Health Impacts of Air Pollution Episodes in London 2009-2017

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(Imperial College London from July 2020)

November 2020

Title	Health Impacts of Air Pollution Episodes in London 2009-2017

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** Following TfL and GLA comments.*

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NOTE: Although this report has been published in 2020, the analysis was prepared before the coronavirus pandemic. The baseline rates of health outcomes and the pollution levels relate to 2009-2017.

1 Summary

1.1 Introduction

This report is part of a wider set of work packages that gather evidence on the health impacts of emergency / short-term action plans to control air pollution episodes in London. Combined, they explore the information that might be needed if the Mayor wanted to consider introducing a scheme of emergency measures. The work packages a to e:

a. Summarised the health effects of short-term exposure to high levels of air pollution,
b. Estimated the magnitude of the health impact of high air pollution episodes in London,
c. Reviewed the evidence on the effectiveness of emergency measures elsewhere (e.g. Madrid, Paris, Beijing),
d. Assessed the accuracy of existing air quality forecasting for use in triggering emergency air quality measures,
e. Convened an expert workshop that considered the work packages a to d and the conclusions that could be drawn from them.

This report covers work package b. For this purpose, episodes are defined according to the Daily Air Quality Index (DAQI) (Table 1 and Defra (2013)) which allocates particular bands of air pollutant concentrations to levels of health risk (low, moderate, high and very high). This report estimates the additional health impacts of pollution levels on high and very high days compared with the average of all low days over the time period 2009-2017.

This report is primarily intended to give a sense of the size of the health problem as a result of episode days. For context, further analysis was also done analysing the health impacts of pollution levels on moderate days compared with the average impact of all low days over the time period 2009-2017.

1.2 Methods

1.2.1 Pollution data

Concentrations from all background monitoring sites across London were averaged for each day from 2009-2017 for $PM_{2.5}$, nitrogen dioxide (NO_2) and ozone (O_3) (the latter with the addition of the monitoring site at Sevenoaks[1]). These 'London background means' were used for two purposes (i) to allocate the day to a band according to the DAQI and (ii) to calculate concentration differences for use in health impact calculations.

For (i) averaging times were hourly for nitrogen dioxide, running 8-hour mean for ozone and a midnight to midnight daily average for $PM_{2.5}$. For nitrogen dioxide and ozone the maximum index during the day was used to classify the day according to the DAQI (see Table 1 in section 3.1.2). If one pollutant was in the very high band, the day was defined as a 'very high' pollution day, irrespective of the concentrations of the other pollutants.

[1] Ozone is a regional pollutant. Monitoring sites just outside London may therefore represent outer London quite well. See section 3.1.2.

For (ii), the London background mean concentrations of each pollutant on a specific day was calculated according to the averaging time used in the concentration-response function selected to calculate the health impacts. This was the same as in the DAQI for $PM_{2.5}$ and ozone, but the 24-hour average rather than the 1-hour maximum for nitrogen dioxide.

1.2.2 Concentration differences for health impact calculations

The non-episode baseline concentration chosen, for comparison with episode days, was the average of the London background mean for each of the three pollutants on all days, across all the years, when all pollutants remained low. This was then subtracted from the measured data for each pollutant for each day in order to give the additional concentration increment during that specific day's pollution, the "delta".

1.2.3 Choice of concentration-response functions

Concentration-response functions were taken from a large systematic review and meta-analysis of time-series up to 2011, or more recent meta-analyses, if available.

1.2.4 Baseline rates

Baseline numbers of deaths were obtained from ONS and baseline numbers of hospital admissions for all respiratory, all ages; all cardiovascular, all ages; COPD, all ages; asthma age 0-14; asthma age 15-64; cardiac age 65+ and stroke, all ages were obtained from NHS Digital.

