strategy for consultation in 2018.

	European Commission (applying in UK)		**Scottish Government**		**World Health Organization**	
	Legal limits		Target values		Air quality guidelines	
Pollutant	Concentration	Averaging period	Concentration	Averaging period	Concentration	Averaging period
Sulphur Dioxide	350 µg/m3 125 µg/m3	1 hour 24 hours	350 µg/m3 125 µg/m3	1 hour 24 hours	20 µg/m3	24 hours
Nitrogen Dioxide	200 µg/m3 40 µg/m3	1 hour 1 year	200 µg/m3 40 µg/m3	1 hour 1 year	200 µg/m3 40 µg/m3	1 hour 1 year
PM10	50 µg/m3 40 µg/m3	24 hours 1 year	50 µg/m3 18 µg/m3	24 hours 1 year	50 µg/m3 20 µg/m3	24 hours 1 year
PM2.5	25 µg/m3	1 year	10 µg/m3	1 year (by 2020)	25 µg /m3, 10 µg/m3	24 hours 1 year
Ozone	120 µg/m3	Maximum daily 8 hour mean	100 µg/m3	Maximum daily 8 hour mean	100 µg/m3	Maximum daily 8 hour mean

Table 1: Summary of current EU legal limits and Scottish Government and WHO target values for selected air pollutants (Source: EU 10, Scottish Government 23 and World Health Organization 24)

In Scotland, the Scottish Government now recommends the introduction of more ambitious air pollution targets for particulates than the current upper legal limits which apply to the UK as a whole, based largely on World Health Organization (WHO) air quality target values, rather than the EU's legal limits. In their comprehensive strategy, Cleaner Air for Scotland - The Road to a Healthier Future[23], the Scottish Government specifies an annual average target value for PM10 of 18ug m^{-3} (18 microgrammes per cubic meter of air), as opposed to the 40ug m^{-3} legal limit applying to the UK as whole. The Chartered Institute for Environmental Health (CIEH) says it could be argued that the lower limit in Scotland, or even a target level of 20ug m^{-3}, in line with WHO recommendations, might be a more appropriate, outcomes-focussed, goal for the UK as a whole, rather that the current EU legal limit for PM10[25]. Likewise, when it comes to prioritising human health, a specific PM2.5 target could potentially be introduced across the UK based on the Scottish guideline of 10ug m^{-3}, according to the CIEH, again reflecting current WHO recommendations.

It should be noted that there is a lack of *absolute* safety in embracing any specific limits for air pollution, and the As Low As Reasonably Achievable (ALARA) principle is, in reality, the most appropriate goal when it comes to protecting human health. Clearly in the UK, with its highly urbanised population, dense road network and breaches of some EU pollution limits, we are still a long way off achieving this goal.

2. The major forms of air pollution affecting the UK today

While air pollution may be a local problem in smaller towns, for example around busy road junctions, or it may be concentrated around power stations and/or industrial plants, or be accentuated by local topography and weather conditions, it is a particular problem - and therefore has its greatest impact on health - in the major conurbations of the UK: Greater London, Birmingham and the West Midlands, Greater Manchester, Leeds, the Glasgow region, and to a lesser extent Tyneside and South Wales. Here concentrations of air pollutants are at their highest.

We shall now look at the major gaseous and particulate forms of air pollution in turn (excluding heavy metals) and the risks they pose to human health. The pollutants of particular concern for health are now thought to be nitrogen dioxide (NO_2) and smaller particulate matter (PM2.5), both closely linked to diesel vehicle emissions (see Section 5 below).

Sulphur Dioxide (SO_2)

When it comes to sulphur dioxide (SO_2) - identified as the main cause of the London smog deaths - the gradual decline in coal-fired power stations and in the home, together with flue-gas desulphurisation in power plants, has led to a sharp decline in SO_2 emissions across the UK, with emissions from power stations in 2015 falling to just 3% of their 1970 levels[26]. Sulphur dioxide therefore poses a far lower risk to human health today. In addition, the new UK Government regulations, implementing the EU's Medium Combustion Plant Directive mentioned above, should further improve SO_2 emissions from UK power plants.

Particulate Matter

Particulate matter (PM) of all sizes used to be referred to as black carbon, but it is now, generally, classified as PM particles of different sizes, based on the aerodynamic diameter of the particles.

This is the key classification used when describing particulate matter in the air (see the Glossary at the end of this paper for more detailed definitions):

- Total suspended particulates (TSP) are all particles in the air regardless of size.
- PM10 is all particulate matter with a diameter of less than 10 µm (micrometres: 1 micrometre is 1/1,000,000 metre)
- PM2.5 is the smaller part of PM10, consisting of all particles with a diameter of <2.5 µm (often referred to as 'fine' particles).
- Coarse particulate matter (PMc) is technically everything between 10 and 2.5 µm i.e. the difference between PM10 and PM2.5.

Ultrafine particles are the smallest fractions of PM2.5 and are <0.1 µm (100 nanometres) in diameter (1 nanometre is 1/1000,000,000 metre); they are sometimes referred to as nanoparticles in the context of manufactured ultrafine particles, but the term ultrafine particles will be used for the purposes of this briefing.

Coarse Particulate Matter (PM10)

PM10 (above PM2.5 in diameter), is the coarse fraction of the particles of liquid or solids in the air we breathe. It comes, largely, from crushing or grinding industrial operations, as well as from dust stirred up by vehicles on our roads. These particles are small enough to be inhaled deep into the lungs, which is why they are therefore sometimes called the 'inhalable' or 'thoracic' fraction of particles. The Department for Environment, Food and Rural Affairs (Defra) said in 2016 that all zones in the UK "met the limit value for annual mean concentration of PM10 particulate matter"[27] - although Transport for London said, in a recent technical note, that there is no 'safe' level for this particular pollutant[28].

According to a WHO study published in 2016, using air quality data from 2008 to 2013, annual average PM10 levels exceeded WHO target limits in ten urban areas in the UK during that period, including in London[29]. As discussed above, the WHO sets a “safe” annual average of 20ug m^{-3} for PM10, a much lower value than the EU’s 40ug m^{-3} annual legal limit, so such reports can be confusing for the public at large when the legal EU limits are more often quoted by the Government. In this study, while London breached the WHO’s PM10 air quality targets, it actually had better PM10 air quality than Port Talbot and Glasgow, for example. Other areas that breached the WHO’s PM10 safe annual limits were Scunthorpe, Leeds, Eastbourne, Nottingham, Oxford and Southampton: i.e. the effect was seen right across the country. The WHO’s air quality standards are not legally binding, as are the EU’s, which could explain why they can, in practice, specify tougher recommended limits [30].

Non-exhaust, vehicle-related emissions such as resuspension, tyre-wear and brake-wear also contribute to the total burden of coarse PM10 particles, with exhaust and non-exhaust traffic-related sources estimated to contribute almost equally to traffic-related PM10 emissions [31]: any increase in traffic therefore automatically increases both exhaust and non-exhaust pollution in the atmosphere.

Fine Particulate Matter (PM2.5)

PM2.5 refers to tiny airborne particles or droplets with an aerodynamic diameter of 2.5µm or less. The main source of PM2.5 in urban areas is vehicle exhaust (see Fig.3 overleaf) and outdoor levels are most likely to be raised on days with little or no wind or mixing of air, when the air may appear hazy. Particles in the PM2.5 size range are able to travel deep into the respiratory tract, reaching the lungs, but unlike PM10, it is also thought they can pass from the lungs into the bloodstream, potentially posing a much greater risk to health. PM2.5 also persists in the air for longer than large particulate matter. PM2.5 pollution in the UK runs broadly in a band from south-east to north-west England and the Glasgow region, through the major conurbations of the UK [32].

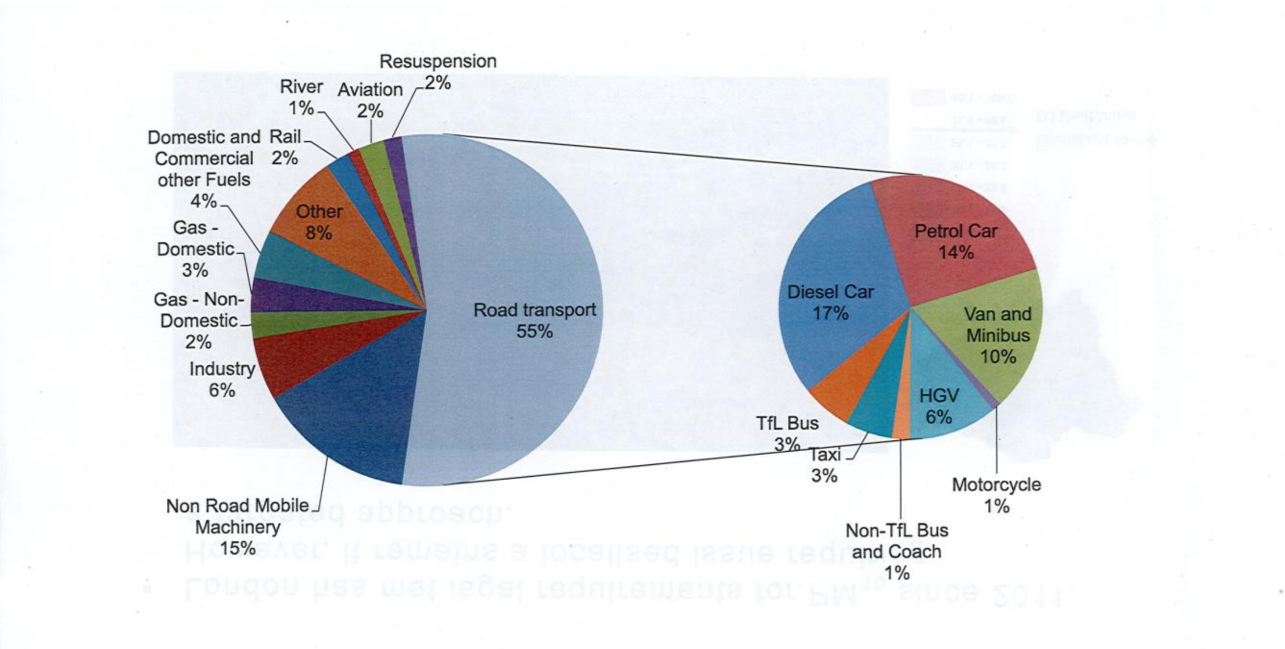

Fig. 2: Average mean PM2.5 concentrations in London in 201333 (Source: Greater London Authority)

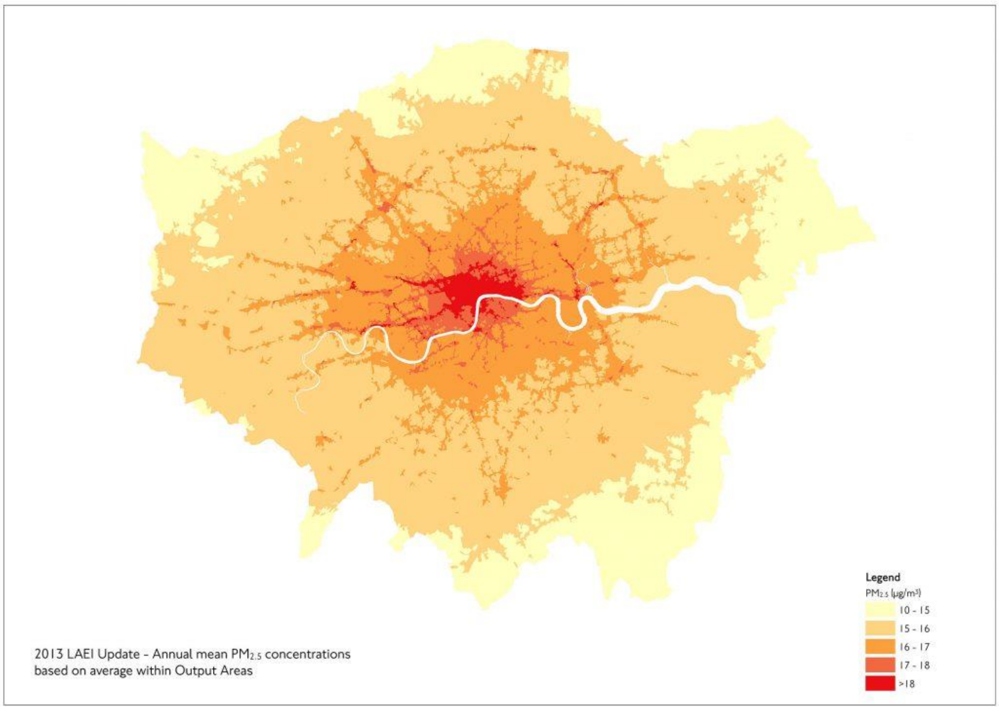

Fig. 3: Source of PM 2.5 Emissions in London by activity 2013[34]

According to the WHO study quoted above [29,] when it comes to PM2.5 air pollution, only 11 of the 51 UK cities measured met the WHO's annual guideline limit for PM2.5 from 2008-2013. One should again note that the non-binding WHO guidelines are more stringent for PM2.5 than the binding EU standards to which the UK has to adhere, with EU legal limits being more than double the WHO's guideline values. In Fig. 2 above, one can see the concentrations of PM2.5 in London for 2013, illustrating particularly high levels in Central London.

