The continuing struggle to clean London’s air

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Abstract
Pollution from smoke has been a problem ever since people first started to make fires in order to cook food, to keep warm, and to work metals. The problem became far worse in London with its rapid growth and industrialisation during the nineteenth century, but little effective action was taken until the London fog of 5 to 8 December 1952 that resulted in the premature death of between 3,500 and 4,000 people. The Clean Air Act then led to a steady reduction in smoke and sulphur dioxide concentrations, aided by the replacement of coal by oil and then of oil by gas from the North Sea.

The early regulations limiting air pollutant emissions from vehicles were effective, and were progressively strengthened. However, over the last decade it has become increasingly evident that many vehicles that meet the requirements of the regulations under test conditions, fail to do so on the road. Nitrogen dioxide (NO₂) emissions from these engined passenger cars and light trucks are a particular problem, with little prospect of London meeting the NO₂ requirements of the European Union Ambient Air Quality Directive for some years. The Mayor of London introduced a Low Emission Zone in 2008 and is now proposing to supplement this with an Ultra-Low Emission Zone from 2020 in the hope of achieving compliance with the Directive.

Introduction
Pollution from smoke has been a problem ever since people first started to make fires in order to cook food, to keep warm, and to work metals. London in particular had long been recognised as having an air pollution problem resulting from the burning of coal in particular, with a Royal Proclamation prohibiting the burning of sea coal as early as the fourteenth century. At this time coal was mainly used in industrial processes such as the production of lime for use in building construction (Brimblecombe 1987). It was not until the seventeenth century that coal began to be used to a significant extent to heat people’s homes but many founds its sulphurous fumes objectionable. John Evelyn (1661) presented King Charles II with a treatise entitled Fumifugium: or the Inconvenience of the Aer and Smoak of London Dissipated on the problem of smoke, suggesting that smoke pollution would shorten the lives of people living in London.

There is plenty of evidence of interest in the causes and effects of air pollution in the eighteenth century, but it was hardly an age of environmental activism. Physicians advised their asthmatic and consumptive patients to move to the country where they could avoid the harmful effects of city air (Brimblecombe 1987). But even the country was not immune from the effects of London smoke. Gilbert White (1789), the vicar
of Selborne in Hampshire which is 75 kilometres from London, noted in his journal for 16 October 1784 that he had “observed a cloud of London smoke to the N and N.N.E.” (that is to the north and north north east). In his Meteorological Observations White notes that “When such mists appear they are usually followed by dry weather”, weather conditions that today would be recognised as occurring when there is a anticyclone stationary over south east England.

London in the nineteenth century was marked by a rapid growth in the population and a growth in trade and industry. Between 1801, the year of the first national census of population, and the census year 1901 the population of the area that is today the administrative region of Greater London grew from just over 1 million people to 6.5 million. London had always been a significant trading city but trade expanded rapidly through the century, necessitating the construction of enclosed docks on either side of the River Thames to handle the ships that could no longer be accommodated in the river alone (Ackroyd 2007). New industries sprang up, many linked to the import and export of goods. All this growth was fuelled by coal. Coal was used by the growing population to cook and keep warm. Manufacturing industries used coal. Steam engines operated the docks, and steam cranes moved goods in and out of ships. As the century progressed, more and more ships were powered by steam rather than sail. All this use of coal meant that vast quantities of smoke was sent up into the London atmosphere.

The first street lighting was introduced in London in 1807, burning gas. This gas was produced from coal and is today often referred to as ‘town gas’ to differentiate it from naturally occurring methane or ‘natural gas’. Gas began to be used in homes for lighting from the 1840s onwards, and then also for cooking and heating. Gas street lighting was followed by electric lighting from 1878, with the world’s first public power station established in London by Thomas Edison in 1883. By 1914 there were 70 power stations in London (Ackroyd 2000). The gas works and power stations all added smoke to the London atmosphere.

The valley of the River Thames is naturally prone to the formation of winter fogs, and this is aided by clear skies and calm conditions. Cold air settles along the river basin and the moisture in it condenses as fog. It is often associated with a temperature inversion with warmer air above the floor of the valley. Ever increasing quantities of smoke from coal burning combined with the natural fog to turn day into night and to choke Londoners. There are reports of thick smog, smelling of coal tar, which blanketed London in December 1813. Lasting for several days, people claimed you could not see from one side of the street to the other. Fogs became more frequent through the nineteenth century, and the severe fog in December 1873 saw the death rate across London rise 40% above normal. Marked increases in death rate occurred, too, after the notable fogs of January 1880, February 1882, December 1891, December 1892 and November 1948. The worst affected area of London was usually the East End, where the density of factories and homes was greater than almost anywhere else in the capital. The area was also low-lying, making it hard for fog to disperse (Brimblecombe 1987; Corton 2015).

Fog features in many novels of the nineteenth and early twentieth century, particularly those of Charles Dickens. For example, in The Old Curiosity Shop (Dickens 1841) the evil character Quilp comes to a just end when he looses his way in the dense fog, falls, and drowns in the
River Thames. His later novel Bleak House (Dickens 1853) begins with a description of the all enveloping and choking fog in the city, along the river, and beyond London in the Essex Marshes. The year of its publication was also the year that the first effective legislation, the Smoke Nuisance Abatement (Metropolis) Acts 1853, discussed below, was passed by Parliament. Fog feature in several of Arthur Conan Doyle’s stories about the fictional detective Sherlock Holmes. In The Adventure of the Bruce-Partington Plans (Conan Doyle 1908) London fog is an integral part of the plot, in which the plans for a new submarine are stolen, concealing the activities of the protagonists. The story is set in November 1895, a period when fogs were denser and more frequent than when it was published in 1908 (Corton 2015).

Until the early nineteenth century, attempts to deal with the smoke problem were local and sporadic. In 1819 a Select Committee was set up by Parliamentary to consider the problem of smoke from steam engines and furnaces, and whether they could be operated in a way that was less prejudicial to public health and comfort. The committee concluded that smoke was indeed prejudicial to health, and Eric Ashby (1974), speaking on the twenty-second anniversary of the December 1952 fog (see below), suggested that this was the beginning of the long gestation that ended in the Clean Air Act 1956. In 1843 another Select Committee investigated the problems of smoke and how it might be prevented, and expressed the hope that black smoke from fires and private dwellings might eventually be avoided. A subsequent bill related only to smoke from furnaces heating steam boilers but nevertheless encountered fierce opposition and was dropped. A third Select Committee in 1845 said that in the then state of knowledge action should be limited to furnaces used to generate steam, but again the subsequent bill was defeated in Parliament.

In 1851 the City of London (2) secured powers under the City of London Sewers Act to control smoky furnaces and, under pressure from the Court of Common Council, these powers were extended to the whole of the metropolis two years later. The Smoke Nuisance Abatement (Metropolis) Acts 1853 and 1856 empowered the police in London to take action against furnaces used to raise steam and in factories, public baths and wash houses, and steam vessels on the River Thames. These Acts continued in use in London till the passing of the Public Health (London) Act 1891 which transferred responsibility from the police to the sanitary authorities (subsumed into the 28 Metropolitan Borough Councils in 1899). Reserve powers were given to the London County Council (LCC) (3), which had been established in 1889, to act if a sanitary authority default. The LCC instructed its coal officers to report cases of nuisance from black smoke and their reports spurred some authorities to act.