1.2.5 Health impact calculations

Concentration-response functions per 10 $\mu g\ m^{-3}$ were adjusted to the relevant concentration difference for the day on the log-scale. The adjusted concentration-response function in terms of a percentage increase was then applied to the baseline numbers of health outcomes to give the additional admissions on high and very high days. Calculations were also done for moderate days and a comparison with a baseline of the average of concentrations for each pollutant on all days where all pollutants were low or moderate.

1.3 Results

Air pollution on very high days was associated with **210-310 deaths brought forward[2], 710-840 respiratory admissions and 240-360 cardiovascular admissions over the period 2009-2017,** compared with days when all pollutants are classified as 'low' according to the Daily Air Quality Index. The range is for a total with and without nitrogen dioxide, accounting for the potential overlap with $PM_{2.5}$. Results at the lower end of the range are more likely. The numbers for very high days were smaller as there were very few of them.

In most cases, $PM_{2.5}$ (and the parts of the pollution mixture it represents) was responsible for the largest number of admissions within the total. Cardiac admissions in the elderly and COPD admissions of all ages, were the largest contributors amongst the more specific causes of hospital admissions. Numbers of asthma admissions were smaller but affected children more than adults.

Using a baseline of the average of each pollutant's concentration on all days when all pollutants were moderate or low gave slightly smaller answers: **190 -280 deaths brought forward, 610 - 740 respiratory admissions and 220-330 cardiovascular admissions over the period 2009-2017.** The

[2] 'Deaths brought forward' is a term used to represent the fact that the deaths may be brought forward by a relatively short time, although it is actually unknown whether by days, weeks, months or longer. It is known that at least some of the deaths are brought forward by months or longer.

smaller concentration increments in this scenario may still be greater than those achievable with emergency measures.

The health impacts of moderate days are greater since there are many more of them. This gives results of **1150 -1580 deaths brought forward, 4000-4600 respiratory admissions and 980-1500 cardiovascular admissions over the period 2009-2017** compared with low days. This emphasises the importance of general measures to reduce concentrations of air pollution overall.

1.4 Discussion and conclusions

This report has considered the health impacts of high and very high pollution days from 2009-2017. This makes it clear that there is a health burden to address. The same methods could be used for more detailed cost-benefit analysis of potential emergency measures to be implemented on episode days. Nonetheless, the greater overall health impact of moderate days (due to their greater frequency) emphasises that long-term measures to reduce air pollution overall are also important.

2 Purpose

This report is part of a wider set of work packages that gather evidence on the health impacts of emergency / short-term action plans to control air pollution episodes in London. Combined, they explore the information that might be needed if the Mayor wanted to consider introducing a scheme of emergency measures.

The work packages a to e:

a) Summarised the health effects of short-term exposure to high levels of air pollution,
b) Estimated the magnitude of the health impact of high air pollution episodes in London,
c) Reviewed the evidence on the effectiveness of emergency measures (e.g. Madrid, Paris, Beijing).
d) Assessed the accuracy of existing air quality forecasting for use in triggering emergency air quality measures,
e) Convened an expert workshop that considered the work packages a to d and the conclusions that could be drawn from them.

This report for work package b is intended to provide an estimate of the size of the health problem that the emergency measures, if agreed, would be intended to address. This does not necessarily mean that such emergency measures could address the whole of the pollution reduction required – long-term policy measures are better suited to reducing pollution such that episode days do not occur.

3 Methods

3.1 Determination of episode days and time period for analysis

3.1.1 Time Period Chosen

Whilst there has been widespread nitrogen dioxide and PM_{10} particulate monitoring across the whole of London at both roadside and background for many years the introduction of $PM_{2.5}$ particulate monitoring only expanded significantly during 2008. For this reason, the start year of 2009 was chosen as the first year that representative coverage of $PM_{2.5}$ was available at background locations, i.e. away from roads. The end year of 2017 was chosen as the latest date that health data was available.

3.1.2 Pollution Data

Background sites, being away from roads, represent the area-wide pollutant levels to which the whole of the population is exposed as a minimum.