Figure 3 illustrates the major sources of PM2.5 air pollution in London in 2013, 55% of which was down to road transport, including a greater percentage from diesel than petrol cars.

It should not be forgotten that the burning of domestic coal for heating, smokeless solid fuels and wood, is also a large contributor to harmful particulate matter in both urban and rural areas. In early 2018, Defra published a consultation on the Domestic Burning of House Coal, Smokeless Coal, Manufactured Solid Fuel and Wet Wood [35] - which closed on 28 February 2018 - in recognition of the fact that the burning of house coal, smokeless solid fuels and wood actually accounts for the single largest source of harmful particulate matter emissions in the UK, at around 40% of the total in 2015 - compared to 17% for industrial combustion and 13% for road transport. The result of the consultation will feed into the Government's Clean Air Strategy to be published for consultation later this year.

Ultrafine particles

Ultrafine particles, the smallest fraction of PM2.5, with a diameter of <0.1 micrometres (100 nanometres) have also, recently, been identified as a particular problem associated with road traffic: it is now thought that a major fraction of particles emitted by road transportation is in the previously unmeasured size range of 1.3 - 3.0nm. For instance, in one US research study, in a semi-urban roadside environment, ultrafine aerosol particles (referred to as nanocluster aerosol particles in the US study - NCA) [36] were found to represent 20 - 54% of the total particle concentration in outdoor air. Ultrafine particles are thought to have a potentially very serious impact on health, as we shall see in Section 7, and yet knowledge about the volume of this fraction of particles in the air has, historically, not been reflected in routine air pollution data collection or standards. Although ultrafine particles can be measured in the laboratory, air quality monitoring equipment in the UK does not currently collect data on this size of particles.

Nitrogen Dioxide (NO_2)

Nitrogen dioxide (NO_2) is a gas, chemically related to nitric oxide (NO). Together, NO and NO_2 are known as NOx. NOx is released into the atmosphere when hydrocarbon fuels are burned, for example, petrol or diesel in car engines, or natural gas in domestic central heating boilers and power stations. It is primarily the NO_2 that adversely affects human health; breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system and aggravate respiratory diseases, particularly asthma.

It was widely reported in the media at the start of 2017[37] that London as a whole had breached its EU annual air pollution limits for NO_2 just five days into the year (although the situation improved slightly in 2018). According to EU law, hourly levels of NO_2 must not exceed 200 µg m^{-3} more than 18 times in a year, but at one site on Brixton Road in south London, this hourly limit had been exceeded 24 times by only 6 January 2017. A similar situation applies on high streets in other London Boroughs; for example Putney High Street exceeded its annual NO_2 limit eight days into 2016.

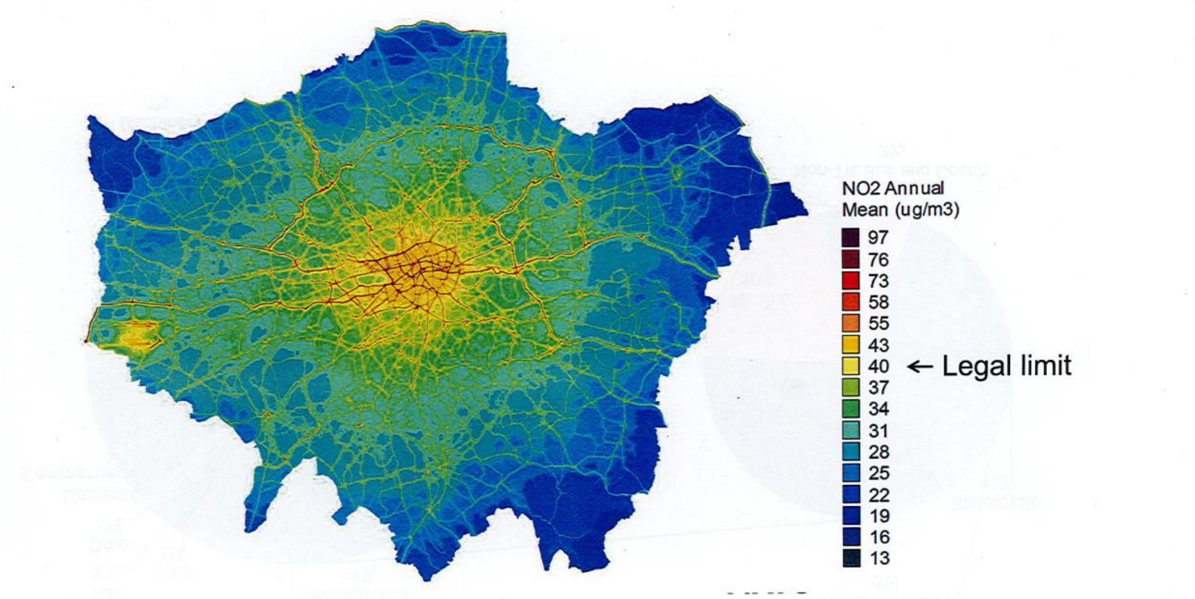

Fig. 4: Annual Levels of NO2 emissions in London in 2013[38] (Source: Aether)

The graphic above shows the distribution of NO2 pollution levels across Greater London in 2013, with the high concentration in central London and around Heathrow being particularly noticeable. This data is four years old now so there could potentially have been a reduction in NO_2 levels since then.

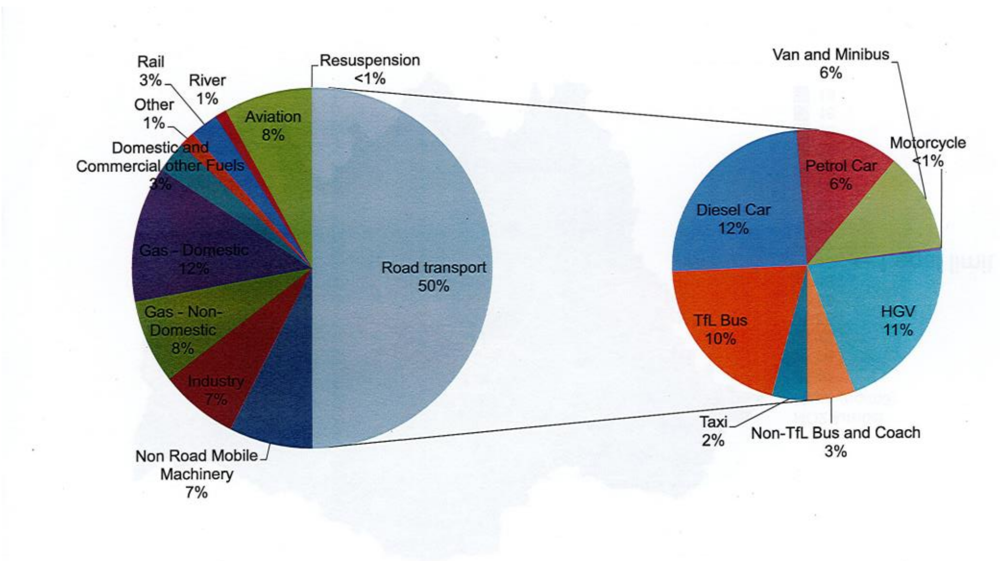

Fig. 5: Sources of all NOx emissions, London 2013[34]

Similar to the pattern in Fig. 4, 50% cent of all NOx emissions were linked to road transport in 2013, of which 12% was from diesel cars and 11% from HGVs.

Ozone (O_3)

Ground level ozone (as opposed to ozone in the upper atmosphere) is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC), in the presence of sunlight. It is still one of the most pervasive outdoor pollutants [39]. Emissions from industrial facilities, power stations, motor vehicle exhaust and chemical solvents are some of the major sources of NOx and VOC and air pollution episodes due to ozone commonly occur in the UK during late spring and summer. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung conditions such as asthma. Children are at particular risk from exposure to ozone because their lungs are still developing and they are more likely to be active outdoors when ozone levels are high, so their levels of exposure may be particularly significant [40]. People who are active outdoors, especially outdoor workers, are also at greater risk in affected areas.

A proportion of the ozone experienced in the UK originating from air pollutant emissions from mainland Europe and beyond. Several European studies have reported that current ozone concentrations in Europe have health effects, especially in the summer, and that daily mortality rises with increases in ozone exposure [41]. Climate change also has the potential to increase ground-level ozone concentrations so this must also be monitored and reflected in measures to tackle ozone pollution going forwards.

The distribution of pollutants

There can be a wide variation in the prevalence and concentration of different pollutants in any given area, depending on local industrial and traffic emissions - including traffic density. Very local factors such as the proximity to road junctions and the roadside, the local topography, or the topography of buildings in a built-up area, and, of course local meteorological conditions, including temperature, precipitation and wind speeds, can affect the build-up of pollutants on a given day. This means that achieving better air quality is partly dependent on improving the local measurement of different types of air pollution so remedial action can be taken.

It is also often in more deprived, inner-city, areas that air pollution concentrations may be at their highest, coinciding with high-density social housing and more concentrated road networks, potentially compounding any existing health inequalities. The siting of facilities such hospitals, schools and nurseries also has an impact on the exposure of local population cohorts to air pollution. For example, according to a report published in 2017 by the Guardian and Greenpeace, on the location of more than 2,000 schools and nurseries in England, it was found that more than 1,000 nurseries, looking after 47,000 infants and children, were in close proximity to roads where the level of NO_2 from traffic exceeded the legal limit of 40µg m^{-3} [42]. The 2017 report by Aether for the Greater London Authority on pollution exposure shows the close correlation between deprivation and higher pollution levels, with “populations living in the most deprived areas being on average more exposed to poor air quality than those in less deprived areas” [38].

Looking at the UK as a whole, the figure below shows the annual mean distribution of roadside NO_2 across the UK, with levels closely linked to major transport routes. A broadly similar pattern is seen when it comes to the concentration of PM2.5.

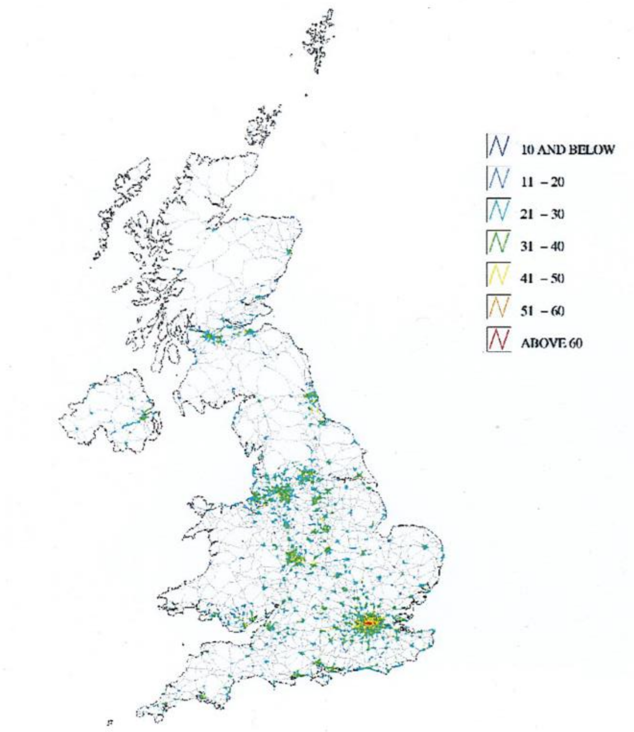

Fig. 6: Urban major roads, annual mean roadside NO2 concentrations, 2016, (µg m-3)[43]

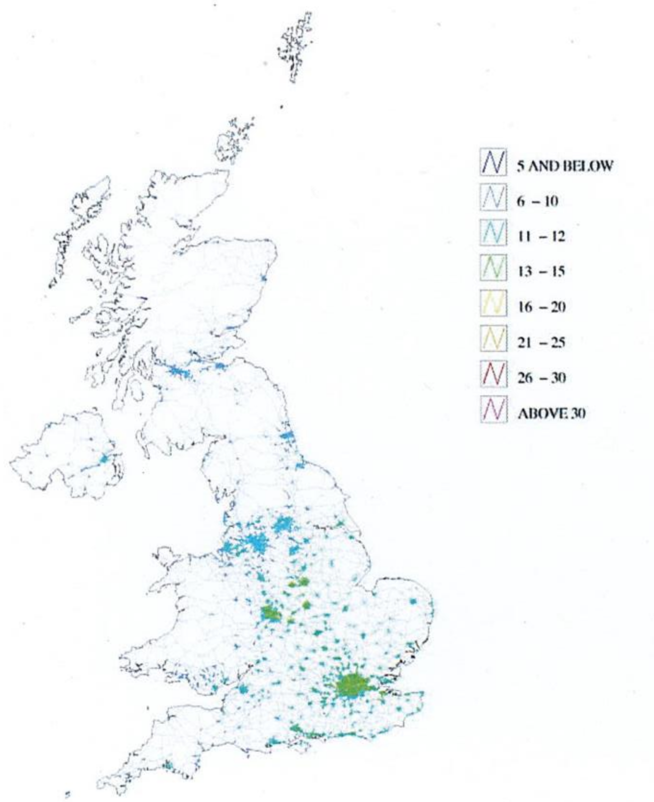

Fig.7: Urban major roads, annual mean roadside, PM2.5 concentrations, 2016 (µg m-3)[43]

Although we do not look in detail at the health effects of benzene in this report, the distribution of roadside benzene, which has been linked to childhood cancers (see Section 7.iii), does generally coincide with the major conurbations of the UK.