Ashby (1974) suggested that one of the impediments to action on smoke was that it was seen as a secondary problem to the threat of cholera. The 1820s saw the spread of cholera from Asia across Europe. There were four major outbreaks in London, the numbers deaths in the city being recorded as:

- 1831 - 2
- 1848 - 9
- 1853 - 4
- 1866 - 5,596

Most people, including doctors and scientists, believed that cholera was transmitted through the air but did not know how this occurred. It was
not until 1849 that Dr John Snow first suggested that water polluted by sewage might be the vehicle by which cholera was spread. During the outbreak of 1853–4, Dr Snow noted the high incidence of cholera amongst users of water from a well near his medical practice. Initially, few were convinced by his hypothesis but in 1857 he published a paper comparing mortality in two areas of south London drawing water from different sources with markedly different mortality rates. This clearly demonstrated that cholera was transmitted in the water rather than through the air. An acceptance of the need for a proper system of sewage disposal, to avoid the contamination of water supplies, led to the construction of the sewer system that is still in use today. There were no further outbreaks of cholera after its completion in 1868 (Halliday 1999).

Although by the beginning of the twentieth century there had been some improvement in air quality, there remained the problem of private houses. When industrialists were charged with smoke pollution, it was a common defence to cite the 95% of smoke that came from chimneys of 700,000 houses in London. The London County Council even seemed to accept the view that “The open fire is such an essential feature of our national home life that any attempt to abolish it is almost out of the question.” (Brimblecombe 1987) Another problem lay in the wording of the legislation which referred to ‘black’ smoke. In order to proceed successfully against a smoke nuisance, it had to be proved to be black, and convictions were rare. Brimblecombe (1987) gives as an example the case in which Chelsea Borough Council sought to oblige the Underground Electric Railway of London to reduce the smoke from its power station. The action failed because the company argued before the court that its smoke was actually dark brown and not black!

**The great London fog**

The event that led to a major change was the London fog of 5 to 8 December 1952. Dense fogs were a common occurrence in London, but this was different. The report of the committee of enquiry set up by the Ministry of Heath commented that “In a city traditionally notorious for its fogs there was general agreement on its exceptional severity on this occasion” (Ministry of Health 1954). The committee estimated that between 3,500 and 4,000 more people had died than would have been expected in the first three weeks of December under normal conditions, but the death toll only became apparent after the event.

The first reported casualties of the fog were cattle at the Smithfield Show. (4) One died, twelve other cattle had to be slaughtered, sixty needed major veterinary treatment, and about a hundred more needed minor attention. All were relatively young and in prime condition. Another indicator of the seriousness of the situation was that at Sadlers Wells theatre the opera *La Traviata* had to be abandoned after the first act because the theatre was so full of fog. Newspapers carried other fog news stories, with correspondents to *The Times* newspaper focusing on the high economic cost of the fog. It was the Coroners, pathologists and the Registrars of Deaths who first became aware of the exceptional effects.

During the fog, both smoke and sulphur dioxide (SO₂) levels reached exceptional concentrations. The mean smoke concentration in December 1951 across twelve sites for which data was available was between 120 and 440 microgrammes per cubic metre (µg/m³). The wind speed dropped on the afternoon of Thursday 4 December and patches of fog had begun to appear by 6 pm. By noon the next day, smoke concentrations at County Hall
in central London had risen from 490 \( \mu g/m^3 \) to 2460 \( \mu g/m^3 \). They continued to rise to 4460 \( \mu g/m^3 \) on both 7 and 8 December. \( \text{SO}_2 \) followed a similar pattern with concentrations rising from 412 \( \mu g/m^3 \) on 4 December to 2148 \( \mu g/m^3 \) on the 5th and to 3831 \( \mu g/m^3 \) on both the 7th and 8th. On Tuesday 9 December concentrations of both smoke and \( \text{SO}_2 \) dropped sharply to 1220 \( \mu g/m^3 \) and 1350 \( \mu g/m^3 \) as wind speeds rose and the fog cleared. The measurements taken at County Hall are shown in Figure 1 above.

Brimblecombe (1987) notes that the air pollution monitoring equipment was fairly primitive and primarily designed to give long-term measurements of air pollutant concentrations. Whilst the highest daily mean concentration was 4460 \( \mu g/m^3 \), over short periods it would have been much higher. The filters of the air conditioning system of the National Gallery normally clogged with particulate material fairly slowly. However, one day during the December 1952 fog they clogged 26 times faster than normal and in one four-hour period they clogged 54 times their normal rate. If it is assumed that the normal particulate concentration was about 250 \( \mu g/m^3 \), the inference is then that the smoke density in these four hours could have been as high as 14,000 \( \mu g/m^3 \) which, as Brimblecombe said, a phenomenally high level of pollution even though it is possible that the flocculating properties of the particles were affected by the fog. The highest hourly value recorded in later air pollution episodes in London were 9700 \( \mu g/m^3 \) in January 1956 and 7220 \( \mu g/m^3 \) in December 1957 (Commins and Waller 1967).

Figure 2 on the next page shows the number of deaths occurring each day just before, during, and just after the fog. In the graph, data for ‘London’ relates to the pre-1965 Administrative County of London, which approximates to the area that is now referred to as ‘Inner London’. The data for ‘Greater London’ relates to an area similar, but not identical, to the current administrative region of Greater London which was established in 1965.

The committee made an estimate of the number of deaths that occurred as a result of the fog by
Figure 2  Deaths occurring daily during the fog

comparing the number of people that would normally have been expected to die with the number of deaths actually registered in the week of the fog and subsequently. Three different methods of calculation were used. The principal feature of mortality was the sudden rise in the week ending 13 December followed by a sharp fall but to a level still well above the level in the weeks preceding the fog. The first method was to compare the excess of deaths registered in the weeks ending 13 and 20 December over the average for the corresponding weeks of 1947 to 1951. This gave a figure of 4,075. A second way was to compare the deaths occurring in the weeks ending 13 and 20 December with those in the preceding week ending 6 December. This gave a figure of 3,717. A third way was to compare the daily average deaths between 30 November and 4 December, when there was no fog, with the period from 5 to 16 December. This gave a figure of 3,412. On this basis the committee concluded that between 3,500 and 4,000 deaths had occurred as a result of the fog, and that a figure nearer 4,000 was the best estimate that could be made.

Information from the death certificates filed in the General Register Office and the results of autopsies carried out by Coroners’ pathologists clearly show that the main causes of death were respiratory and cardiovascular disease. Respiratory diseases alone accounted for 59% of the increase in deaths in the week ending 13 December and 76% in the following week as recorded in the Registers of Deaths. Bronchitis and emphysema were the two conditions that stood out in the Coroners records as showing the greatest increase. Cardiovascular disease accounted for 22% of the increased number of deaths in the first week but the proportion fell to 16% in the week ending 20 December.

The committee noted morbidity and mortality remained elevated from December 1952 until March 1953 in Greater London. The report attributed these increased rates to an influenza epidemic, while recognizing some deaths may have been due to lingering effects from the fog. The December 1952 fog might have impaired resistance to illness, causing higher mortality in subsequent months. However, no follow-up work
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was done to clarify this idea at the time, and official estimates attributed lingering increased rates of illness and death to influenza (Ministry of Health 1954).

To the great majority of normal, healthy individuals the fog was little more than a nuisance. The increased morbidity, of which there was clear evidence, mainly occurred amongst people with pre-existing respiratory or cardiac disorders. As far as could be ascertained, there were no deaths among previously healthy people. The committee concluded that the irritants mainly responsible were probably those derived from the combustion of coal and coal products. However it was impossible to say that one pollutant was the cause of death (Ministry of Health 1954).

In 2002 the fiftieth anniversary of the great London fog led to conferences and reassessments, including suggestions that the original estimates of mortality arising from the London fog of December 1952 were a significant underestimate. Bell and Davis (2001) estimated that there were 12,000 excess deaths, partly because they looked at the effects of the fog over a longer period. Although earlier analysis attributed many of these excess deaths in the period January to March 1953 to a mild influenza epidemic, a closer look at the number of excess deaths indicates only a fraction of them could have been from influenza. Although the excess deaths reported could not be conclusively linked to air pollution, Bell and Davis considered it is highly likely the true tally of this episode was much higher than earlier reported.