The analysis for nitrogen dioxide and $PM_{2.5}$ was carried out on the average of all background air pollution monitoring sites that measured that pollutant within the London Air Quality Network (LAQN) and Defra's Automated Urban and Rural Network (AURN) within London. This was termed the London background mean. For ozone, the reduction of measurements has led to insufficient coverage in the south of London, with no London monitoring site south of a line from Richmond to Greenwich in recent years. To compensate for this, the ozone data from the long-running monitoring site at Greatness in Sevenoaks, Kent was included in the analysis. Ozone is a regional pollutant and periods of moderate or high ozone affect wide areas at the same time. Measurements from the period when ozone measurements were more extensive shows that this location was a good surrogate for concentrations over outer south London suburbs.

During the study period some monitoring sites closed and new ones opened. The pollutants monitored also changed at some sites. The London background mean used was calculated from

Nitrogen dioxide: between 41 and 27 monitoring locations.

$PM_{2.5}$: between 6 and 14 monitoring locations.

Ozone: between 26 and 13 monitoring locations in London, plus Sevenoaks.

The number of background locations monitoring nitrogen dioxide and ozone has decreased whilst the number of $PM_{2.5}$ sites has increased. Local authority monitoring makes up the bulk of the LAQN and AURN. Local air quality management guidance prioritises hot-spot measurement and this, coupled with financial pressures has meant many ozone and background sites have closed. $PM_{2.5}$ has received more support due to its inclusion in Public Health Outcome Framework indicators.

Nitrogen dioxide and ozone is measured in parts per billion (ppb). Conversion factors used to convert to $\mu g\ m^{-3}$ were:

NO_2: 1.9125

O_3: 1.9956

The pollution episodes were defined using the national Daily Air Quality Index (DAQI) (Table 1). This uses different time periods for each pollutant based on the known health impacts; hourly for nitrogen dioxide, running 8-hour mean for ozone and a midnight to midnight daily average for $PM_{2.5}$ particulate. For nitrogen dioxide and ozone, the maximum index during the day was used to classify the day.

Band	Index	Ozone	Nitrogen Dioxide	Sulphur Dioxide	$PM_{2.5}$ Particles (EU Reference Equivalent)	PM_{10} Particles (EU Reference Equivalent)
		Running 8 hourly mean	hourly mean	15 minute mean	24 hour mean	24 hour mean
		μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}
Low	1	0-33	0-67	0-88	0-11	0-16
	2	34-66	68-134	89-177	12-23	17-33
	3	67-100	135-200	178-266	24-35	34-50
Moderate	4	101-120	201-267	267-354	36-41	51-58
	5	121-140	268-334	355-443	42-47	59-66
	6	141-160	335-400	444-532	48-53	67-75
High	7	161-187	401-467	533-710	54-58	76-83
	8	188-213	468-534	711-887	59-64	84-91
	9	214-240	535-600	888-1064	65-70	92-100
Very High	10	241 or more	601 or more	1065 or more	71 or more	101 or more

Table 1 Daily Air Quality Index as defined in the update of 2013. The 24-hour mean used for PM2.5 is specified as a fixed midnight to midnight daily average. Defra (2013)

Each day was classified on the banding of each individual pollutant and then the maximum banding across all three pollutants was taken to create an overall classification. An episode day was defined on the overall classification. So, for example, if $PM_{2.5}$ was high but ozone and nitrogen dioxide low, this day would be counted as a high day in the analysis.

3.2 Creation of pollutant concentration differences for health impact analysis

To examine the additional impact of pollution on episode days it was first required to establish a baseline of the pollution levels on non-episode days. This was done by calculating the mean for each pollutant on low days[3]. These concentrations were then subtracted from the measured data for each episode day in order to give the additional impact, the "delta" for all three pollutants. Although the days were classified on the DAQI time metrics described above, the concentration response function time period for nitrogen dioxide concentrations for the health impact calculations (as opposed to for the banding classification) was based on the daily average not the hourly. The hourly measurements were therefore averaged over 24 hours for this purpose.