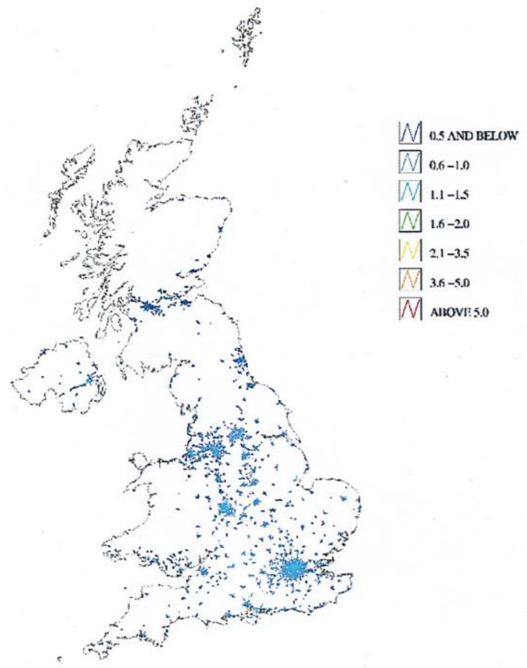

Fig.8: Urban Major Road, Annual Mean Roadside Benzene Concentrations 2016 (µg m-3)[43]

3. Particular health problems caused by a significant shift from petrol to diesel vehicles

The key factor that has led to increasing concern about raised NO_2 and particulate matter pollution in our urban environment is now well recognised: a major switch from petrol to diesel vehicles over the past 15 years.

Decades before that exhaust emissions from petrol vehicles fell dramatically after the addition of catalytic converters - first used in the US in the mid-1970s. Two-way, and then, three-way catalytic converters were added to cars to oxidise the key pollutants in their exhaust emissions - converting nitrogen oxides to nitrogen and oxygen; carbon monoxide to carbon dioxide; and unburnt hydrocarbons (HC) to carbon dioxide and water. Cars with catalytic converters have much lower CO, HC and NOx emissions - but at the expense of creating much higher CO_2 emissions, due to the oxidation of carbon monoxide to form CO_2.

In 2001, to address increasing concerns about rising CO_2 emissions - which had by then been linked to global warming - Gordon Brown, the then Chancellor of the Exchequer, introduced a lower vehicle tax for diesel cars on the basis that they would be less polluting (at least in terms of CO_2 emissions) and this would bring down overall CO_2 levels. By the end of 2016 there were 37.3 million vehicles licensed for use on the roads in Great Britain, of which 30.9 million were cars. Of these, 12.1 million were diesel cars, accounting for 39% of the total number of cars - up from only 10% in 1996[44].

Compared to petrol cars with a catalyst, diesel vehicles have much higher emissions of nitrogen dioxides (NOx) and particulate matter and, unfortunately it is NO_2 and particulate matter, seen at particularly high concentrations close to roads that are now having the greatest impact on human health. As mentioned, PM2.5 and ultrafine particles emitted from diesel vehicles, and associated with the wear of tyres and brakes, can be inhaled deeper into the respiratory system, and it is now thought that the finer particles can even cross the lungs' cell membranes into the bloodstream. While earlier research was not clear as to whether ultrafine particles were as bad for health as PM10 or PM2.5 [45], more recent findings have shown that ultrafine particles are at least as seriously implicated in the damage caused to human health as larger particulate matter[46].

There is some good news on declining sales of new diesel cars in the UK, which fell by 23.5% to 28,317 sales in February 2018, compared to 37,020 sales in February 2017, representing a corresponding fall in market share for new diesel cars from 44.5% to 35% over the same period. The demand for second hand diesels has also declined since the Volkswagen emissions testing scandal of September 2015 [47].

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4. The effects of climate and weather on air pollution

Pollution is highly mobile and it can be carried over long distances by inter-continental and regional weather systems: a proportion of the ozone in the UK atmosphere for example, originates from emissions from mainland Europe and beyond. The impact of air pollution can also be exacerbated by local weather conditions, such as temperature inversions which drain air into low-lying areas, so climate and local weather conditions can play an important part in the transmission, dispersal and exacerbation of pollutants. Levels of air pollution can be high on a still day when dispersion is limited, but they can be much lower the next day or even within a few hours if the wind direction changes, wind speeds increase, or there is precipitation. That is what makes measuring pollution levels so challenging.

As we have mentioned, ozone (O_3) result from the action of sunlight on other pollutants such as vehicle emissions and, as well as harming human health, it can damage crops and trees. There is some concern that global warming could exacerbate O_3 production. Any decrease in overall precipitation in a region would also tend to lead to an increase in particulate matter in the air; this could be a particular problem in some developing countries.

As levels of air pollution can vary daily, so does their impact on health. To help those suffering from conditions such as asthma, Defra now issues daily predicted pollution updates and alerts. The Daily Air Quality Index (DAQI) provides the public with information on levels of different types of air pollution across the UK, with recommended actions and health advice. The index is numbered 1-10 and divided into four bands, from low (1) to very high (10), in order to provide details about air pollution levels in a simple way, similar to the sun index or pollen index [48].

Public emergency warnings are also issued when pollution levels reach critical levels. For example, the Mayor of London's Office issued a "very high" air pollution alert in January 2017 [49] and another alert in June 2017, when it was anticipated that high temperatures combined with southerly winds would lead to dangerously toxic air in England and Wales [50]. The alerts are, in particular, issued to protect vulnerable groups such as the elderly and those with respiratory conditions and, in London, emergency alerts can now be displayed at bus stops, on road signs and on the Underground. In early 2018, the Mayor's Office announced further measures were being put in place to alert the most vulnerable groups in the capital to potentially hazardous spikes in air pollution, including in schools, with advice potentially spreading to care homes and GPs surgeries. Such measures, ideally, need to be replicated in all large conurbations across the UK.

Current official public health advice does not extend to suggesting people stay away from travelling to work, for example, when air quality is particularly bad, in the same way as cold weather alerts might do in the most severe weather conditions. This is, potentially, something that could be considered if the DAQI is very high in order to protect vulnerable groups with existing respiratory or heart conditions. Until pollution regulations are tougher, it would seem sensible to do more to protect the population from the adverse health effects of air pollution, through additional precautionary measures.

We will now consider in more detail what the growing body of medical evidence tells us about the impact of air pollution on human health, the main purpose of this briefing.

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5. The major impacts of air pollution by condition: an overview

Adverse health effects have been associated with all of the air pollutants covered by EU legislation, notably: sulphur dioxide (SO_2); nitrogen oxides (NOx), particulate matter (PM10 and PM2.5), benzene, carbon monoxide, ozone, lead nickel, arsenic, cadmium, mercury and benzo[1]pyrene (B[a]P. A short summary of the key health effects associated with these substances is set out in Defras's publication, Air Pollution in the UK 2016 [43].

Defra has reported in the past that for people who are young and in a good state of health, low to moderate air pollution levels are unlikely to have a serious effect on their health, at least in the short-term [51]. However, elevated levels and/or long term exposure to air pollution can lead to more serious symptoms - and have long-term effects. Also for some substances, such as mercury and lead, there are no minimum safe levels of exposure [52.]

It has been known for a long time that air pollution can affect the respiratory and cardiovascular systems, but it is now also implicated in a much wider range of conditions, including cancer; it has even been potentially linked to neurological disorders such as dementia. The overall impact of air pollution on health is complex, as it may both trigger certain diseases, and, more usually, make existing conditions worse.

Below we take a condition-specific view on the latest research linking different air pollutants to specific health problems. We will primarily be focusing on the impacts of NO_2 and particulate matter (PM10 and PM2.5) on health in this short briefing, as much of the recent attention in the scientific literature and the media has been directed at these particular pollutants.

5.1 Respiratory conditions: asthma; COPD; respiratory infections and TB

The most common respiratory problems associated with air pollution include asthma and chronic obstructive pulmonary disease (COPD), although it is also thought that pneumonia, bronchitis and TB can be adversely affected by air pollution, and there may even be a link to lung cancer.

The last comprehensive survey of UK respiratory disease epidemiology was the British Thoracic Society's 2006 report [53], but the European Respiratory Journal has updated its findings for the period from 2008-2012 [54]. Their more recent research shows that around 585,000 respiratory disease diagnoses are made each year in the UK, half due to asthma and COPD. An estimated 12 million people in the UK have had a lung disease diagnosis – nearly 1 in 5 of the population - and lung disease is responsible for around 115,000 deaths a year – one in five of all deaths; it is the UK's fourth largest cause of mortality according to the British Lung Foundation [55]. If air pollution is affecting respiratory health, even at low levels, the overall impact is likely to be significant. The British Thoracic Society's earlier 2006 report [53] - more than 10-years old now - suggested at the time, that lung disease was costing the NHS £6.6 billion to treat each year.

In terms of respiratory health, research has shown over a long period of time that air pollution can have a very significant impact on lung conditions. It is known that $N0_2$, $S0_2$ and O_3 irritate the airways of the lungs, increasing the symptoms of those suffering from lung disease. Fine particles which are the product of diesel combustion (PM2.5), and ultrafine particles, associated with the wear and tear of tyres and road surfaces in road transportation, can also be carried deep into the lungs where they can cause inflammation.

A detailed paper in 2014 by Professor Kelly of the MRC-PHE Centre for Environment and Health and the NIHR Health Protection Research Unit in Environmental Hazards at King's College, London [56], assessed the evidence for the impact of pollution on respiratory health, including asthma, COPD and respiratory infections and we shall draw on this in the following sub-sections.

Asthma

The charity Asthma UK say that two thirds of people with asthma tell them that poor air quality makes their asthma worse, putting them at a higher risk of an asthma attack [57]. In 2016, the last year for which data is available, 1,410 people died from asthma, so determining the extent to which air pollution may be implicated is important.

In terms of medical evidence, the role of air pollution in triggering asthma exacerbations in both young and adult asthma patients is now well established [58], with researchers as far back as 2005 detecting an association between respiratory conditions such as asthma and pollution, particularly in warm weather. Several studies also point to air pollution having a role in the *development* of childhood asthma [59,60].

Professor Frank Kelly, a world-renowned expert on air pollution and health, concluded in his 2014 paper [56] that: "Clear strong linkages have been established between air pollution and exacerbation of asthma. Moreover, epidemiological studies point to several potential causal agents for the observed association. Ozone exposure has been linked with hospital admissions, worsening of symptoms…. as well as asthma attacks..." while: "NO_2 exposure has been associated with emergency room visits, wheezing, and medication use amongst children with asthma."

An article in the Lancet [61], also dating back to 2014, similarly concluded: "short-term exposures to ozone, nitrogen dioxide, sulphur dioxide, PM2.5, and [traffic-related air particles] TRAP, is thought to increase the risk of exacerbations of asthma symptoms." The authors point to increasing evidence suggesting that long-term exposures to air pollution, especially TRAP and its surrogate, nitrogen dioxide, can also contribute to *new-onset* asthma in both children and adults," with even exposure in the womb being a potential risk to the unborn child. The Lancet article concludes unequivocally: "data suggest[s] that TRAP exposure, especially in urban areas, has a tremendous effect on disease morbidity in individuals with asthma," although they also noted that determining exactly which components of traffic pollution are responsible for asthma exacerbations and onset remains a substantial challenge."

A Europe-wide study published in 2015 found, somewhat surprisingly, that there was: "…no significant association between air pollution exposure and childhood asthma prevalence in five European birth cohorts [62]," but a paper published in the Lancet in 2017, however, looking at pollution levels at young people's home addresses, concluded: "Overall, the risk of incident asthma up to age 14-16 years increased with increasing exposure to NO_2 and PM2.5 absorbance [63]."