Hunt et al. (2003) reviewed autopsy diagnosis and tissue samples held at the Royal London Hospital, using techniques far in advance of those available in the early 1950s, for clues as to the character of the particulate matter inhaled and retained in the lungs. This confirmed the importance of ultrafine carbonaceous and metal particulate matter. The smoke concentrations at that time were reported in milligrams per cubic metre (mg/m³) whereas today particulate concentrations are generally given in microgrammes per cubic metre (µg/m³). The highest recorded concentration during the December 1952 fog was 4460 µg/m³ whereas the highest daily figure recorded in central London during 2005, before the black smoke monitoring network was closed down, was 22 µg/m³. The relationship between black smoke measurements and PM_{10} and PM_{2.5} is uncertain. For example Muir and Laxen (1995) found daily average black smoke to be a reasonable predictor of both daily average and daily peak 1 hour PM_{10}. However Alison Loader (2013), who was involved in co-location studies in the 1990s, found the relationship between PM_{10} and black smoke to be site-specific and seasonal. Heal et al. (2005) found that the ratios of black smoke to both PM_{10} and PM_{2.5} were significantly lower in summer than in winter, reflecting either or both a greater contribution of non-black secondary particles in summer and a greater contribution from combustion for heating in the winter.

Clean Air Act

The Government’s immediate response to the December 1952 fog was to deny that it had any responsibility in the matter or that there was any need for further legislation even though the London County Council (LCC) (3) had produced a report in January 1953 clearly detailing its appalling effect. Harold Macmillan, the Minister for Housing and Local Government at the time but later to become Prime Minister, said “I am not satisfied that further general legislation is needed at present” (HC Deb 22 January 1953, c382). He urged local authorities to use the powers that they already possessed. Eventually
the Government gave way to pressure from MPs and the LCC, announcing that a committee of inquiry would be set up under the chairmanship of Sir Hugh Beaver. The committee published an interim report after only four months and its final report a year later. The Ministry of Health also published the report mentioned above.

Sir Hugh Beaver’s committee was asked to look at the general problem of air pollution, wherever and in whatever form it occurred, but the interim report focused on the air pollution arising from fuel combustion in relation to the London fog. “The domestic fire is the biggest single smoke producer. In ratio to the coal burnt, it produces twice as much smoke as industry and discharges it at a lower level” (Committee on Air Pollution 1953). Recommendations in the final report included the creation of smokeless zones in which emissions of smoke would be entirely prohibited and smoke control areas in which domestic use of bituminous coal would be restricted, as well as the provision of grants for the conversion of domestic fires to burn smokeless fuels (Committee on Air Pollution 1954).

Even after the publication of the reports by Sir Hugh Beaver and the Ministry of Health, the Government was reluctant to act. Gerald Nabarro MP therefore introduced a private bill in Parliamentary based heavily on the Beaver report. However, he later withdrew this when the Government promised to bring forward its own bill. Although weaker than Gerald Nabarro’s draft, the Government bill became the Clean Air Act 1956.

St. Bartholomew’s Hospital had begun an air pollution research programme, with daily measurements of smoke and SO$_2$ in January 1954. More frequent measurements were made when pollutant concentrations were particularly high. Measurements were made using the standard smoke shade method and using a high volume sampler on loan from the United States Public Health Service. Results for the ten years 1954 to 1964 were reported by Commins and Waller (1967) in a paper which includes an Appendix with a description of the monitoring methods. Over the ten years there was a significant fall in smoke concentrations, which the authors link to a steep decline in coal consumption in the London area.

SO$_2$ concentrations, on the other hand, changed erratically but with a very slight upward trend. Commins and Waller refer to the increased emissions of SO$_2$ in the vicinity of the hospital from power stations and new office buildings using oil fuel rather than coal. St. Bartholomew’s Hospital was only 1 kilometre from the rebuilt oil-fired Bankside Power Station, the first stage of which opened in 1953 and the second stage in 1963. This contrasts with the same period at County Hall, shown in Figure 3, where SO$_2$ was showing a significant downward trend by 1964. County Hall was both up-wind and much further from Bankside Power Station, with less new office building nearby.

London local authorities had responded positively to their new powers and the Metropolitan Borough of Holborn was the first local authority in the country to complete its designation of Smoke Control Areas. By 1969, when the former Greater London Authority (GLC) undertook a review of the effectiveness of smoke control for the London Boroughs Association, over 60% of premises and over 50% of the area of Greater London had already been covered. The study concluded that “the boroughs have been right to press ahead quickly with the imposition of Smoke
Control: firm control and a small expenditure on behalf of the community has yielded a clear profit for the community as a whole” (Plank 1970).

Figure 3 shows the steady decline in black smoke and SO$_2$ concentrations in central London (at County Hall from 1950 to 1986) until black smoke measurements ceased in 2005. This improvement is generally attributed to the success of the Clean Air Act 1956. For example the Royal Commission on Environmental Pollution (1971) said that “Since the first Clean Air Act became law in 1956 there has been a steady reduction in the emissions of smoke and sulphur dioxide into the air over Britain…” However, Auliciems and Burton (1973) studied a run of data from Kew in west London from 1922 onwards as well as data from other towns that did not introduce smoke control areas. They suggest that the decline in smoke concentrations was part of a much longer term trend and that the Clean Air Act simply speeded up a process that was already occurring.

By the mid-1970s Ball and Hume (1977) were concluding that majority of dark smoke in London was originating from motor vehicles rather than coal. As the only significant widespread source of lead in central London was tetraethyl lead, then still used to boost the octane level of gasoline, they anticipated that lead measurements might act as a tracer indicating the contribution of vehicles to smoke concentrations. Measurements taken at County Hall between May 1975 and April 1976 indicated a strong correlation between dark smoke and lead concentrations. The term ‘vehicle’ is used to refer to all types of vehicles for, although only gasoline engines and not diesel engines use lead additives, the lead is representative of the combined emissions if the mix of traffic is constant. In central London, both the mix and overall volumes of traffic varied by less than 10% throughout the year. Ball and Hume concluded that vehicle emissions accounted for as much as 77% of dark smoke during the year, and an even higher proportion during high pollution episodes.

Whilst dark smoke proved to be a good indicator of vehicle traffic, the smoke shade technique was not a good measure of the gravimetric concentration.
of particles, being particularly sensitive to particle reflectance and particle size. In the measurements at County Hall, dark smoke only accounted for about 15% by weight of total particulates and was comparatively insensitive to the remaining 85% of particulate matter (Ball and Hume 1977).

Smoke emission limits for diesel-engined road vehicles were defined by European Directive 72/306/EEC (European Community 1972), but the method of establishing these regulations which was based upon the ‘acceptability’ to a panel of observers of the visible appearance of the emitted smoke was considered out-dated. In the view of Ball and Armorgie (1983) control was needed over the mass of smoke emitted, with progressively tighter standards phased in as technological developments and practicability allowed. In fact this did not happen for nearly ten years with the introduction of the Euro 1 standards for diesel engined passenger cars in 1992 (Directives 91/441/EEC), followed by light-duty diesel trucks in 1994 (Directive 93/59/EEC) and for heavy-duty diesel trucks in 2000 under the Euro III standard (Directive 1999/96/EC).

Road traffic was also recognised as a major source of oxides of nitrogen (NOₓ) at this time, although Schwar and Ball (1983) comment that there was “a dearth of data on nitrogen dioxide levels”. The GLC operated two permanent monitoring sites, one at roof level at County Hall providing information on background concentrations and one at the roadside. The annual mean of hourly concentrations in 1980-81 was 47 μg/m³ at roof level and 69 μg/m³ at the roadside.

In 1980 the Council of European Communities passed a Directive on air quality ‘limit’ and ‘guide’ values for SO₂ and suspended particulates in order to provide a consistent framework for the protection of health and the environment throughout the Community (European Community 1980). The Directive stated that the limit values should not be exceeded as from 1 April 1983, and Member States should take appropriate measures to ensure this. For cities such as London, which have a long history of air pollution, the introduction of mandatory standards such as these tends to be viewed with caution for, while in most quarters there is a genuine desire to improve environmental quality, there is concern over the potential economic implications and practicality of introducing the necessary abatement measures (Ball and Armorgie 1983).