On each day the calculations were done not only for the pollutant that led to the definition of the banding for that day but also for the other pollutant concentrations on that day, that were not necessarily raised at all.

It is important to note that a daily delta can be negative. If you consider ozone this is a highly seasonal pollutant, being elevated during the sunny summer and some of the spring, but lower during the autumn and winter. So, for a winter day when particulate matter was particularly high, ozone could be relatively low. (Nitric oxide may also accumulate on such winter days and this destroys ozone). Subtracting this especially low ozone concentration from the average ozone on days when all pollutants are low, could result in a negative delta and hence a negative health impact.

3.3 Selection of concentration-response functions

The starting point for the selection of concentration-response functions was a Department of Health systematic review and meta-analysis project funded for the purpose of developing concentration-

[3] Across 2009-2017 for days when all pollutants were low.

response functions from time-series studies published up to 2011. The results of this project were published as Atkinson *et al* (2014); Mills *et al* (2015) and Walton *et al* (2014a). An ongoing literature search on 'systematic reviews and air pollution' was checked for more recent reviews and meta-analyses, in addition to use of reviews identified or performed as work on other projects. Reports from the Committee on the Medical Effects of Air Pollutants (COMEAP) were also used e.g. the 2015 COMEAP report on ozone incorporated some aspects of Walton *et al* (2014a). The selected concentration-response functions are given in the tables below (Tables 2 – 8). These were all for single-pollutant model results. The potential overlap between pollutants was addressed later (see section 3.5).

The focus on time-series studies of outcomes such as deaths brought forward and hospital admissions was because these are well-established types of outcomes used in quantification. There is evidence (but fewer studies) for wider health effects such as GP consultations, asthma symptoms, A&E visits etc. These are discussed further in the health effects report.

Pollutant	**% increase in all-cause mortality, all ages, per 10 µg m^{-3} (95% confidence interval)**
$PM_{2.5}$ (24- hour average)	1.04 % (0.52 % to 1.56%)[a]
NO_2 (24- hour average)	0.71% (0.43% to 1.00%)[b]
O_3 (max 8-hour average)	0.34% (0.12 to 0.56%)[c]

Table 2 Concentration response functions for all-cause mortality, all ages. 95% confidence intervals around the concentration-response function is given in brackets. All-cause mortality excludes external causes. These concentration-response functions are used to calculate deaths brought forward.

[a] *Atkinson et al (2014)*

[b] *Mills et al (2015)*

[c] *COMEAP (2015)*

Pollutant	**% increase in all-respiratory hospital admissions, all ages, per 10 µg m^{-3} (95% confidence interval)**
$PM_{2.5}$ (24- hour average)	1.90% (-0.18 to 4.02%)[a]
NO_2 (24- hour average)	0.52% (0.09 to 0.95%) [b]
O_3 (max 8-hour average)	0.75% (0.30 to 1.20%)[c]

Table 3 Concentration response functions for all respiratory admissions, all ages.

[a] *Atkinson et al (2014)*

[b] *Mills et al (2015)*

[c] *COMEAP (2015)*

Pollutant	% increase in asthma hospital admissions per 10 µg m^{-3} (95% confidence interval)	
	Children 0-14 Asthma	**Adults 15-64 Asthma**
$PM_{2.5}$ (24- hour average)	2.9% (1.6% to 4.2%)[a]	Evidence from 4 studies suggests no association[b]
NO_2 (24- hour average)	3.6% (1.8% to 5.4%)[d]	1.2% (1% to 2.3%)[e]
O_3 (max 8-hour average)	1.2% (-0.8% to 3.2%)[g]	2.15% (-0.18% to 4.47%)[h]