The research does seem fairly incontrovertible: air pollution, in particular NO2, PM2.5 and ozone, can all exacerbate asthma, with some evidence that air pollution can trigger new cases of asthma in children and young people too.

Chronic Obstructive Pulmonary Disease

A global, systematic review of 59 studies looking at the link between air pollution and COPD, published in December 2016, concluded: "Short-term exposure to air pollutants increases the burden of risk of COPD acute exacerbations significantly. Controlling ambient air pollution would therefore provide benefits to COPD patients[64]."

Previously, Professor Kelly had also stated in his 2014 paper[56]: "In addition to the well cited detrimental effects of PM, both O_3 and NO_2 have also been associated with increased hospital admissions and respiratory mortality in patients with COPD."

Some authors have questioned the direct causal link. For example, in a paper in the European Respiratory Journal in 2014, the authors state: "Evidence of the chronic effects of air pollution on the prevalence and incidence of COPD among adults is suggestive, but not conclusive [65]." However, a more recent study of 168 COPD sufferers in Massachusetts, which reported in 2016, found that "despite living in an area with air pollution concentrations below current USEPA NAAQS (United States Environmental Protection Agency National Ambient Air Quality Standards) [these] COPD patients appeared to suffer increased risk of COPD exacerbation following short-term exposures to increased concentrations of SO_2 and NO_2[66]." COPD appears to be worsened by air pollution then, which is not, in many ways, a surprising finding.

Respiratory infections

Although this briefing focusses almost exclusively on outdoor air pollution, the WHO has reported that, in children under five, more than half of premature deaths worldwide due to pneumonia, and over half of deaths due to acute lower respiratory infections (ALRI) are caused by the particulate matter inhaled from household air pollution[67]. However, what of outdoor air pollution and respiratory infections? There is less clear evidence on whether air pollution can actually cause infections such as bronchitis or pneumonia. In 2010, a study was published suggesting that increased levels of NO_2 and PM2.5 were each associated with hospitalisation for community-acquired pneumonia in older adults; SO_2 levels were, however, not found to be a contributory factor[68].

More recently, the University of Leicester has reported that the bacteria which cause respiratory infections are affected by air pollution, possibly increasing a person's risk of infection and even, potentially, compromising the effectiveness of antibiotics for their treatment [69]. The research found that particulate matter emitted from various sources, including diesel cars and lorries, can change the way in which bacteria grow in the body, including how they survive on the lining of the human respiratory tract; this can, in turn, adversely affect the human immune response. This provides a somewhat more complex explanation of how pollution can potentially trigger respiratory infections.

In their 2014 report [70], the UK Government's Committee on the Medical of Pollution (COMEAP) commented that while they "found some evidence of an association between chronic bronchitis and long-term exposure to air pollution (mainly particulate air pollution)," "the overall body of evidence is inconsistent and is not sufficient to imply a causal relationship." This was not the view of the contemporaneous EU report which attributed around 103,000 cases of bronchitis in children aged 6-12 in the UK to PM2.5 pollution, although this was based on an EU analysis of the available data[71].

Tuberculosis

Although indoor air pollution is a known risk factor for tuberculosis (TB), the possible link between outdoor air pollution and TB development has been less fully studied. However, in a South Korean Study published in 2014 [72], researchers assessed the impact of outdoor air pollution on the development of TB in the Seoul metropolitan area of South Korea and found a link between TB and SO_2 pollution. Between January 2002 and December 2006, a total of 41,185 TB cases were reported in Seoul. Data on the distribution and levels of different air pollutants was also considered over this period. It was found that while concentrations of PM10, O_3, CO, and NO_2 were not found to be associated with TB incidences in males or females, an increase in SO_2 concentration was associated with a 7% increase in the incidence of TB in males (females did not appear to be affected). The paper reported that this might be due to gender differences in susceptibilities to air pollutants, as well as to TB. SO_2 is fortunately a pollutant of declining significance in the UK, given the decline in coal-fired power stations and heavy industrial plant.

It is not surprising, in fact, that air pollution inhaled into the lungs can cause irritation, inflammation and possibly even infection. Overall, Professor Kelly concluded in his 2014 paper on air pollution and respiratory illnesses [56] that: "as the adverse effects on the respiratory system have been observed at concentrations below ambient air quality standards, it appears that current [air pollution] legislation should be more stringent and pollution control strategies should focus on specific sources and constituents."

We will consider lung cancer in the section on cancer below.

5.2 Cardiovascular disease: stroke and heart attack

There are four main types of cardiovascular disease (CVD): heart disease (including angina and heart attacks); strokes and transient ischaemic attacks; peripheral arterial disease and aortic disease.

According to Policy Connect correspondence with Edinburgh University [73], inhaled particles - and potentially the gases in air pollution too, although the biological pathways are less clear - can damage the cardiovascular system in many ways. These include: (i) constriction of blood vessels and a loss of the ability of blood vessels to relax appropriately; (ii) the exacerbation of vascular inflammation, promoting disease of the arteries; (iii) promoting arrhythmia (irregular heartbeats); (iv) disruption of the neural regulation of the heart; (v) sensitizing the heart to damage from ischaemia (lack of oxygen in the heart from, say, a blocked coronary blood vessel; (vi) making the blood more prone to clotting (and therefore more likely to clog a narrowed artery); (vii) impairing the ability of the body to remove blood clots; (viii) altering circulating substances in the blood (which may promote all of the above); and (ix) increasing blood pressure. All these factors will promote many, if not all, of the four main types of CVD outlined above.

There are now a large number of epidemiological studies, which have looked for associations between air pollution and disease across populations, supporting a clear association between air pollution and CVD, and the biological pathways described above. There is always going to be some uncertainty with such studies, especially when proving causality (i.e. that air pollution actually causes disease and is not just linked to it is some indirect/unrelated way), but strong evidence for causality and the striking effects of short-term exposure to pollution have come from "controlled exposure studies" where volunteers are exposed to a specific type of air pollution in a chamber where other confounding variables can be controlled. In these studies, research has shown that, even short-term exposure to diesel exhaust, equivalent to levels found on a busy street, can have substantial detrimental effects on the heart, blood vessels and the blood itself. The effects occur rapidly (within 2 hours) and are relatively long-lasting (for at least 24 hours)[73].

Overall, evidence is mounting that air pollution can be a trigger for CVD, particularly when it comes to the particulate matter in vehicle exhaust. A paper by Nick Mills as early as 2009, reviews the evidence well [74].

In a further scientific review of the epidemiological evidence by Du et al, published in early 2016, the authors conclude "a wide array of experimental and epidemiological studies have unequivocally provided persuasive evidences on the negative impact of PMs on cardiovascular events and outcomes. In addition, numerous findings indicate that even a few hours to weeks of short-term exposure to PM particulates can trigger CVD-related mortality and events, especially among susceptible individuals at great risk, including the elderly or patients with pre-existing coronary artery disease [75]." They went on to conclude: "Air pollution is now becoming an independent risk factor for cardiovascular morbidity and mortality. Numerous epidemiological, biomedical and clinical studies indicate that ambient particulate matter (PM) in air pollution is strongly associated with increased cardiovascular disease such as myocardial infarction (MI), cardiac arrhythmias, ischemic stroke, vascular dysfunction, hypertension and atherosclerosis. "

In a global survey of risk factors implicated specifically in strokes, published in the Lancet, air pollution in the form of fine particulate matter, PM2.5, ranked seventh in terms of its impact on mortality worldwide [76]. The effect is especially prevalent in low and middle-income countries where two thirds of all strokes occur. Research by scientists at Edinburgh University, funded by the British Heart Foundation, also found such a link; in their 2015 British Medical Journal paper [77], the authors concluded: "Gaseous and particulate air pollutants have a marked and close temporal association with admissions to hospital for stroke or mortality from stroke. Public and environmental health policies to reduce air pollution could reduce the burden of stroke." Some of these global study results include a large amount of data from low-income countries, where there are often high levels of outdoor air pollution, but the implications of air pollution for stroke cases in the UK can not be overlooked.

Studies in animals have also shown that ultrafine particles in diesel exhaust or general air pollution can promote chronic (i.e. long-term) cardiovascular diseases, such as the vascular disease atherosclerosis - the build-up of fatty and inflamed plaques on the inner surface of arteries, which underlies the vast majority of cardiovascular conditions). A relatively early paper by Miller et al in 2013, identifies the potential mechanism involved [78].

Research published last year [79], points to another mechanism by which particulate air pollution may contribute to cardiovascular disease. The study looked at 6,500 adults, finding that because air pollution appears to reduce 'good' cholesterol HDL (high density lipoprotein) in the body, HDL is then less able to removed 'bad' LDL (low density lipoprotein) from the body. Women were found to be more badly affected than men. The study appeared to show that the effects of air pollution can trigger such physiological changes at even comparatively low concentration levels.

Also in 2017, further ground-breaking research was published by Edinburgh University suggesting that extremely small particulates (ultrafine particles) have the potential to bypass the lungs' protective filter system, potentially building up in the blood vessels and thereby raising the risk of heart disease [80]. Reported in the New Scientist [81] and widely commented on in the media, some scientists believe that this is the much sought after explanation for how particulate air pollution can cause cardiovascular disease - although other scientists are urging caution, saying more research is required.

Professor Kelly of King's College London, however, commented on the research saying "[this] goes a long way in plugging a gap in the mechanistic understanding of how small particles contribute to vascular injury and disease [82]. "Professor David Newby of Edinburgh University, who led the latest research, put it very simply: ultrafine particles which "stop blood vessels relaxing and contracting, increase the risk of clots and heart attacks [83]". He also said at the time that "even where air quality is relatively good, as in the UK, there is still a link between air pollution and heart attacks and heart failure."

The conclusion must surely be drawn that current efforts to regulate particulate matter through legislation focusing on PM10 and PM2.5 only, are inadequate, as ultrafine particles are at least as hazardous to health. The challenge then becomes to develop and deploy equipment that is sophisticated enough to routinely measure such ultrafine particles in our urban environment so remedial action can be taken at the local level. Even now, however, we know that air pollution, in particular particulates, increases the risk of cardiovascular disease in those exposed to it, especially in already vulnerable groups.

One of the key differences between the risk of cardiovascular disease due to air pollution and that associated with other risk factors such as smoking or high blood pressure, is that whole populations - certainly in urban areas - are exposed to the risk, without them easily being able to take remedial action to protect themselves. The question should be asked: is this an acceptable level of risk for urban populations to face?

5.3 Different forms of cancer

The International Agency for Research on Cancer (IARC), part of the World Health Organization, has now classified outdoor air pollution as a carcinogen, concluding that outdoor air pollution causes lung cancer [84]. As early as the 1990s, the work of Pope, Dockery et al in the U.S. (The Six Cities Studies), published in the New England Journal of Medicine, concluded that particulates should be considered to be mutagenic carcinogens for which there is no safe level of exposure[85].

More specifically, it is estimated that 7.8% of lung cancer cases each year in the UK are attributable to PM2.5 air pollution exposure - or approximately 3,500 people out of a total of around 45,000 cases each year - a startling statistic[86]. Looking at the medical evidence, a paper published in Lancet Oncology in 2013, based on studying 312 944 cohort members, concluded that particulate air pollution (PM2.5 and PM10) “contributes to lung cancer incidence in Europe” (although they did not find a causal link between NO_2 and lung cancer in the same study)[87].

A Chinese study in 2014, analysing US and European data, concluded that elevated fine particulate air pollution exposure was associated with a statistically significant increase in lung cancer mortality [88]. The authors said: “The linkage between fine particulate air pollution and lung cancer motility is observed even after controlling for cigarette smoking, occupational exposure, and other risk factors. This finding is in alignment with observations in China which show an upward trend of lung cancer incidences coupled with a downward trend in the number of smokers.” Chen et al also concluded, in their 2014 meta-analysis of existing research studies to December 2013 that “Exposure to traffic-related air pollution significantly increased the risk of lung cancer[89].”

At a recent seminar in November 2017 on climate change and health, hosted by the All-Party Parliamentary Health Group and the All-Party Parliamentary Group on Climate Change, Hugh Montgomery, Professor of Intensive Care Medicine at UCL, noted that there had been an increase in lung cancer cases in the UK amongst non-smokers, which it is likely to be attributable, in part at least, to air pollution.

A rise in childhood cancers in general over the past 20 years is well documented, but in a scientific review of whether air pollution causes childhood cancers in 2006, admittedly a decade ago now, the report concluded “the evidence for an association between traffic-related air pollution and childhood cancer is weak [90].” Little less than a decade later, however, a meta-analysis published in 2016, came to a very different conclusion, certainly with regard to leukaemia: “Overall, our results suggest that traffic-[related] air pollutants increase the risk of childhood leukaemia, both among all leukaemia’s as well as within the major subtypes, acute lymphoblastic leukaemia (ALL) and acute myeloid leukaemia (AML).” The authors said such findings were consistent across the different indicators of exposure (traffic density, contaminant levels, petrol stations), and the study region [91].” Here benzene exposure was the strongest predictor of a disease risk.