The GLC had compiled an inventory of the sources of emissions of SO₂ which showed the burning of fuel oil to be the largest source of emissions (Ball and Radcliffe 1979). It had found that there was an area with an exceptionally high density of emission in the centre, coinciding with the main commercial area. Changes in fuel use patterns, especially the increased usage of natural gas, had resulted in a significant decline in SO₂ and smoke emissions by then. However, Ball and Armorgie considered the future trend to be uncertain and that further control measures might be necessary. There was no reason for them to foresee the rapid replacement of oil by gas.

**Changing use of fuels**

Figure 4 shows how the use of fuels in London has changed from 1950 to 2000. The start of the decline in the use of house coal, from about 1957, coincided with the rapid growth in the use of oil. The economy was growing strongly and oil was favoured as a cleaner and less labour intensive fuel. For example, many school boilers throughout London were converted to burn oil in place of coal or coke. Later they were to be converted again to burn gas. Oil use continued to grow steadily until the first ‘oil crisis’ in 1973/4 when
the Association of Arab Petroleum Exporting Countries quadrupled the price of oil.

Natural gas was discovered in abundance in the North Sea in 1965, and in 1967 a national programme began to convert boilers and other gas burning equipment to use natural gas in place of town gas. Initially gas started to replace coal whilst oil use continued to grow. However, the high price of oil and the uncertainty over supplies resulting from the first ‘oil crisis’ in 1973/4, and the second ‘oil crisis’ in 1979 following the revolution in Iran, made gas much more attractive to industrial and commercial customers. Indeed, demand rose to the extent that commercial gas prices were raised as a restraint in the first instance, and in the second the demand could not be met and the British Gas Corporation had to use its statutory power to refuse to supply new customers requiring more than 25,000 therms (2.6 terajoules) per year.

Because of concerns over London’s ability to meet the requirements of the European Communities Directive on smoke and SO₂, the GLC approached the British Gas Corporation to see whether a programme could be established for the replacement of coal and heavy fuel oil by gas, particularly in central London, as a means of further reducing smoke and sulphur dioxide emissions. British Gas was unable to support a substitution programme because it would not have been able to meet the resultant demand. However, oil prices began to decline from 1981 and then fell sharply at the end of 1985 and through 1986, but by then gas supplies had eased and gas had captured almost all of the coal market and 60% of the market met by oil at its peak in 1973 in London. SO₂ concentrations continued to fall in a way that could not have been predicted in the early 1980s.

**Control of air pollution from industrial processes**

Air pollution from industrial processes began to become a serious problem in the nineteenth century. Alkali works, mostly producing sodium carbonate from salt from the 1820s onwards, produced large volumes of hydrogen chloride gas and an unpleasant smell. Local authorities tried to deal with the problem by banning them, without making any constructive suggestions about how to deal with the problem. All too often
the nuisance continued unabated. In 1862 a Royal Commission was set up to examine the problem.

The Royal Commission, and the Alkali Act 1863 which implemented its recommendations, adopted a new approach. The Act required that 95% of the offensive emissions should be abated (Brimblecombe 1987). The second Alkali Act 1874 required the adoption of the “best practical means” (BPM) to prevent the release of noxious and offensive gases, a principle first applied under local powers in Leeds in 1842. The general principle has remained a cornerstone of industrial air pollution control in the UK, although it has been amended by recent legislation and is now the “best available technique” (BAT). The 1874 Act also for the first time introduced emission limits for hydrogen chloride at 0.2 grains per cubic foot (0.46 grams per cubic metre). The Alkali Inspectorate was set up to implement the Act, and remained in being until 1983 when it became HM (Her Majesty’s) Industrial Air Pollution Inspectorate. In 1987 it was absorbed into the unified HM Inspectorate of Pollution, which was itself absorbed into the much larger Environment Agency in 1996.

The Environmental Protection Act 1990 established two pollution control systems: integrated pollution control which is administered by the Environment Agency and covers the larger and more hazardous process, referred to as Part A1 processes, and local air pollution control for the smaller and less hazardous Part A2 and Part B processes which is administered by the London Borough Councils within London. Both the Agency and the boroughs are required to ensure that pollution from industry is minimised through the use of the best available techniques, subject to an assessment of the costs and benefits.

The first Europe-wide directive controlling air pollution from industrial processes was Directive 84/360/EEC which set limits on the emissions from individual plants. Succeeding directives have extended the range of pollutants controlled, the types of industrial processes controlled, and impose more stringent emission limits. Industrial plants throughout Europe are now required to operate in accordance with the Industrial Emissions Directive (IED), which has been introduced in stages from January 2003 to January 2016. It brings seven different directives, including the Large Combustion Plant Directive and the Waste Incineration Directive, into one and has been incorporated into UK law through The Environmental Permitting (England and Wales) (Amendment) Regulations 2013 and corresponding regulations in Scotland and Northern Ireland.

Regulating vehicle emissions

At the beginning of the 1990s, the regulatory approach to reducing pollution taken by the European Commission related only to vehicles. Fuels were excluded. However, the vehicle manufacturers argued that because they had made great progress since traffic emissions were first regulated in 1970, future technical limits to traffic pollution should include fuel quality improvements. There was at that time a debate between the automotive and oil industries on the relative merits of the two technical approaches to reducing traffic pollution. The automotive industry maintained cleaner fuels would be cheaper and more effective whilst the oil industry argued from exactly the opposite point of view (European Federation for Transport and Environment 1999). The motor manufacturers also argued that their technology options were limited by the poor quality fuel. For example, some abatement technologies would not work with fuel with a high sulphur content.
The UK was a leader in the reduction of sulphur in road fuel for diesel vehicles to enable the use of catalytic emission reduction systems and to reduce exhaust odour. The UK legislated lower sulphur content at an earlier date than EC regulations until harmonisation at 10 parts per million (ppm) was achieved. The sulphur content was reduced from 500 ppm to 150 in 2000 and in two stages to 10 ppm at the end of 2007. The three-way catalyst had been used in the USA from the 1970s but was not adopted in Europe until Euro 1 (1992).

Additionally, it was clear that despite great advances in cutting emission levels of new cars since 1970, the actual levels of traffic pollution over the same period had increased greatly. The automotive industry argued that this could be explained by the fact that the most important step taken, the introduction of three-way catalytic converters, had yet to have a large impact on the problem. Many more new cars with catalytic converters needed to replace older cars before the full effect of the technology would be evident. The automotive industry argued that it was being asked to make further costly investments before the need to reduce emissions still further had been demonstrated.

The Auto Oil Programme was devised by the European Commission as a way of resolving these conflicting industry views by harnessing the expertise available to both, and was launched in 1992. In June 1996 the Commission adopted Directive 94/12/EC, which came into effect on 1 January 1997 and is generally referred to as the Euro 2 standard for passenger cars, based on the results of the Auto Oil Programme. The Auto Oil II Programme, which involved a much wider group of organisations including local authorities and non-governmental organisation, led to the adoption of Directive 98/96/EC which introduced the Euro 3 standard for 2000 and Euro IV standard.

A major problem today is that conformity of vehicles with the emission limits laid down in European and other regulation is checked in the laboratory, under a process known as ‘type approval’, rather than on the road where vehicles are actually used. The emission limits are linked to a standardized chassis dynamometer test cycle that the vehicle under test has to follow while its exhaust emissions are measured. Ideally, the test cycle is a realistic approximation of the actual conditions that vehicles will encounter in normal use. However, this is not always possible because the emission tests must be conducted within narrow limits in order to ensure that results from different vehicles can be directly compared, and vehicles can be tested in different laboratories, and in different countries, for compliance with the same emission limits. Also, the vehicles tested for compliance are pre-production vehicles, rather than vehicles off the mass-production line, and are specially prepared for testing (Archer 2015).