Table 4 Concentration-response functions for air pollution and asthma admissions.
[a]Source: meta-analysis of results from 11 studies, 22 cities (Walton et al 2019)
[b]Source: meta-analysis of results from 4 studies, 4 cities (Walton et al 2019)
[c]Source: meta-analysis by Atkinson et al 2014, 4 studies, 4 cities
[d]Source: meta-analysis of results from 8 studies, 24 cities (Walton et al 2019)
[e]Source: meta-analysis of results from 3 studies, 6 cities (Walton et al 2019)
[f]Source: meta-analysis by Mills et al 2015, 7 studies, 7 cities
[g]Source: meta-analysis of results from 12 studies, 19 cities (Walton et al 2019)
[h] Source: meta-analysis of results from 4 studies, 6 cities (Walton et al 2014a)

Pollutant	% increase in COPD hospital admissions, all ages, per 10 µg m^{-3} (95% confidence interval)
$PM_{2.5}$ (24- hour average)	3.93% (1.06% to 6.89%)[a]
NO_2 (24- hour average)	1% (0 to 2%)[b]
O_3 (max 8-hour average)	1.12% (0.59 to 1.66%)[c]

Table 5 Concentration response functions for COPD admissions, all ages. Asthma is excluded (some studies combined COPD and asthma in the elderly as they are difficult to distinguish. Those studies were not included.
Footnote – COPD – chronic obstructive pulmonary disease.
[a] Moore et al (2016) 3 European studies
[b] Moore et al (2016) 13 European studies, from an odds ratio, but prevalence is low so approximates to a relative risk.
[c] Walton et al (2014a) European estimate 2 studies, 6 cities, (preferred over Moore et al as the latter mixes different types of studies).

Pollutant	% increase in all-cardiovascular hospital admissions, all ages, per 10 µg m^{-3} (95% confidence interval)
$PM_{2.5}$ (24- hour average)	0.90 % (0.26 % to 1.53%)[a]
NO_2 (24- hour average)	0.66% (0.32 to 1.01%)[b]
O_3 (max 8-hour average)	0.11% (–0.06 to 0.27%)[c]

Table 6 Concentration response functions for all cardiovascular admissions, all ages.
[a] Atkinson et al (2014)
[b] Mills et al (2015)
[c] COMEAP (2015)

Pollutant	% increase in cardiac hospital admissions (in the elderly) per 10 µg m^{-3} (95% confidence interval)
$PM_{2.5}$ (24- hour average)	3.05% (1.64 to 4.48%)[a]
NO_2 (24- hour average)	1.65% (1.02 to 2.29%)[b]
O_3 (max 8-hour average)	0.40% (-0.40 to 1.21%)[c]

Table 7 Concentration response functions for cardiac admissions in the elderly, age 65+.

[a] *Atkinson et al (2014)*

[b] *Mills et al (2015)*

[c] *Walton et al (2014a)*

Pollutant	% increase in stroke hospital admissions, all ages, per 10 µg m^{-3} (95% confidence interval)[a]
$PM_{2.5}$ (24- hour average)	1.1% (1.0 to 1.2%)
NO_2 (24- hour average)	2.3% (0.95 to 3.5%)[b]
O_3 (max 8-hour average)	0.2% (0 to 0.4%)[c]

Table 8 Concentration response functions for hospital admissions for stroke, all ages.

[a] *All from Shah et al (2015)*

[b] *Converted from RR 1.012 (1.005 to 1.018) per 10ppb, averaging time not given.*

[c] *Converted from RR 1.001 (1.000 to 1.002) per10ppb, averaging time not given.*

3.4 Baseline rates

Baseline numbers of deaths[4] for Greater London were obtained from the Office for National Statistics (ONS) via NOMIS[5] for 2013 onwards and from data previously obtained from ONS for previous reports (Walton *et al* 2015; Williams et al 2018) prior to 2013 (Table 9).

[4] These are all deaths whether inside or outside hospital. Deaths were by area of usual residence.