This builds on Heck ET all’s earlier findings of 2013 citing “new evidence suggesting that exposure to traffic-related pollution in pregnancy and early childhood may increase the risk for acute lymphoblastic leukaemia (ALL) and two rare childhood cancers: retinoblastoma, and germ cell tumours[92].”

In May 2017, a new US study found that people living in areas with the worst air pollution appeared 10 per cent more likely to get cancer [93]. Not only were lung cancer rates higher, but prostate and breast cancer rates also appeared to be raised too, although cause and effect were not established, only the epidemiological trends. It could be, for example, that people living in more polluted areas are poorer as a whole and that other factors such as a worse diet might be contributory factors to the observed raised cancer rates. Nonetheless the report concluded: “prostate and breast cancer demonstrated the strongest positive associations with poor environmental quality.”

A further Italian study published in 2017, looking at people living near a coal-oil-fired thermal power plant in north-eastern Italy, concluded that “air pollution exposure may have had a role with regard to the risk of lung and bladder cancers, but only in women aged ≥75 years." The authors concluded that further research was warranted, particularly as cigarette-smoking had not been screened out as a factor [94]. In another large-scale medical study which reported in 2017, led by the Barcelona Institute of Global Health, IS Global, researchers observed an association between some air pollutants and mortality, not only from bladder cancer, but also from kidney and colorectal cancers. PM2.5, for example, was associated with a raised mortality from kidney and bladder cancers (with a 14 and 13% increase, respectively, for each 4.4 µg m^{-3} increase in exposure), while exposure to NO_2 was associated with an increase in colorectal cancer deaths, with a 6% increase for each 6.5 parts per billion (ppb) increment [95]. The bladder cancer link to air pollution was, however, rejected in a European study which reported just the previous year in 2016[96], so further research is clearly warranted in this area.

In a further study published in 2017, researchers from the University of Florida looked at almost 280,000 women to discover whether there was a link between pollution and breast cancer only. This was the first study to assess the correlation between air pollution and breast density (a common precursor of breast cancer). The study found that "each one unit rise in PM2.5 increased the chance of a woman having dense breast tissue by four per cent." This could be one of the reasons behind geographic breast cancer patterns according to the researchers [97]. Since the early 1990s, breast cancer incidence rates have increased by a fifth (20%) in the UK according to Cancer Research UK [98]. Could air pollution be just even a small, potentially overlooked, risk factor? It may be too early to tell, but the University of Florida study certainly suggests more research is needed on this.

A Chinese study which reported in 2017 suggested that PM10 was found to be an independent risk factor contributing to excess oesophageal cancer mortality, based on research carried out in Shandong Province, with women disproportionately affected. Levels of air pollution in China would generally be far in excess of those experienced in the UK, although the reporting of a statistically significant link is concerning [99].

5.4 Neurological effects: cognitive impairment in children and dementia in older people

Neurodevelopment and cognition in children and young people

According to a North American/Mexican study published in 2014, "there are several emerging trends of evidence suggesting that air pollution may be associated with an array of…. neurocognitive and behavioural changes in children and teens [100]." The authors of the research reported that: "Neurocognitive effects of air pollution are substantial, apparent across all populations, and potentially clinically relevant as early evidence of evolving neurodegenerative changes." A systematic review of existing research, which appeared a few years later, points to the same conclusions, suggesting that extensive neuro-inflammation, caused by airborne pollution, contributes to actual cell loss within the central nervous system [101], which may be responsible for the negative cognitive effects detected.

More specifically, in a study published in 2015, carried out by researchers at the Centre for Research in Environmental Epidemiology (CREAL) in Barcelona, part of IS Global, 7-10-year-olds attending schools exposed to high levels of traffic-related air pollution, were found to exhibit slower cognitive development than those attending schools in low pollution areas[102]. The researchers measured three different cognitive outcomes (working memory, superior working memory, and attentiveness) four times a year, over a 12-month period, in 2715 primary school children at 39 different schools. By comparing the pace of cognitive development in children attending schools where exposure to air pollution was high, to those children attending schools with a similar socio-economic index where exposure to pollution was low, they were able to observe a significant difference in cognitive progress. For example over the study period, there was an 11.5% increase in working memory observed in the children attending schools in low pollution areas, compared to only a 7.4% increase in children attending schools in highly polluted areas.

In the RCP/RCPH report of 2016 [1], the authors also concluded that there was "emerging evidence that air pollution adversely affects both the developing and the ageing brain," although they say further work to establish cause and effect, screening out socio-economic factors, would be desirable. In the 2014 research quoted at the start of this section [102], the authors talk of "a complex scenario where air pollution and SES [socioeconomic status] can influence neural development and cognition along with known factors such as psychosocial stress and poor nutrition, thereby influencing and determining mental health, academic achievements and overall life performance." Clearly air pollution is just one of the factors influencing childhood cognitive development, albeit a potentially significant one. The authors concluded, however: "there is enough evidence supporting the perspective that the effects of air pollution on brains of children and teens ought to be key public health targets." Indeed, if air pollution poses even a potential risk to the cognitive development of children, public health measures surely need to reflect this.

Finally, a much more recent report by UNICEF published in December 2017 [103], presents very thorough evidence on the global impact of air pollution on cognitive development, although their report indicates that the scale of the problem is far more serious in the lower income countries of South and East Asia. On the question of the impact on the foetus, the report states: "Air pollutants inhaled during pregnancy can cross the placenta and affect the developing brain of a foetus, with potential lifelong effects. Research shows an association between prenatal exposure to high levels of air pollution and developmental delay at age three, as well as psychological and behavioural problems later in childhood, including symptoms of attention deficit hyperactivity disorder (ADHD), anxiety and depression." It appears that cognitive problems in children linked to air pollution can begin even before birth.

Neurological effects in older people including dementia

Turning to older people and, in particular, the degenerative long-term condition, dementia, some epidemiological evidence in the medical literature suggests that air pollution can potentially contribute to memory impairment. A recent Swedish paper, published in 2016, looked at 1,806 study participants and annual mean NO_2 levels (as opposed to other pollutants) at their residential addresses, of whom 191 participants went on to be diagnosed with Alzheimer's disease and 111 with vascular dementia; the authors concluded that "if the associations we observed are causal, then air pollution from traffic might be an important risk factor for vascular dementia and Alzheimer's disease [104]."

The findings in this study, focusing on the link between NO_2 and dementia, are in line with a growing number of other epidemiological studies which appear to show an association between exposure to air pollution and cognitive impairment in older people, including papers by Ailshire and Clarke in 2015 [105] and Chang et al in 2014[106]. Even a study published almost a decade ago concluded "air pollution has been shown to cause neuro-inflammation, oxidative stress, cerebral vascular damage, and neurodegenerative pathology," with the effects beginning in childhood and being cumulative[107]; the authors mention ultrafine particles as being implicated in the observed cognitive effects.

Further epidemiological studies from around the world are now also giving rise to concerns about the role particulate pollution plays in dementia. A decade-long study published in Translational Psychiatry in 2017[108],' for example reported that living in places with PM2.5 exposure higher than the US Environmental Protection Agency's (EPA's) standard of 12 µg m^{-3} (half the EU legal limit), nearly doubled the risk of older women suffering from dementia. The report concluded "The association between PM2.5 exposure and increased dementia risk suggests that the global burden of disease attributable to PM2.5 pollution has been underestimated, especially in regions with large populations exposed to high ambient PM2.5."

According to UNICEF, ultrafine magnetite particles are now coming under closer scrutiny in terms of their impact on the brain, both in adults and children. They are so small that they can enter the body through the olfactory nerve in the brain and the gut. Magnetite is very common in urban outdoor air pollution, and a recent study [109] found that it was considerably more present in the brains of people living in areas where urban air pollution is high. Magnetite nanoparticles are highly toxic to the brain due to their magnetic charge and they are increasingly being linked to neurodegenerative diseases. The UNICEF report[103] also points to evidence that polycyclic aromatic hydrocarbons (PAHs), a specific class of pollutants formed from fossil fuel combustion and commonly found in areas of high automobile traffic, contribute to a loss of or damage to white matter in the brain.

Measuring the effects of pollution on the brain is, of course, complex. There can be both short-term effects of air pollution related to the last few hours and days of exposure, superimposed on the effects associated with long-term exposure, so determining cause and effect in relation a specific form of air pollution, or a cocktail of pollutants, is not straightforward. Indeed, a recent article in the Lancet published in February 2018, concluded: "the potential negative effects of environmental pollution on neurological health should receive more attention from researchers, funders, regulators, and governments[110]." This conclusion speaks for itself.

5.5 Diabetes

In 2015, a systematic review was published on the effects of environmental air pollution (outdoor and indoor) on Type 2 diabetes which considered the results of 21 published studies on the subject. The authors' conclusions were clear: "Air pollution is a leading cause of insulin resistance and incidence of type 2 diabetes mellitus. The association between air pollution and diabetes is stronger for traffic-associated pollutants, nitrogen dioxide, tobacco smoke and particulate matter[111]. " The authors go so far as to suggest that minimising air pollution is important for lowering the incidence of Type 2 diabetes.

A more recent US study, published in the journal Diabetes in January 2017, in fact, corroborates these findings, also offering a potential mechanism for the biological changes observed[112]. A group of researchers tracked the health of a group of 314 overweight and obese children in Los Angeles County and the relative levels of residential air pollution they were exposed to, for about 3.5 years (both NO_2 and small particulate PM 2.5). They found an association between chronic exposure to air pollution and the breakdown of beta cells, special cells in the pancreas that secrete insulin and help to maintain the appropriate level of sugar in the bloodstream. The findings point to the fact that the negative effects of elevated and chronic exposure to NO_2 and small particulates can begin in early life - as with the impact of pollution on cognitive impairment - concluding that this mechanism could be partly responsible for an increase in childhood obesity levels. As Sung Kyun Park, of the School of Public Health at the University of Michigan, concluded in an appraisal of recent research on the subject in 2014, "Traffic-related pollution may be a previously unrecognized contributor to the epidemic of paediatric obesity and related metabolic conditions in the U.S [113]." In a paper by the same author in 2015, however, the link is presented as being less clear: "Our study provides evidence that supports the association between long-term exposure to air pollution and the prevalence of diabetes mellitus (DM). However, our results do not support the hypothesis that long-term exposure to air pollution is associated with incidence of DM[114]."

A very recent paper published in the Lancet in 2018 on ambient air pollution and diabetes, certainly appears to confirm at least an epidemiological link between the two. The paper, which analysed rates of diabetes in more than 15,000 individuals in China, concluded: "Long-term exposure to air pollution was associated with [an] increased risk of diabetes in a Chinese population, particularly in individuals who were younger or overweight or obese[115]. "Whether a similar link would apply in the UK, with its generally far lower air pollution levels, is not at all clear, but at a time when Type 2 diabetes is increasingly common in the UK - with over 3 million people diagnosed with the condition – any potential causal link warrants further medical investigation – and taking the appropriate public health action if the link is found to be substantiated.

5.6 The immune system

Dr Ian Mudway, of King's College London, said at a British Thoracic Society meeting in Westminster in December 2016, that the pollution in diesel emissions is thought to have an effect on the human immune system, making people more susceptible to a range of illnesses [116]. This was mentioned above in the context of respiratory infections. Even before that, a potential link between the immune system and pollution was identified by researchers at Stanford University and the University of California, Berkeley. They found that air pollution exposure suppressed the immune system's regulatory T cells (Treg), and that the decreased level of T cell (Treg) functioning appeared to be linked to a worsening of asthma symptoms and lower lung capacity [117]. The worsening of asthma symptoms was therefore found to be linked directly to a reduced immune response, triggered by ambient air pollution rather than just to the pollution itself. T cells are also important in other autoimmune disorders - so the implications of this research could apply beyond just asthma. Indeed, there are papers in the scientific literature which look at the potential impact of pollution on newborn thyroid function [118], and one paper dating from 2010, indicated that people living near petrochemical complexes had a higher risk of developing the anti-thyroid antibodies, associated with Hashimoto's thyroiditis (a form of hypothyroidism) [119]. The link between all forms of air pollution and autoimmune disorders is certainly worthy of further investigation.

5.7 Eyesight and eye health

As early as 1989, a paper in the Journal of the American Optometry Association asserted that "The eye is vulnerable to the effects of air pollution. Manifestations of air pollution can range from minimal or no symptoms to chronic discomfort and eye irritation" [120].