This situation has led to vehicle emissions being certified through laboratory procedures that do not reflect the full range of operating conditions encountered in use. Tests are carried out at around 22°C whereas the average temperature in London is 10.4°C, and this affects the effectiveness of emissions abatement devices. Test do not adequately reflect congested cities, missing the extremes of the stop start and low speed traffic. In addition, a single emission result is given for the entire test cycle, which covered both urban conditions and high speed steady state driving, the latter being much easier to optimise but with far less public health benefits. Meanwhile the emission limits have become increasingly stringent. For
example, the NO\textsubscript{x} emission limits for diesel passenger cars on the basis of the NEDC driving cycle were reduced by 68\% from Euro 4 to Euro 6. This has further encouraged the adoption of engineering strategies that achieve fuel efficiency and compliance with the relevant emission limits under laboratory conditions. Under real driving conditions (RDC) fuel consumption and emissions are quite different, and the difference has been increasing. The gap between the average reported carbon dioxide (CO\textsubscript{2}) emissions from European passenger cars, based on type approval tests, and emissions under RDC has grown from 8 \% in 2001 to 40\% in 2014 (Tietge et al. 2015).

By 2008 the mismatch between emission standards and on-road emissions was evident in roadside remote sensing studies. A study in west London by Rhys-Tyler, Legassick and Bell (2011) showed statistically significant reductions of carbon monoxide (CO), hydrocarbons (HC), nitric oxide (NO) and particulate emissions from gasoline cars with the introduction of each new emissions standard, from pre-Euro through to Euro 4. Whilst nitrogen dioxide (NO\textsubscript{2}) is of greatest concern due to its effects on health, discussed more fully below, NO measured in this study is important because of the ease with which it is converted to NO\textsubscript{2} in the atmosphere. Taken together NO and NO\textsubscript{2} are referred to as oxides of nitrogen (NO\textsubscript{x}).

Given the continued increase in the number of diesel cars in the UK fleet, and concerns over the increasing proportion of primary NO\textsubscript{2} in total NO\textsubscript{x} emissions from new diesel cars, this had significant implications for local air quality.

The emissions legislation on light-duty vehicles (European Union 2007) requested the European Commission to investigate the use of portable emissions measurement systems (PEMS) in order to bring emissions under real driving conditions into line with those measured at type approval. This will now be introduced from September 2017 (European Commission 2015) but vehicles will still be able to emit more than the type approval limit value, as discussed below.

The results of tests modern diesel passenger cars under real driving conditions using PEMS estimated that average emission levels of NO\textsubscript{x} were 7 times the certified emission limit for Euro 6 vehicles (Franco et al. 2014). There were, however, some remarkable differences among the performance of all the vehicles tested, with a few vehicles performing substantially better than the others. This supports the notion that the technologies for “real-world clean” diesels (i.e., vehicles whose average emission levels lie below Euro 6 emission limits under real-world driving) already exist.

The most recent data from Emissions Analytics (2015) in the UK shows that full compliance with the Euro 6 limits on NO\textsubscript{x} is already being achieved by some diesel vehicles. Of over 400 vehicles tested, only one Euro 5 car met the Euro 5 NO\textsubscript{x} limit, whereas four Euro 6 vehicles have already met the more challenging 0.08 g/km Euro 6 regulation. It is also abundantly clear that the majority of cars tested have failed to meet the regulations in real-world driving, with the average
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NO\textsubscript{X} levels four times more than they were certified as emitting. One of the problems with diesels and NO\textsubscript{X} is that unlike the three-way catalytic converter which, with rapid warm-up techniques is operational nearly all the time, the diesel vehicles lack temperature in their exhaust to achieve this with selective catalytic reduction (SCR). Exhaust gas recirculation (EGR) must also be scheduled carefully to avoid particulate emissions and cannot be used in a cold engine or under acceleration. This explains why in stop-start urban conditions NO\textsubscript{X} is not controlled anywhere near as successfully in diesel as in gasoline engines and thus real driving conditions show a significant divergence from expectation and very much higher emissions.

The introduction of PEMS testing is set to reduce this divergence between laboratory results and real-world driving. However, vehicles will not actually have to meet the type approval limit for NO\textsubscript{X} of 0.08 g/km but 0.08 multiplied by a Conformity Factor of 2.1, which means that vehicles can emit 0.168 g/km on the road. This is considered necessary “Given technical limits to improving the real world emission performance of current production diesel cars in the short term” (European Commission 2015). Data from Emissions Analytics shows that 29% of Euro 6 diesel cars already meet the 0.08 g/km limit, as well as all gasoline cars, and that 36% meet the 0.168 g/km implied by the 0.08 g/km limit plus the Conformity Factor of 2.1. This Conformity Factor will be reduced to 1.5 in 2020 for new models and 2021 for all new vehicles.

But why has there been such a rapid growth in the proportion of diesel cars in UK and European fleet? It is now more than 120 years since Rudolf Diesel patented the compression ignition engine that bears his name. Whilst many saw diesel as the engine of the future, it was not until 1936 that the Citroen ‘Rosalie’ diesel was launched at the Paris Motor Show and Mercedes-Benz put the 260D car into production. But until the mid-1970s diesel cars were regarded as heavy, sluggish, dirty and noisy. In 1975 this changed with the launch of the VW Golf Diesel. With a turbocharger the Golf GTD became a fashion icon and other European carmakers rapidly produced their own compact-class cars to compete in the new market. The European car industry continued to push forward the development of diesel engine technology with the launch of direct injection in 1989.

Cames and Helmers (2013) in their critical evaluation of the diesel car boom consider possible factors. Certainly in the 1980s and 1990s the oil industry was keen to find alternative outlets for middle distillates previously produced as heating oil. Figure 4 clearly shows how the market for oil to heat offices and homes had shrunk following the introduction of natural gas. The European car industry was keen to benefit from the investment that it had already made in diesel direct injection technology. Diesel car were also widely seen as having lower CO\textsubscript{2} emissions than gasoline cars, and have received tax concessions. However, the UK’s Air Quality Expert Group (2007) observed that overall benefits of diesel in this respect are less apparent when other factors are accounted for. The refinery processes used to produce diesel are increasing in energy intensity to meet increased diesel fuel demand and fuel compositional requirements. Some emerging emissions control technologies for diesel vehicles can also result in increased fuel penalties, which would reduce their CO\textsubscript{2} benefit compared to gasoline. Finally, recent modelling work indicates that black carbon emissions associated with diesel vehicles contribute to warming effects, although the magnitude of these effects is uncertain. These issues suggest
that it is important to consider emissions and effects beyond those associated with tailpipe emissions.

Schipper and Fulton (2013) ask whether Europe was ‘Dazzled by diesel?’ By 2009 diesels had captured over 55% of the European new vehicle market. While the diesel version of a given car model may have as much as 35% lower fuel use per kilometre and 25% lower CO₂ emissions than its gasoline equivalent, diesel buyers have chosen increasingly large and more powerful cars than the gasoline market. As a result, new diesels bought in 2009 had only 2% lower average CO₂ emissions than new gasoline cars, a smaller advantage than in 1995. Schipper and Fulton calculated that more than 95% of the reduction in CO₂ emissions per kilometre from new vehicles arose because both diesel and gasoline new vehicle emissions per kilometre fell, and only 5% arose because of the shift from gasoline to diesel technology. Increases in the weight and power for both gasoline and diesel cars absorbed much of the technological efficiency improvements offered by both technologies. Bonilla (2009) came to very similar conclusions when he looked at the effects of dieselisation in the UK. The Air Quality Expert Group (2007) also noted that diesel cars tend to have larger engines than equivalent gasoline cars.