[5] https://www.nomisweb.co.uk/query/construct/summary.asp?mode=construct&version=0&dataset=161

All deaths excluding external causes	
Year	**All ages**
2009	46,761
2010	46,397
2011	44,773
2012	46,132
2013	46,575
2014	46,505
2015	49,210
2016	47,270
2017	48,295

Table 9 Deaths excluding external causes for different years in Greater London.

Baseline rates of hospital admissions in Greater London were obtained on our behalf from Hospital Episode Statistics (NHS Digital). Time-series studies usually analyse emergency admissions because it is not expected that planned admissions would correlate with air pollution levels. Data was restricted to those for London residents. Other criteria were the first episode of an admission, ordinary and day case admissions and finished consultant episodes (this allows the use of the final diagnosis rather than the initial diagnosis on admission)[6].

As we were always applying the calculations to the same population, we used total numbers of admissions in Greater London rather than rates. The totals used are given in Table 10 below.

[6] In terms of coding Epiorder=1; Admimeth in (21,22,23,24,25,28,2A,2B,2C,2D); Epistat=3; Classpat in (1,2,5) and Resgor=H.

	All Respiratory (ICD-10 J00-J99)	**Asthma (ICD-10 J45)**		**COPD excl asthma (ICD-10 J40-J44)**	**All cardiovascular (ICD-10 I00-I99)**	**Cardiac (ICD-10 I00-I52)**	**Stroke (ICD-10 I60-I69)**
Year	All ages	Aged under 15	Aged 15-64	All ages	All ages	65 and over	All ages
2009/10	70,367	3,455	4,247	12,120	58,988	25,887	9,756
2010/11	75,953	3,581	4,515	12,695	59,005	24,787	10,480
2011/12	75,144	3,213	3,899	12,297	59,780	25,621	10,765
2012/13	82,450	3,508	4,362	13,082	59,968	25,667	10,768
2013/14	80,668	3,473	4,340	12,832	60,534	25,924	10,724
2014/15	87,896	3,570	4,591	12,990	59,552	25,113	10,353
2015/16	93,451	3,375	4,476	13,299	62,662	26,875	10,887
2016/17	98,664	3,564	4,792	13,283	62,170	27,558	10,557
2017/18	99,351	3,377	4,584	13,325	64,336	28,120	10,641

Table 10 Annual number of emergency admissions by cause and age group, London residents, 2009/10 to 2017/18.

3.5 Method of calculation

The concentration difference 'delta' (see 3.1.2), the concentration-response function and the baseline numbers of admissions were the inputs needed to calculate the health impacts of air pollution episode days. Concentration-response functions were derived from time-series studies that used using Poisson regression (the appropriate statistical technique for counts) which relates the log of the number of events to the concentration., The health impact calculation takes this into account, as explained below.

As well as the pollution data, we also created database tables holding the concentration response functions for the various age groups and health outcomes (see section 3.3), and the matching hospital admissions for London each year (see section 3.4). The coding then matched for each day the pollutant concentrations, the concentration response functions for that pollutant, and the year's hospital admissions to give the required outcome of additional admissions per day. Individual code runs were made to produce impact results for each health outcome and age range.

The calculation was

Additional Admissions =

```
(EXP(((LOG((ConcResponseFunction/100)+1)/10)*Pollution Delta))-1)*Admissions/365
```

Where

'ConcResponseFunction' is the relative risk per 10 µgm^{-3};

'Admissions' is the annual number of hospital admissions for the relevant cause.

The first term converts the relative risk to a percentage increase.

The wider brackets contain a term that divides by 10 and multiplies by the pollution delta on the log scale to adjust the percentage increase from the increase for 10 µgm^{-3} to a new percentage increase for the pollution delta.

The exponential of this term gives the percentage increase out of the log scale and applies this to the daily number of admissions, to give the expected additional admissions as a results of the additional concentration over and above the baseline of the pollutant concentration for the average of all low days.

This calculation was repeated for each pollutant and health outcome.