Air pollution is firstly thought to precipitate dry eye syndrome. Research presented at the Annual Conference of the American Academy of Ophthalmology in 2013, reflected in a paper in the Journal Ophthalmology in 2014, found cases of dry eye syndrome in veterans were clustered in urban areas of the United States with the highest levels of pollution. Study subjects in and around Chicago and New York City were found to be three to four times more likely to be diagnosed with dry eye syndrome, compared to less urban areas with relatively little air pollution [121].

A further study published in JAMA Ophthalmology in 2016 also examined the association between outdoor air pollution and Dry Eye Disease (DED) in a Korean population [122]. It found that higher ozone levels and lower humidity levels were associated with Dry Eye Disease (DED), but PM10 levels were not implicated. It seems that, of all the air pollutants, ozone might be the most implicated in causing DED.

Dry eye syndrome can be serious as it can cause visual disability and may go on to affect the effectiveness of corneal, cataract, and refractive surgery. In addition, exposure to air pollutants in concentrations present in large cities can contribute to the diseases of the eyelid such as blepharitis, an inflammation of the margins of the eyelids [123]. Dry Eye Syndrome is also commonly associated with blepharitis. In severe meteorological conditions, some opticians have warned of the impact of air pollution and dust on eye irritation [124].

5.8 Vulnerable groups

Some groups are more vulnerable to air pollution than others and they are generally the same sections of the population that are more vulnerable to illness as a whole. They include babies in the womb, infants and young children with developing lungs, the elderly, and those with existing long-term conditions. As discussed, those with pre-existing respiratory problems, such as asthma and COPD, are more susceptible to the health effects of air pollution due to the additional strain placed on their respiratory systems.

In their report, the RCP and RCPH [1] summarised the problems faced by babies in the womb as: lower weight birth, premature birth, still birth and organ damage. In terms of pre-term birth (PTB) attributed to air pollution, a US study published in December 2016 concluded that "PM2.5 may contribute substantially to the burden and costs of PTB in the United States, and considerable health and economic benefits could be achieved through environmental regulatory interventions that reduce PM2.5 exposure in pregnancy [125]." The study published in the journal Environmental Health Perspectives, looked at data on almost 4 million births in 48 US states, including pre-term births, and compared this to the distribution of PM 2.5 across these states and counties. Earlier studies had also pointed to evidence of a link between preterm births and outdoor air pollutants [126, 127]. In 2012, Stieb et al concluded: "while there is a large evidence base which is indicative of associations between CO, NO_2, PM and pregnancy outcome, variation in effects by exposure period… should be further explored."

A recent paper published in the British Medical Journal in December 2017, reported that "air pollution from road traffic in London is adversely affecting fetal growth[128]." It concluded: "Our single air pollutant model findings are consistent with recent meta-analyses which report increased risk of low birth weight (LBW) and reduced mean birth weight associated with NO_2, PM2.5, and PM10."

At the toddler stage, the RCP/RCPH report also identified developmental problems, wheezing and coughs, asthma and slower development of lung function as potential problems associated with air pollution. Toddlers are often pushed in buggies at vehicle exhaust level, so they may be picking up a far greater concentration of roadside pollutants than adults. Young children walking to school along busy roads are probably similarly vulnerable. Choosing a route to school along less busy roads would be beneficial for children, and parents should be encouraged not to drive to school, in order to reduce air pollution around school and nursery premises.

Elderly people, who may have declining respiratory and heart functions, will also generally be at greater risk. In addition, those sections of the population living in inner cities - some of whom already experience relatively high levels of economic deprivation and health inequalities - may also be living in higher density housing, closer to road arteries, compounding any other health problems they may have.

A recent investigation by the Guardian and Greenpeace, based on an analysis of Government data, revealed that more than 1,000 nurseries, looking after 47,000 babies and children, are sited in close proximity to roads where the level of NO_2 from diesel traffic exceeds the legal limit of 40µg m^{-3}. The highest pollution pocket of 118.19µg m^{-3} – almost three times the legal limit – was reported to have been at the site of a nursery in Tower Hamlets, East London [129].

In addition to assessing the impacts of pollution on health within the legal limits set by the EU, it is important to understand the health impacts of pollutants where there are spikes in emissions and/or pollution levels consistently exceed the legal limits, as is still the case for some pollutants in the UK, notably NO_2.

The health impacts of outdoor air pollution: some conclusions

We have seen that medical evidence suggests air pollution, in all its forms, and at high concentrations, can have a significant impact on human health. The effects on health are different for different pollutants so there is a complicated picture of cause and effect at work: for example whereas respiratory diseases appear to be more closely associated with particulate matter of all sizes and NO_2, dementia appears to be more closely linked to fine particulate matter, insofar as a link has been established. When it comes to cardiovascular disease, ultrafine particles again may be the most significant agents.

Also while legal upper air quality limits apply in the UK for different pollutants, based on EU legislation, researchers now say that even exposure below these levels could well be harmful, especially in individuals who may be genetically more susceptible to pollution. For example, in the Medicare population in the US, there was significant evidence of adverse effects related to exposure to PM2.5 and ozone at concentrations *below* current national standards[130] and US air quality standards are stricter than the EU's for Nitrogen Oxides (NOx) and Particulate Matter (PM). As the RCP/RPCH point out in their report: "neither the concentration limits set by government, nor the WHO's air quality guidelines, define levels of exposure that are entirely safe for the whole population[1]". This is particularly the case for vulnerable groups with pre-existing health conditions such as CVD.

We have not considered airborne metallic pollutants such as lead, arsenic, cadmium and mercury in this short briefing paper, but for some heavy metals such as lead there is no safe exposure limit.

A final key question is, to what extent does pollution actually cause ill-health and to what extent does it exacerbate pre-existing conditions? That is worthy of a paper in itself, and the answer will, no doubt, depend on the condition. Whatever the scenario, the net effect of air pollution on human health is now recognised as being potentially very significant indeed. Further research would be useful to establish more clearly:

- The links between different pollutants and specific health conditions, screening out, potentially significant, confounding socio-economic factors;
- To what extent air pollution can cause a much wider range of illnesses than previously thought, including cancer, diabetes; autoimmune disorders and dementia;
- The cumulative effects of exposure to different pollutants over a lifetime, as opposed to just assessing the relatively short-term effects;
- How far existing, and even new EU regulations coming into force, will offer adequate protection to all sections of the population, including vulnerable groups; and
- The extent to which ultrafine particles in particular, largely associated with road traffic in urban areas, may have a far more serious impact on health than previously thought.

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6. What is the estimated 'excess mortality' attributable to air pollution in the UK?

Particulate matter - PM 2.5

In 2010, the Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP), reported on the health impacts of particulate matter pollution, specifically focussing on PM 2.5, concluding that: "The current (2008) burden of anthropogenic particulate matter air pollution is… an effect on mortality equivalent to nearly 29,000 deaths in the UK, or an associated loss of total population life of 340,000 life-years [131]". They concluded in their report that removing all anthropogenic ('human-made') particulate air pollution (PM2.51) could "save the UK population approximately 36.5 million life years over the next 100 years" and would be associated with an average increase in UK life expectancy from birth of six months.

The COMEAP report also calculated that a policy which reduced the annual average concentration of PM2.5 in the air by 1 µg m^{-3} would result in a saving of approximately 4 million life years or an increase in life expectancy of 20 days, in people born in 2008.

Analysing the statistical data and causation is difficult, as the report points out: "Given that much of the impact of air pollution on mortality is linked with cardiovascular deaths, it is more reasonable to think that air pollution may have made some contribution to the earlier death of up to 200,000 people in 2008, with an average loss of life of about two years per death affected, though that actual amount would vary between individuals. However, this assumption remains speculative[131]."

A blog by David Spiegelhalter of the Winton Centre for Risk and Evidence Communication at Cambridge University in 2017, points out that the number of deaths attributable to pollution is actually hard to determine, as people do not, thankfully, 'drop dead' from pollution as they did in the days of the London smogs [132.] As we have seen, excess deaths from air pollution are caused because air pollution tends to make existing conditions such as asthma and cardiovascular disease worse (as do other factors such as smoking) - although there is now some evidence that air pollution can cause the onset of some conditions such as asthma; lead to poor lung development in the womb resulting in illness later in life; and, by quite complex mechanisms, potentially increase a person's risk of suffering from dementia or stroke.

Also, statistically speaking, although COMEAP's main estimate is of around 29,000 excess deaths attributable to air pollution from PM2.5, they admit that the figure could potentially lie anywhere between 5,000 to 60,000, depending on statistical variance (see Table 2 below): "Using the 75% plausibility interval suggested by the expert elicitation in COMEAP (2009) this means a range of effects on mortality equivalent to between 4,700 and 51,000 deaths with a loss of between 55,000 and 597,000 years of life in 2008, or effects on life expectancy." In addition, COMEAP says that there is even a 1 in 4 chance that the effect on mortality is outside even this very wide range. This statistical variance reflects some uncertainty around the exact relationship between ambient PM2.5 concentrations and mortality, and the underlying complex dynamics of cause and effect.

The COMEAP data doesn't specifically consider any burden of illness attributable to ultrafine particulate matter, for which the evidence is much more recent and less well established in terms of mortality. In addition this data is quite old now (based on 2008 PM levels). As PM2.5 levels have generally stayed at the same level over the past decade (see Fig.1), the health effects based on today's PM2.5 levels should, however, also be broadly similar today, although recent regulatory changes in cities like London (see Section 11) could start to bring PM2.5 levels down in the capital going forwards. Other UK cities need to follow suit if they are not already doing so.

Measure of effect (2008)	Estimate of mortality	Plausible interval
'Attributable deaths'	29,000 (approx.)	4,700 to 51,000
Loss of total survival in the population	340,000 years	55,000 to 597,000
Hypothetical population (and size of group)	**Hypothetical average loss of life expectancy**	
For whole population aged 30+ (38.35million)	3 days	½ to 6 days *
For all deaths aged 30+ (569,000)	6 months	1 to 12 months (for England and Wales)
For deaths from cardiovascular disease aged 30+ (191,000)	2 years	4 months to 4 years
For 'attributable' deaths	11.5years	1.9 to 23 years

Table 2: Hypothetical average years of life expectancy lost in 2008 due to the contribution of anthropogenic particulate air pollution (PM2.5), averaged over different sections of the UK population with 75% plausibility intervals (COMEAP, 2010 131 and Spiegelhalter D, the Winton Centre, Cambridge University 132) * = shaded area with plausibility estimates by Spiegelhalter.

Nitrogen Oxides

COMEAP also made a statement on the health effects of nitrogen dioxide (NO_2) in 2015, concluding that evidence associating NO_2 with adverse health effects has strengthened substantially in recent years [133].

Defra has put figures to this, saying in its report, Air Pollution in the UK 2015 (published in 2016), that there are an estimated 23,500 deaths attributable to NO_2 each year [27]. Here again, given similar uncertainties about cause and effect, there is an uncertainty interval surrounding this figure, with Defra saying excess deaths could vary from 9,500 to 38,000.

Overall mortality rates

Defra point out in their Air Pollution in the UK 2016 report [43], quoting COMEAP, that adding the results of deaths attributable to particulates and NO_2 would give an overestimate of the combined effects of the two pollutants as studies show that the combined effect of the pollutants may be less as there is an 'overlap' effect of between 0 and 33%. COMEAP is still carrying out their research work into the scale of the overlap. According to King's College London, the WHO currently estimates that there is up to a 30% overlap between the effects of PM2.5 and NO_2 pollution when it comes to assessing the combined mortality rates associated with both pollutants [134]. Unfortunately, very few long-term studies provide estimates of the health effects for two-pollutant models.

Spiegelhalter notes in his article [132] that "the World Health Organization, using a different methodology, estimate that there are "only 16,000 attributable deaths" in the UK from air pollution, considerably less than the combined COMEAP and Defra figures, so clearly there is a wide degree of variation on estimating attributable deaths both across different methodologies and within them.

The landmark RCP/RCPH 2016 report [1], nonetheless, attributes around 40,000 excess deaths a year to outdoor air pollution, the combined average calculated deaths from particulate matter and nitrogen dioxide exposure, taking into account variations in estimates and an estimated overlap in mortality associated with the effects on health of both pollutants take together. Despite the caveats expressed above, the 40,000 excess deaths figure appears to be an estimate that has now been widely accepted, and one which is widely quoted as being the number of excess deaths caused by air pollution in the UK each year.

At the European level, the European Environment Agency (EAA) reported in 2016 that, in 2013, air pollution in the EU-28 was responsible for the following years of life lost in its citizens: 4.67million years for PM2.5, 723,000 years for NO_2 and 179 000 years for 0_3 [135]. Putting these statistics in another way: in the EU-28, "the premature deaths attributed to PM2.5, NO_2 and O_3 exposure are 436 000, 68 000 and 16 000, respectively."