**Standards for ambient air quality**

The setting of standards for air quality, which is now an accepted part of air quality management, has its origins in the 1973 European Communities Programme for Action on the Environment. The Commission of the European Communities established a procedure under which it asked member states to agree levels of pollutant concentrations which were not be exceeded after a given date. The first Directive covering smoke and SO₂ discussed above, came into effect in 1980.

The European approach of setting standards had not been supported by the Royal Commission on Environmental Pollution (1976) that wrote “While we welcome the intent to improve air quality… we do not think that the achievement of this aim by imposing rigid statutory limits is either wise or practical. We believe that such limits would be unenforceable in practice and would bring the
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law into disrepute.” The Commission favoured much looser and non-statutory guidelines.

The Environment Act 1995 introduced for the first time a requirement for the Government to produce a national air quality strategy containing standards and objectives and measures to achieve the objectives. This was published in 1997. The Act also established a system of local air quality management that requires local authorities periodically to review and assess the current and future quality of air in their areas. If there is any chance that part of a local authority’s area will fail to meet the air quality objectives, then the local authority must designate the area as an Air Quality Management Area and draw up a plan for achieving the objectives.

The standards and objectives in the national strategy are derived from the EU Air Quality Framework Directive 96/62/EC and the daughter Directives which identify twelve pollutants for which limit or target values were to be set. They were SO₂, NO₂, particulate matter, lead, CO, benzene, ozone, polyaromatic hydrocarbons, cadmium, arsenic, nickel and mercury. These supersede the earlier air quality Directives. The first Air Quality Daughter Directive established legally binding limit values for SO₂, NO₂, fine particles (PM₁₀) and lead, to be achieved by 1 January 2005 and 2010.

The National Air Quality Strategy acknowledged that while it expected most parts of the country to be able to take action in order to achieve the NO₂ objective “possible exceptions are London and a few other large urban areas... The measures that may be necessary could have major transport implications that cannot be justified in cost and benefit terms, currently, on the basis of the evidence in the interim report of the [Government’s] Interdepartmental Group on Costs and Benefits.” The National Air Quality Strategy made the objective for NO₂ provisional and its status was to be reviewed following a review of the European NO₂ standard that was scheduled for 2003.

The Mayor’s Air Quality Strategy

The former Greater London Council had been abolished in 1986 as the government at that time saw it as an unnecessary tier of government. The 32 London Borough Councils and the City of London Corporation had succeeded remarkably well in co-ordinating their activities but by the 1990s there was widespread agreement that a metropolitan authority was required to deal with some of the intractable long-term problems including traffic congestion. The Greater London Authority Act 1999, which came into effect in 2000, created a new Greater London Authority (GLA) with the country’s first directly elected Mayor.

Amongst the many duties and functions imposed on the Mayor and on the GLA by the Act was a duty to prepare an air quality strategy for London. The strategy was intended both as a framework for coordinating action by the London Boroughs and many other agencies to improve air quality in London, and to set out the actions which the Mayor could take directly, particularly in relation to transport. Whilst there was no doubt that London’s air quality had improved greatly since the 1950s, there was also ample evidence that London would fail to meet the targets set in European Directives and national regulations without further actions. The first air quality strategy, Cleaning London’s air, was published in 2002 (Greater London Authority 2002).

One of the key proposals was the creation of a
Low Emission Zone. The strategy explained that this was an area from which high polluting vehicles are barred and was an approach that had been pioneered in Sweden. It had been operating in Stockholm, Gothenburg and Malmo since 1996, and subsequently in Lund. In these cities, heavy-duty trucks (over 3.5 tonnes) must be under eight years of age to be allowed to enter the zone, and were required to display a permit confirming that they meet the standard. In Gothenburg, by the summer of 1997, 95% of heavy-duty trucks and 100% of buses had fulfilled the requirements to drive into the zone. The Gothenburg zone was estimated to reduce particle emissions by 15 to 20% and NOx emissions by 1 to 8%. It was also predicted to reduce the maximum level of noise by two to three decibels.

The London feasibility study that followed recommended that the low emission zone start with a scheme that targeted heavy-duty trucks and buses. These vehicles had disproportionately high emissions per vehicle and targeting them would result in the greatest improvement for the least cost. Vehicles should meet the Euro III standard, or the Euro II standard and have been retrofitted with particle traps to reduce their emissions and be eligible for a Reduced Pollution Certificate, in order to enter the zone. Reduced Pollution Certificates (RPC) were introduced by the government in order to encourage the operators of heavy-duty trucks and buses to retrofit their vehicles in order to reduce their emission. Operators that did this could apply for an RPC and then be eligible for a discount on the annual vehicle licencing tax known as Vehicle Excise Duty (VED). The feasibility study also recommended that the zone be potentially extended in later years to include light-duty trucks and taxis. The study did not recommend that cars were included in the scheme, but said that some additional action was needed to remove the oldest cars in London (those built before 1993) (Watkins et al. 2003).

London buses are operated by private companies under contract to Transport for London (TfL). TfL determines the bus routes, service frequency, fares and the types of buses, with 8977 buses operating more than 700 different routes. The Mayor’s air quality strategy included a commitment to progressive improvements in the bus fleet, with all buses fitted with particle traps by 2005.

Many other measures have also been introduced to improve air quality. For example, the Sustainable Design and Construction: Supplementary Planning Guidance (Mayor of London 2014a) requires ultra-low NOx boilers in all new developments and sets emissions standards for all new cogeneration and biomass plant. The Supplementary Planning Guidance also sets out guidance for the achievement of ‘air quality neutral’ development in London. The aim is to ensure that when a building or an area is redeveloped, this does not result in any increase in emissions of air pollutants. This is achieved by establishing benchmarks for both building and transport emissions which all new developments must comply with. Where compliance cannot be achieved, developers are required to prepare strategies to demonstrate how the excess will be mitigated, on the site or at another location. The Control of Dust and Emissions during Construction and Demolition: Supplementary Planning Guidance (Mayor of London 2014b) seeks to reduce emissions of dust, PM10 and PM2.5 from construction and demolition activities in London. It also aims to manage emissions of NOx from construction and demolition machinery by means of a new non-road mobile machinery ultra low emissions zone. The Mayor has set a challenging
target for all newly licensed taxis to be zero emissions capable from 1 January 2018 (Transport for London 2015).

The problem of nitrogen dioxide
NOx emissions from all forms of combustion have historically been among the most difficult to reduce. The drive for more fuel-efficient combustion has lead to higher temperatures and therefore to higher NOx emissions. NOx emissions in the UK were relatively constant until 1984 when they began to rise with increasing road traffic, reaching a peak in 1989. Vehicle emission controls and reduced use of coal in power generation then led to a steady decline (Williams and Carslaw 2011). However, by 2004 the trend had levelled and urban NOx concentration have remained stubbornly stable since then.

This change was observed fairly quickly but the reasons took longer to discover. The first European Directive to regulate emissions from motor vehicles was 70/220/EEC which limited emissions of CO and total hydrocarbons from gasoline engined cars and light-duty trucks. This came into force in 1971 and was followed by Directive 72/306/EEC which limited black smoke emissions from heavy-duty vehicles. These, and the Directives that followed which set additional limits for NOx, CO and PM10 for cars and both light and heavy-duty trucks, were successful in reducing emissions from all categories of motor vehicles. Regulations increasingly took account of a wider range of vehicle operating factors such as refuelling and the increased emissions when vehicles are started from cold. Type approval tests sought to replicate typical European driving conditions. Detailed measurements were made of the emissions and fuel consumption of samples of typical vehicles already in use in traffic conditions typical of European cities including London (Jost et al. 1992).

It was assumed that emissions would continue to fall in parallel with the further tightening of regulations. However, it gradually became apparent that this was not happening and a gap was opening up between the regulatory requirements and what was being achieved on the road. Also, there was a discontinuity in European regulatory policy between the vehicle regulations which limit NOx emissions and the ambient air quality standards for NO2 (Carslaw and Beevers 2004). This has become particularly significant because of the growth in the proportion of the UK passenger car fleet that is diesel engined—from 7.4% in 1994 to 37.8% at the end of 2015 (Department for Transport 2016).