According to research by King's College London, when it comes to excess deaths from air pollution in London, in particular PM2.5 and NO_2 [136], the 'mortality burden' in 2010 of PM2.5 and NO_2, taken together, was estimated to be 9,481 deaths: 3,537 deaths (52,630 life-years lost) attributable to PM2.5 - and 5,879 deaths (88,113 life-years lost) attributable to long-term exposure to NO_2, assuming the WHO value of up to a 30% overlap between the effects of PM2.5and NO2. Some of these excess deaths may, of course, also be due to the associated effects of other traffic pollutants.

A more recent authoritative study published by the Lancet in October 2017 [137], as part of the Global Burden of Disease research initiative, suggested that the number of excess deaths linked to air pollution in the UK was actually significantly higher at 50,000. The BBC reported that this puts the UK in 55th place out of the 188 countries measured in terms of the number of deaths attributable to air pollution [138], with the US and many European countries, including Germany, France, Spain, Italy, Denmark all doing better than the UK. This could, partly, be explained by the UK's relatively high dependence on diesel vehicles – although that is slowly beginning to change now, as reported above.

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7. Regional variations in excess deaths from air pollution and local risk factors

Although we have touched on the estimated excess deaths from air pollution in London, there are, of course, significant variations in excess mortality across the UK as a whole as shown in the map for PM2.5 below, which, as one would expect, points to much higher mortality rates in larger urban conurbations [139].

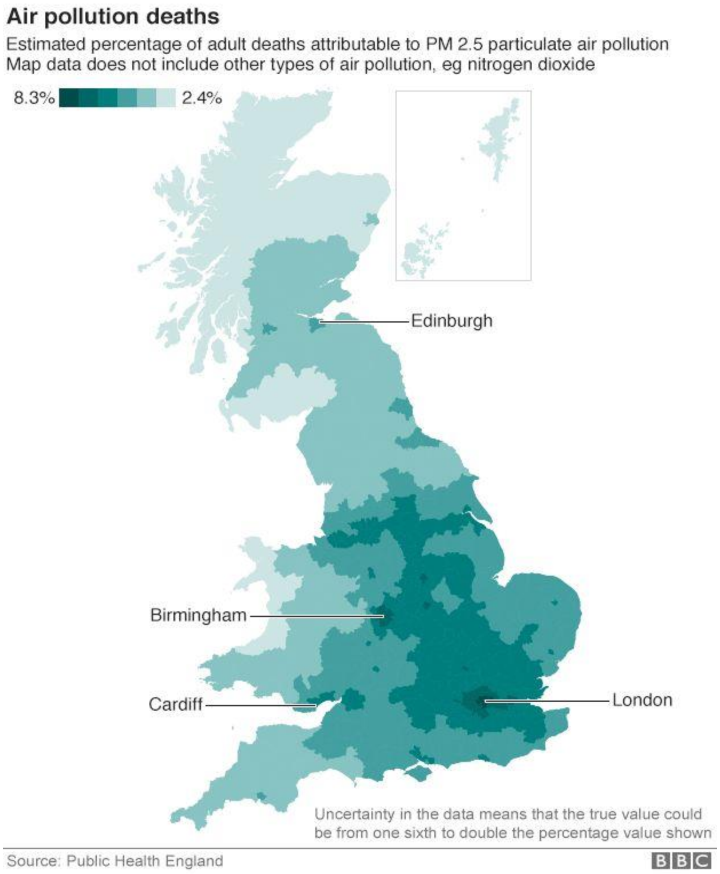

Fig. 8: Estimated percentage of deaths attributable to PM2.5 in the UK[139]

In addition to these estimated regional mortality patterns, which correspond closely to the major conurbations in Britain, there are, of course, very large local variations in exposure to pollutants, across neighbourhoods and even between local streets, corresponding to the location of major road arteries, which can have localised health effects. According to research published in 2014 by Professor Barratt of King's College London, who measured the exposure to pollution of people travelling by car, bus, bicycle and walking in London, it can be drivers themselves who are exposed to some of the highest levels of airborne pollutants [140].

Child passengers are particularly at risk. Professor Sir David King, a former government chief scientific adviser, quoted in the Guardian in June 2017 [141,] made the point that children are at serious risk from dangerous levels of air pollution in cars. Professor Stephen Holgate, an asthma specialist at Southampton University and Chair of the Royal College of Physicians working party on air pollution, quoted in the same article, said: "Children are in the back of the car and often the car has the fan on, just sucking the fresh exhaust fumes coming out of the car or lorry in front of them straight into the back of the car."

Taking a side street route when walking through a city can cut a person's air pollution exposure by 30-60%, according to a report published in 2017 by King's College London's Environmental Research Group [142]. Signposting cleaner air routes and providing online maps could keep people away from heavily polluted main streets and would clearly have health benefits. Some Clean Air Walking Routes are now being developed in London, but official public health advice about avoiding the most polluted pedestrian routes does not appear to have been shared more widely with colleges, schools, parents and employers.

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8. Assessing the cost of air pollution to the UK economy and healthcare system

A joint report by the World Bank and Institute for Health Metrics and Evaluation (IHME) in the US reported that an estimated 5.5 million lives were lost worldwide in 2013 due to diseases associated with outdoor and household air pollution, costing the global economy about US$225 billion in 2013 [143]. This, of course, does not even begin to describe the high toll of human suffering caused by such air pollution. The report concluded that diseases linked to outdoor and indoor air pollution caused 1 in 10 deaths worldwide in 2013, or more than six times the number of deaths caused by malaria.

In Europe, the World Health Organization Regional Office for Europe and the OECD estimated that there were around 600,000 premature deaths from diseases associated with ambient *and* household air pollution in 2010 in the 53 WHO European Region countries (as opposed to the EU-28 figures quoted above), with an associated cost of US$ 1.6 trillion (which includes the additional cost of treating pollution-induced illness[144]). Even though the number of premature deaths has declined by 12% from the level in 2005 according to the WHO, the associated costs still rose.

In 22 of the 48 countries of the WHO European Region for which data was available, the economic cost of premature deaths from outdoor *and* indoor air pollution was estimated to be around 10% of GDP overall. For the UK, the figure reported fell from 4.3 to 3.7% of GDP between 2005 to 2010, lower than the European Region average, even though this, reportedly, still amounted to an associated annual cost of around $US 80 billion (for outdoor pollution only) - around £57 billion at today's exchange rates). This appears to be a higher cost than reported elsewhere as we will see below.

In a statement in June 2017, the United Nations urged action in Europe to tackle the indoor and outdoor air pollution which they estimate to be responsible for 620,000 deaths each year in the wider European region, although they recognise that cardiovascular deaths and diseases from environmental pollutants in general are three times higher in low and middle income countries than in high income countries such as the UK.[145].

The 2016 RCP/RCPH report of 2016[1] concluded that the overall cost to the wider UK economy of outdoor air pollution is more than £20bn per year, in terms of healthcare costs, premature illness and the impact on business. The report pointed out that the European Commission and the US Environmental Protection Agency have decided that action to control air pollution is economically justified in terms of reducing healthcare costs and fewer working days lost.

Looking again at the costs to London, the detailed modelling done by King's College London [136] asserts: "The estimated annual costs across both pollutants (PM2.5 and NO_2) ranges from a core result of £1,383 million (including all the hospital admission effects of PM2.5, plus respiratory hospital admissions and deaths brought forward from short-term exposure to NO_2) to an 'extended' result of £3,653 million, including all core results except deaths brought forward from short-term exposure to NO_2, as the effect of long-term exposure to NO_2 on mortality is added in."

If the cost of outdoor air pollution for London as a whole is reported to be around £3.6 billion where around one in eight of the population lives, it seems unlikely that the total cost to the UK amounts to £57b as estimated by the WHO. Twenty billion does appear to be a more plausible figure. The Government have themselves put the economic cost of air pollution in the UK at between £9billion and £19 billion every year [146]. This is comparable to the cost to the economy of obesity (over £10 billion).The Government also recently quoted a much lower figure in relation to lost productivity only: "Evidence shows that poor air quality is the largest environmental risk to public health in the UK, costing the country up to £2.7 billion in lost productivity in 2012 [147]."

Global warming is also set to exacerbate the effects of air pollution on health through higher average annual temperatures, with higher associated costs, although this is more likely to be a particular problem for developing countries.

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9. What recent measures have been put in place nationally and locally to tackle air pollution?

The purpose of this briefing is primarily to assess the health effects associated with outdoor air pollution, but it would be useful to say something, in brief, about the extent to which the UK Government currently complies with existing EU air quality targets, in order to assess what further measures are needed to tackle the problem.

The UK is divided into 43 zones for the purposes of air quality assessment: 28 agglomeration zones (large urban areas) and 15 non-agglomeration zones. This was the situation in 2016, as reported by DEFRA [43]:

1 The UK met the limit value for hourly mean nitrogen dioxide (NO_2) in all but two zones.

2 Six UK zones were compliant with the limit value for annual mean NO_2. The remaining 37 exceeded this limit value.

3 Four zones exceeded the target value for benzo[a]pyrene.

4 Three zones exceeded the target value for nickel.

5 All zones met both the target values for ozone.

6 All zones except one exceeded the long-term objective for ozone set for the protection of human health.

7 All zones met the limit value for daily mean concentration of PM10 particulate matter.

8 All zones met the limit value for annual mean concentration of PM10 particulate matter.

9 All zones met the target value for annual mean concentration of PM2.5 particulate matter - the Stage 1 limit value, which came into force on 1st January 2015, and the Stage 2 limit value which must be met by 2020.

10 All zones met the EU limit values for sulphur dioxide, carbon monoxide, lead and benzene.

11 The UK therefore met its EU targets for both PM10 and PM2.5 in 2016, which is not always the impression one gets from media reports, although breaches in NO_2 limits remain a serious problem for the UK.

In February 2017, the European Commission gave the UK a final warning over its failure to meet air pollution limits for NO_2. At this point the issue became very pressing for the UK Government. In a consultation of May 2017, the UK, Scottish and Welsh Governments, and the Department of Agriculture, Environment and Rural Affairs in Northern Ireland, sought views on a revised plan to reduce levels of NO_2 around roads, within the shortest possible time [148]. The consultation closed on 15th June 2017 and by July 2017, Defra and the Department for Transport had already published their preliminary plan, The UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations [149]. This strategy outlined how councils with the worst levels of air pollution, at busy road junctions and hotspots, had to take action to combat excessive NO_2 pollution.

The Plan includes an additional £255m in funding for local councils across the country named as having persistent breaches of NO_2 limits, to allow them to accelerate their air quality plans. It sets out 29 local authorities, including seven districts in Greater Manchester, which have to undertake comprehensive feasibility studies to identify solutions to local NO_2 exceedances, with the final local plans to be agreed by the end of 2018. Local authorities will also be able to bid for money from a new Clean Air Fund, to support improvements such as changing road layouts, removing traffic lights and speed humps, or upgrading their bus fleets. In the 2016 Autumn Statement, the Government had also allocated a separate £100 million for the retrofitting of buses and the ordering of new low emission buses across the country.

Well before the national NO_2 plan, the Mayor of London's Office announced in July 2016, a comprehensive Clean Air Action Plan for London to tackle air pollution at source [150] which included the following measures:

- From October 2017, an additional £10 toxicity charge (T-Charge) will apply to the oldest and most polluting vehicles in Central London.
- From early 2019 an Ultra Low emission Zone (ULEZ) will create strict new emissions standards for diesel vehicles (24 hours a day and 7 days a week). Those that do not comply will face a charge. It is hoped that this action will reduce harmful NOx emissions by about 50 per cent in central London, 40 per cent in inner London and 30 per cent in outer London.
- £300m is being spent on transforming London's bus fleet by retrofitting buses, with a commitment to phase out diesel-only double decker buses from 2018.
- Low Emission Bus Zones are expected to reduce NOx emissions by 84 per cent in the selected areas. In these zones, bus operators will only be able to use bus fleets which comply with the new Euro VI engine standards.
- London and Paris will be launching a new vehicle pollution scoring scheme to help consumers choose less polluting cars.

At the beginning of 2017 the Mayor of London also announced plans to protect London's schools from pollution, including 50 'air quality' audits to take place at primary schools in areas exceeding the legal limits for NO_2. Regionally, in Leeds, there are now also plans to charge the owners of high-emission vehicles for entering the city centre, and tighter emission controls can, hopefully, be expected to spread to other UK cities.

Results from the first Low Emission Bus zone in Putney appear positive. Between February and June 2017 the EU's hourly nitrogen dioxide (NO2) objective was exceeded only six times at the kerbside pollution monitor, compared to 742 times during the same six month period in 2016 and 640 times in 2015, according to the London Borough of Wandsworth [151].

In London, at the beginning of 2018, London's NO_2 levels also were within legal limits in mid-January for the first time in 10 years. City Hall attributes this improvement in part to the new Low Emission Bus Zones and the T-Charge, although legal limits for the whole year were still exceeded by the end of January [152], so this was only a relatively small improvement.

Some of the recognised solutions to the problem are well documented. Reducing air pollution from vehicles, in particular diesel vehicles, is perhaps the area where the greatest change can be achieved most quickly. Four major cities - Paris, Athens, Mexico City and Madrid – all plan to ban diesel vehicles by 2025 and Scotland aims to phase out new petrol and diesel cars and vans by 2032. In late February 2018, the top administrative court in Germany ruled that cities in Germany now have the right to ban diesel vehicles in order to improve their air quality levels[153]. Some German cities are now also offering the public free public transport to reduce air pollution [154].

The National Institute for Health and Care Excellence (NICE) produced general guidance in June 2017, Air pollution: outdoor air quality and health [155], which outlines major recognised strategies for reducing outdoor air pollution:

Encouraging cycling and walking to work, school and college in order to reduce the populations' reliance on vehicular transport (this relies on safe walking and cycling provision in cities and between communities, and has the added benefit of promoting exercise with all the associated health benefits).

Improving access to public transport, thereby reducing the public's reliance on car transportation; this is already well-advanced in cities like London.

Reducing pollution from transport service and heavy goods fleets through improved driving techniques, no idling engines when vehicles are stationary, the possible removal of speed bumps (if this does not compromise pedestrian safety) etc.

- Introducing Clean Air Zones in major cities.
- Suitable planning restrictions to ensure nurseries and schools are not cited near busy roads.
- Measures to discourage road transport in cities, such as road tolls and bypasses.
- Introducing incentives to consumers to switch from using diesel vehicles to lower and non-polluting vehicles.
- Reducing air pollution from industrial sites and power stations.

By 2040, the Government plans to end the sale of all new conventional petrol and diesel cars and vans with the aim that no petrol and diesel vehicles will be on Britain's roads by 2050. Concerns have been raised in many quarters about the length of time before this sales ban will be in place – still more than 20 years. Greenpeace, for example, said the Government was right to put an expiry date on petrol and diesel cars, "but 2040 is far too late." On the other hand, the Society of Motor Manufacturers has said that an outright ban on diesel cars now would affect jobs in the vehicle manufacturing sector [156].

Prior to the announcement of the Plan in July 2017, 67 MPs from all parties had signed a joint letter urging the Environment Secretary, Michael Gove, to include a diesel scrappage scheme in the Government's Air Quality Plan. However a diesel scrappage scheme was only muted for consideration in the July 2017 announcement, rather than there being a definitive commitment. In response to the Government's 2017 Plan, the London Mayor's Office commented that "we need a fully-funded diesel scrappage fund now [157]."

The Chartered Institute for Environmental Health, in their response to the Government's Plan [158], also expressed concern that a targeted scrappage scheme will only be considered, not implemented and that the plans:

- Overlook particulate matter as the single biggest contributor to premature deaths and ill-health, placing too much of an emphasis on reducing NO_2 emissions;
- Fail to consider, in their cost/benefit analysis, the burden on the NHS and the wider health implications on people and local communities, concentrating solely on the impact on business;
- Do not acknowledge that, based on current rates, by 2040 there could be up to 920,000 excess deaths from air pollution, which is unacceptable.

The Government has said that it will publish a draft Clean Air Strategy in 2018 which is expected to address all forms of air pollution, not just NO_2, so it likely that a more comprehensive package of measures, including on particulates, will address some of these concerns. A joint inquiry by the Environment Food and Rural Affairs, Environmental Audit, Health, and Transport Committees into Air Quality [159], is also due to report in March 2018, so hopefully their recommendations will also be reflected in the Strategy.

Finally, in terms of legislation, there is currently a Private Members' Bill going through Parliament, the Clean Air Bill 2017-2019 [160], sponsored by Geraint Davies MP. The Bill would require the Secretary of State to: set, measure, enforce and report on air quality targets; take action to mitigate air pollution, including through the use of Clean Air Zones; improve vehicle emissions testing; and restrict the approval and sale of vehicles with certain types of engines. The Bill is still due to have its second reading in the House of Commons.

10. Is current pollution monitoring in the UK adequate for the protection of public health?

The main purpose of this briefing is to investigate the health effects associated with different types of air pollution. However, collecting the data needed to analyse the impact of air pollution on health relies on having high-quality environmental monitoring, for example to establish whether the UK is complying with its EU air quality obligations. According to the Chartered Institute of Environmental Health (CIEH), there is currently no UK-wide pollution monitoring strategy; neither is there uniformity when it comes to the measurement methods adopted locally, so data between areas is not necessarily comparable. There is also no direct funding stream for local authorities to support local air quality monitoring, and, given the high costs associated with the acquisition and maintenance of air monitoring equipment, at a time of financial restraint in local government, pollution monitoring may not be seen as a priority by local councils.

Councils are currently following national guidelines on air pollution, which require them to "take a risk-based approach" and only monitor locations which are most at risk, but is this really adequate for protecting public health? Many local authorities are in fact failing to fulfil their legal requirements on air quality reporting due to a lack of resources, according to the campaign group DeSmog UK [161]. This information raises broader questions about the effectiveness of continuing to place responsibility for addressing air pollution problems solely onto local authorities. According to DeSmog UK, documents and correspondence with officials in local authorities across the Midlands, for example, show air pollution reporting failures in many areas with illegal levels of air pollution. It was reported in 2016 that over half of local councils do not monitor air quality outside schools [162].

Clearly, Defra and local authorities need to discuss the purpose and effectiveness of current local air pollution monitoring arrangements, above all to drive the positive interventions needed to protect public health. Dedicated funding streams may also be needed to achieve this. High quality public health information and advice, particularly for vulnerable groups with pre-existing health conditions, relies upon accurate and meaningful data on local air pollution levels, which may require continuous monitoring in pollution hotspots.

Conclusions

European and global health leaders are increasingly concerned about the toll that air pollution is taking on human health. There is a long way to go before the estimated figure of almost 40,000 excess deaths in the UK attributable to air pollution starts to fall significantly and this can only be achieved through concerted national, regional and local action.

While the link between air pollution and respiratory and cardiovascular conditions is now generally well established, further research is urgently required to determine whether, and to what extent, air pollution, in all its forms, is responsible for a much wider range of health conditions, including: cancer, diabetes, cognitive impairments in the young, vascular dementia in older people, and endocrine and immune disorders.

Determining which pollutants trigger - or exacerbate - which particular health conditions is important, both in terms of short-term *and* long-term exposure and for different populations, including vulnerable groups. The cumulative effects of air pollution over a lifetime, is something that is not always emphasised in the literature. This should be done in the context of existing EU air pollution legislation, to assess whether, and to what extent, the current legal limits in place for substances such as NO_2, PM10, PM2.5 and ozone, are adequate for protecting human health. If they are not adequate, the UK Government should consider adopting the more stringent WHO air quality guideline, as has Scotland, which would afford greater protection to human health across the UK. The UK's departure from the EU needs to be appraised in terms of possible future impacts on air pollution standards in the UK as a whole - and any corresponding impacts on the health of the population.

Defra and local government also need to urgently assess whether the existing air pollution monitoring network in the UK is adequate to pick up local variations in concentrations of different pollutants, to inform better public health decision-making. The lack of equipment measuring concentrations of ultrafine particles should also be a cause for concern. As Dame Sally Davies concluded in her recent Chief Medical Officer's Annual Report (March 2018), "air quality has many components and more effort should be made to measure the various pollutants harmful to health [163]."

A more in-depth analysis of the financial burden associated with air pollution across the UK, would also be helpful, as has already been done for London by King's College London. This should look at the healthcare costs associated with both short-term and long-term exposure to pollutants, and the consequent impact on economic productivity and the burden placed on health and care services.

Improved public health information is required so individuals can take precautionary measures to protect themselves from the effects of pollution, through things such as choosing a better route to work or taking public transport rather than riving, but ultimately diesel vehicles also need to be phased out speedily because of particular risks to health associated with the combustion of diesel fuel. Such action could, in some ways, be seen as analogous to the action taken to ban smoking in public places.

Glossary

Ambient Air	Outdoor air.
Benzene	A chemical compound harmful to human health. As an air pollutant, benzene can be emitted from domestic and industrial combustion processes, and road vehicles.
Carbon Monoxide (CO)	A pollutant gas found released in road vehicle exhausts.
Cohort Study	An epidemiologic study in which the groups of individuals (cohorts) are selected on the bases of factors that are to be examined for possible effects on some outcome. For example, the effect of exposure to a specific risk factor on the eventual development of a particular disease can be studied.
Epidemiology	Is the study of the distribution and determinants of health-related states or events (including disease), and the application of this study to the control of diseases and other health problems (WHO).
Limit value	The Air Quality Directive sets 'limit values' for outdoor concentrations of pollutants. Limit values are legally binding and must not be exceeded. All Member States of the EU must make limit values part of their own air quality legislation.
Meta-analysis	A quantitative, formal, epidemiological study design used to systematically assess the results of previous research to derive conclusions about that body of research.
Microgrammes per cubic metre ($\mu g\ m^{-3}$)	This is a unit of measurement used to express the concentration of a particular pollutant in air: i.e. one-millionth of a gram per cubic metre of air.
Micrometre	A unit of measurement (also known as a micron): One micrometre is one millionth of a metre.
Nanometre	A unit of measurement One nanometer is one billionth of a metre.
Nitric oxide (NO)	One of the oxides of nitrogen formed during combustion processes. NO is not harmful to human health, but it combines with oxygen to form nitrogen dioxide (NO_2) which can be harmful to health.
Nitrogen Dioxide (NO2)	One of the oxides of nitrogen formed during combustion processes. At high concentrations NO2 is an irritant to the airways.
Nitrogen Oxides (NOx)	Compounds formed when nitrogen and oxygen combine. NOx, which comprises nitric

	oxide (NO) and nitrogen dioxide (NO2), is emitted during the combustion process. Main sources include power generation, industrial combustion and road transport.
Ozone (O3)	A pollutant gas which is not emitted directly from any source in significant quantities, but is produced by reactions between other pollutants in the presence of sunlight (known as a 'secondary pollutant'). Ozone concentrations are greatest in summer.
Particulate Matter (PM)	Small airborne particles. PM may contain many different materials such as soot, wind-blown dust or particles formed in the atmosphere as a result of chemical reactions. Some PM is natural and some is man-made.
PM10	Particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter, as defined in ISO 7708:1995, Clause 6. This size fraction is important for human health, as these particles are small enough to be inhaled into the airways of the lung – described as the 'thoracic convention' in the ISO standard.
PM2.5	Particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 2.5µm aerodynamic diameter, as defined in ISO 7708:1995, Clause 7.1. This size fraction is important for human health, as these particles are small enough to be inhaled very deep into the lung – described as the 'high risk respirable convention' in the ISO standard.
Sulphur dioxide (SO2)	An acid gas formed when fuels containing sulphur impurities such as coal are burned.
Target Value	As well as limit values, the Air Quality Directive and Fourth Daughter Directive set target values for some pollutants. These are similar to limit values but are not legally binding. Member States must take all necessary measures, not entailing disproportionate costs, to meet these target values.

This glossary is adapted from Air Pollution in the UK 2016 (Defra, 2017) [43]

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Acknowledgements

Policy Connect would like to thank the following individuals and organisations for their technical expertise, advice and support in producing this publication. We are very grateful for their expert assistance:

Professor Frank Kelly, Deputy Director of MRC-PHE Centre and Theme Lead: Air Pollution, Noise and Health. Professor of Environmental Health at King's College London

Dr Ian Mudway, Senior Lecturer in Respiratory Toxicology, Department of Analytical, Environmental and Forensic Sciences, King's College London

Dr Benjamin Barratt, Lecturer in Air Quality Science; Department of Analytical, Environmental and Forensic Sciences, King's College London

Dr Elizabeth Hayes, Scientific Manager, MRC-PHE Centre for Environment and Health, Imperial College London

Dr Mark Miller, Senior Research Fellow, University/British Heart Foundation (BHF) Centre for Cardiovascular Science at the University of Edinburgh and an Expert Member of COMEAP, the governmental advisory Committee on the Medical Effects of Air Pollution.

Tony Lewis, Head of Policy Chartered Institute of Environmental Health.

Sir David Spiegelhalter OBE FRS , Winton Professor for the Public Understanding of Risk in the Statistical Laboratory, Centre for Mathematical Sciences, University of Cambridge.

March 2018
The paper was researched and written by Judith Abel, Head of Health Policy, Policy Connect.

The views and opinions presented in this report do not necessarily represent members of the All-Party Parliamentary Health Group or All-Party Parliamentary Climate Change Group.

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