Written in 2002, the Mayor’s Air Quality Strategy (Greater London Authority 2002) had commented that “All combustion processes in air produce oxides of nitrogen (NOx) which comprises mostly nitric oxide (NO) and NO2. It is NO2 which is primarily associated with adverse effects on human health … . Though some NO2 is produced directly, it is principally a secondary pollutant, arising from the conversion of NO in the atmosphere—a reaction in which ozone plays a part. This is why when discussing concentrations, nitrogen dioxide (NO2) is referred to, and when discussing emissions oxides of nitrogen (NOx) are referred to.” It was soon to become evident that, within a heavily congested city like London, the view that NO2 was principally a secondary pollutant was out-dated.

One of the factors that had not been fully appreciated was the effect of fitting diesel particle filters to heavy-duty trucks and buses. The particle filters used operate by converting NO to NO2 and use the NO2 to help oxidize the particles. They tend to use NO2 rather than O2 to oxidise the particles because NO2 is more

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suited to the temperatures found in a vehicle exhaust system (Liu et al. 2012). These filters tend to produce higher proportions total NOx as NO2 compared to vehicles without filters. In the early 2000s, there were relatively few measurements of primary NO2 from vehicles fitted with particle filters but Carslaw and Beevers (2004) referred to a large-scale study conducted by the Danish Road Safety and Transport Agency in 2002 that showed that primary NO2 increased from approximately 5% to 15–20% when particle filters were fitted to heavy-duty trucks and buses.

A detailed study carried out in 2011 (Carslaw et al. 2011) showed not only that the previous decline in NOx concentrations had stopped but also that the fraction of primary NO2 in vehicle exhausts emissions had risen from 5 to 7% in 1996 to 15 to 16% generally and to 21 to 22% in London in 2009. More recent data from Emissions Analytics (2015) has found that the variation in this fraction of NO2 in NOx between car models has also grown, as a result of differences in after-treatment technologies, from 27 to 70% in Euro 5 models to 17 to 80% in Euro 6 diesel cars. Carslaw et al. looked at data relating to other European cities and concluded that that in 2008 (the most recent data available at that time) the trends in NOx and NO2 were very similar to those in London and the rest of the UK. Figure 6 shows how the trend continues to the end of 2015 at the Bloomsbury monitoring station in central London (NO2 data for 2002 and 2003 was incomplete so is not shown). Whilst many areas of outer London do meet the European Directive annual mean limit value of 40 μg/m3, there was nothing to suggest that central London is about to do so. The annual mean at the Marylebone roadside monitoring station in central London was 85 μg/m3 in 2015. It also exceeded the hourly mean limit value of 200 μg/m3 on 46 occasions in 2015(5), and several roadside monitoring station exceeded the hourly mean limit value on more than the annually permitted 18 occasions before the end of January 2016.

Air pollution is an important determinant of health. A wide range of adverse effects of ambient air pollution on health has been well documented by studies conducted in various parts of the world. There is significant inequality in exposure to air pollution and related health risks; air pollution
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combines with other aspects of the social and physical environment to create a disproportionate disease burden in less affluent parts of society. The World Health Organisation (2013) published a Review of evidence on health aspects of air pollution –REVIHAAP Project.

In the UK the Committee on the Medical Effects of Air Pollutants (COMEAP 2015a) has published a review of the evidence for the effects of NO₂ on health. NO₂ has been associated with adverse effects on hospital admissions for various diagnoses, decrements in measures of lung function and lung function growth, increases in respiratory symptoms, asthma prevalence and incidence, cancer incidence, adverse birth outcomes and mortality. However, it has not been clear whether the effects are caused by NO₂ itself, or by some other pollutant (s) with which it is correlated in ambient air.

COMEAP says that the evidence of associations of ambient concentrations of NO₂ with a range of effects on health has strengthened in recent years. These associations have been shown to be robust to adjustment for other pollutants including some particle metrics. Although it is possible that, to some extent, NO₂ acts as a marker of the effects of other traffic-related pollutants, the epidemiological and mechanistic evidence now suggests that it would be sensible to regard NO₂ as causing some of the health impact found to be associated with it in epidemiological studies.

COMEAP (2015b) is also currently investigating whether it is possible to quantify the association of long-term average concentrations of NO₂ and mortality. There are a number of scientific and methodological challenges to consider, including interpreting the extent of the independence of the associations of mortality with concentrations of NO₂ and PM. Using both a single-pollutant coefficient for NO₂ and a single-pollutant coefficient for PM₂₅ is likely to give an overestimate. COMEAP intends to publish a report during 2016.

The Environmental Research Group at King’s College London has derived estimates of the mortality burden of both PM₂₅ and NO₂ in London in 2010 (Walton et al. 2015). The term burden is used for approximate ‘snapshot’ calculations of the health effects of the total amount of man-made air pollution in a particular year. The term is used generally for the total burden of a particular disease but in this context is applied to approximate calculations of deaths and life years lost from long-term exposure to air pollution (COMEAP 2010).

Walton et al. estimated the total mortality burden of anthropogenic PM₂₅ for the year 2010 to be 52,500 life-years lost, equivalent to 3,500 deaths at typical ages, and 88,000 life-years lost, equivalent to 5,900 deaths at typical ages for NO₂. Taking into account the WHO’s recommended value of up to a 30% overlap between the effects of PM₂₅ and NO₂ gives a total of 141,000 life-years lost, equivalent to 9,500 deaths at typical ages, for the combined effects of PM₂₅ and NO₂. However, some of this effect may be due to other traffic pollutants.

It is tempting to try to compare mortality burden imposed on Londoners by atmospheric PM₂₅ and NO₂ with the original estimate of 3,500 and 4,000 deaths that had occurred as a result of the London fog in December 1952 (Ministry of Health 1954) or with the revised estimate by Bell and Davis (2001) that there were 12,000 excess deaths. However, these were deaths that occurred immediately, or very soon after, an event that lasted just five days. The data does not exist to
try to calculate the mortality burden imposed for a whole year by smoke and SO₂ in 1952 on a similar basis to that used for calculating the health impact of PM₂.₅ and NO₂ today. Perhaps the most that one can say is that Londoners lived every day with pollution concentration far higher then are ever found today and this must have had a huge effect on the health and longevity of the average Londoner.

**What will London do next?**

In April 2015 the UK Supreme Court upheld a challenge brought by the legal NGO ClientEarth and ordered the Department for Environment Food & Rural Affairs to develop a new air quality plan by the end of the year (Supreme Court of the United Kingdom 2015). The court explicitly said that the UK had breached the 2008 Ambient Air Quality Directive, which set binding limit value for NO₂ by failing to put in place plans that would secure compliance. As previously explained, this is due in part to the failure of Euro standards to deliver the expected benefits in terms of reductions in emissions of NOₓ from diesel vehicles, and the increase in the proportion emitted as primary NO₂ which is not controlled by any existing legislation. In response to the legal action the government published it plan for *Improving air quality in the UK* in December 2015 (Department for Environment Food & Rural Affairs 2015a). Although this covers the whole of the UK, it also summarizes the Mayor’s proposals for further action in London, which are set out in detail in *Air Quality Plan for the achievement of EU air quality limit value for nitrogen dioxide (NO₂) in Greater London Urban Area (UK0001)* (Department for Environment Food & Rural Affairs 2015b).

The London Low Emission Zone mentioned above came into operation in 2008 and is the world’s largest. It covers an area of more than 1500 square kilometres and operates 24 hours a day and 7 days a week, and was introduced in a series of phases. Cameras with automatic number plate recognition technology check the compliance of vehicles against the national vehicle registration database. The operators of vehicles not meeting the emission criteria, or not registered, are charged a daily rate, and foreign vehicle operators need either to register or pay the daily rate.

Holman, Harrison and Querol (2015) have looked at the experience of Low Emission Zones (LEZ) across Europe including London. There is some evidence from ambient measurements that LEZs in Germany, which restrict passenger cars as well as heavy-duty vehicles, have reduced long term average PM₁₀ and NO₂ concentrations by a few per cent. Elsewhere, where restrictions do not apply to cars and in some cases only to heavy duty vehicles, the picture is much less clear. The effects of day-to-day variations in meteorology on concentrations often mask more subtle effects of an LEZ. Also, separating the direct effects of an LEZ from those of other policy measures, the economy and the normal renewal of the vehicle fleet is not easy, and may give rise to false results. Ellison, Greaves and Hensher (2013) who looked at the first five years of London’s LEZ concluded that it had reduces PM₁₀ concentrations by between 2.46 and 3.07% but that it had made no discernable difference to NOₓ concentrations.

The Mayor of London has now published proposals for introducing an Ultra Low Emission Zone (ULEZ) covering central London, which also form part of the government’s plan. Under these proposals, from 2020 all cars, motorcycles, light-duty trucks, minibuses, heavy-duty trucks and all types of buses will need to meet more stringent exhaust emission standards, or pay an
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additional charge, when travelling in central London. The area covered by the ULEZ is the same as the current Congestion Charge Zone and, like the current LEZ, will operate 24 hours a day and 7 days a week. Like both the Congestion Charge and the LEZ, it will be enforced with automatic number plate recognition cameras.

The standards that will apply in the ULEZ are that all gasoline passenger cars, light duty trucks and minibuses must be a minimum of Euro 4. All diesel vehicles must meet the Euro 6 standard or, for heavy-duty trucks and buses, the Euro VI standard. The problem is, as already explained, that cars and other light duty vehicles have been granted an NO₂ conformity factor of 2.1. Even in January 2021, when the conformity factor is reduced to 1.5, for all new vehicles, new Euro 6 diesel cars will be able to emit 0.12 g/km. The proposed ULEZ standard also means that some gasoline passenger cars could be 14 years old when the ULEZ is introduced in 2020. Non-compliant heavy-duty trucks and buses will be required to pay a daily charge of £100 (¥17,200) whilst cars and other lighter vehicles will pay £12.50 (¥2100). The current Congestion Charge and the LEZ will remain in place.

Transport for London (TfL) is already introducing hybrid-electric buses and by 2020, all 3000 double-deck buses operating TfL routes in central London will be hybrid and 200 single-deck buses will be zero emission at the point of use. As most buses in central London are operating routes that extend far beyond the ULEZ boundary, this means a substantial number of double-decker buses operating in inner London will be hybrid and some in the outer suburbs. Details of other measures aimed at reducing emissions and NO₂ concentrations are set out in Air Quality Plan for the achievement of EU air quality limit value for nitrogen dioxide (NO₂) in Greater London Urban Area (UK0001) (Department for Environment Food & Rural Affairs 2015b).

The Department for Environment Food & Rural Affairs (2015a) overview document Improving air quality in the UK says that “Modelling of London specific measures based on information provided by the Greater London Authority ⋯. shows that with these measures in place NO₂ levels will be at or below limit values by 2025.” These measures rely heavily on diesel vehicles achieving the anticipated reductions in emissions but, as manufacturers have had so much difficulty previously in achieving this in use on urban roads, there must be some uncertainty about how easy it will be to achieve in the future. Also, the proposed Ultra Low Emission Zone will cover the same area as the current Congestion Charge Zone, which is only 21 km² or 13% of the total area of Greater London. Is this area really large enough to have the required effect?

Looking back to the Mayor’s first air quality strategy, it can now be seen as unduly optimistic about what a Low Emission Zone would achieve.

Conclusion

History is never repeated, or not exactly. Nevertheless, the response of Government to the failure of London, and indeed the UK as a whole, to meet the requirements of the European Communities Ambient Air Quality Directive seems reminiscent of the Governments response to the London fog of December 1952. Christine Corton (2015) in her book London Fog quotes from a Confidential Cabinet Memorandum in which Harold Macmillan (later to become Prime Minister) wrote in 1953 “We cannot do very much, but we can seem to be very busy—and that is half the battle nowadays.” There was no sense then, and there is no sense today, that
Government sees the need to do anything; it only needs to appear to be doing something. Just as it was then Gerald Nabarro MP who provoked the Government into action by introduced a private bill in Parliamentary, today it is the Supreme Court of the United Kingdom that is requiring action.

It is difficult to compare the effects on the health of Londoners today from PM$_{2.5}$ and NO$_2$ with the original estimate of 3,500 and 4,000 premature deaths that had resulted from the London fog in December 1952 (Ministry of Health 1954) or with Bell and Davis’s (2001) estimate that fog had a more prolonged effect and eventually resulted in 12,000 excess deaths. These were deaths that occurred immediately, or in the months soon after, an event that lasted just five days. Part of our problem today is that NO$_2$ and the very fine particles of PM$_{2.5}$ cannot be seen and smelt in the way that thick London fogs and smoke were obvious to everyone. Now we have to rely on monitoring equipment and calculations of life-years lost to tell us the scale of the problem.

On the basis of our current experience of Low Emission Zones, the difficulty that diesel passenger cars and other light duty diesel vehicles have in achieving the required emission limits, and the absence of measures to limit the continued growth of diesel vehicles in the light-duty fleet, there must be some doubt that “NO$_2$ levels will be at or below limit values by 2025” as the Government has suggested.

The answer to the question posed by the late Lee Schipper and Lew Fulton is clearly 'yes' – Europe has been “Dazzled by Diesel”. There is scant evidence that London, the UK or Europe has achieved any significant reduction in CO$_2$ emissions through increasing the proportion of passenger cars and other light duty vehicles with diesel engines. These vehicles have failed to meet the type approval emission limits when in everyday use. The limits were not arbitrary; they were set in order to protect people’s health.

The problem of NO$_2$ in European cities is, to a very large extent, one that we have created for ourselves. It is an unforeseen consequence of decisions and actions that, no doubt, all seemed quite sensible at the time that they were taken. The lesson for the future is that we need to be very very vigilant that, in seeking to solve one problem, we do not simply create another equally serious problem in its place.

Notes

(1) The term ‘sea coal’ was originally applied to coal washed up on the seashore on the north east coast of England, but was then applied more widely to coal that was imported by ship from Newcastle to London.

(2) The City of London is both the oldest and the smallest of the local government areas in Greater London. It has existed as an administrative unit since 1141 and has an area of 2.9 km$^2$. Although not technically a London Borough Council, the Corporation of London performs all the functions of a London Borough Council. The City of London now lies at the centre of Greater London, and is also London’s principal financial district.

(3) Between 1889 and 1900 the London County Council (LCC) was the local authority for the Administrative County of London, an area of 303 km$^2$. In 1900 a lower tier of 28 Metropolitan Borough Councils was established and the LCC became the upper tier authority. In 1965 these authorities were all replaced by the Greater London Council (GLC) as the upper tier authority and 32 London Borough Councils as the lower tier over an enlarged area of 1569 km$^2$. In 1986 the GLC was abolished but in 2000 a new metropolitan authority, the Greater London Authority (GLA), was created with the UK’s first directly elected executive Mayor. The City of London has remained a separate local
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government area, within Greater London, throughout this time.

(4) For over 200 years the annual Smithfield Show was one of leading competitive livestock shows in the UK. Its name derived from the Smithfield area in the City of London where it was originally held. At the time of the London fog in 1952 it was held in the Earls Court Exhibition Centre in west London.

(5) Data from the UK national network of air pollution monitoring sites can be found under Monitoring Networks and Data Archive at http://uk-air.defra.gov.uk

(6) UK Pounds (£) converted to Japanese Yen (¥) at the 29 January 2016 exchange rate and rounded to the nearest ¥100.

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