For each day, pollutant and outcome a calculation was done for the 'delta' between the pollutant concentration that day and the baseline of the average of all low days and a second time for the 'delta' between the pollutant concentration that day and the average of all low and moderate days.

Finally, the hospital admissions were summed across pollutants. This was done both with and without nitrogen dioxide. The calculations may result in substantial overlap between the effects of nitrogen dioxide and particulate matter. This reflects substantial correlated exposures in the original health studies leading to the presence of double-counting in the concentration-response functions used. The size of this overlap for short-term exposure studies is unknown. However, by analogy with consideration of studies of long-term exposure (COMEAP, 2018), the combined effects of these two pollutants are probably a bit above that for $PM_{2,5}$ alone but not as high as for the full sum of both the nitrogen dioxide and $PM_{2.5}$ effects. Ozone is generally considered to have effects independent of those of $PM_{2.5}$ as they are not closely correlated on an annual basis. (Actually, ozone is often negatively correlated with $PM_{2.5}$ in the winter and positively correlated in the summer giving a net absence of correlation). Ozone is usually negatively correlated with nitrogen dioxide. There are reasons to think that their health impacts are likely to be additive as they are both oxidants with the potential to lead to oxidative stress (Williams et al 2014). We therefore included ozone impacts in both sums, with and without nitrogen dioxide.

4 Results

The results for sections 4.1 to 4.4 address data on numbers of moderate, high and very high days and concentration differences between those days and the average of all days defined as 'low' days or 'low or moderate' days across the period 2009-2017. Sections 4.5 onwards address the health impacts.

4.1 Number of moderate, high and very high days each year according to the Daily Air Quality Index

The number of days with a particular banding and the responsible pollutant(s) for that banding are shown in Table 11. There were no days classified as high or very high due to nitrogen dioxide and no days classified as very high due to ozone.

	Pollutant Species				
Bandings	**All**	**NO_2**	**O_3**	**PM_{10}**	**$PM_{2.5}$**
Moderate	**358**	**55**	**160**	**149**	**165**
2009	53	8	21	14	26
2010	36	8	17	13	14
2011	53	4	30	27	27
2012	38	4	18	23	18
2013	51	7	25	21	23
2014	39	4	16	13	19
2015	28	7	9	9	11
2016	31	8	12	15	13
2017	29	5	12	14	14
High	**40**		**1**	**20**	**36**
2009	3			3	2
2010	1				1
2011	12			4	12
2012	7			2	7
2013	3				3
2014	5			4	5
2015	2			1	1
2016	5			4	4
2017	2		1	2	1
Very high	**8**			**1**	**8**
2010	2				2
2011	1			1	1
2012	1				1
2015	1				1
2016	1				1
2017	2				2

Table 11 Number of days for each pollutant banding each year. Cells are blank if there were no days in the relevant category e.g. there were no high or very high days for nitrogen dioxide.

4.2 2009-2017 average of all low days and of all low or moderate days

As expected, the average for the pollutant concentrations on all days when all pollutants were low or moderate, was slightly higher (up to around 1.5 $\mu g\ m^{-3}$) than for days when all pollutants were low (Table 12). This difference was relatively small as the number of low days outweighs the number of moderate days. For ozone, the concentrations were very close for the two baselines. Ozone was also the most variable. $PM_{2,5}$ on low days was the least variable.

Pollutant	Type of baseline	Average concentration (µg m^{-3})	Standard Deviation (µg m^{-3})
NO_2	Low Days	33.3	12.3
NO_2	Low or Moderate Days	34.7	13.5
O_3	Low Days	46.9	17.6
O_3	Low or Moderate Days	46.9	19.2
PM_{10}	Low Days	16.9	5.9
PM_{10}	Low or Moderate Days	18.6	8.2
$PM_{2.5}$	Low Days	11.2	5.5
$PM_{2.5}$	Low or Moderate Days	12.8	7.9

Table 12 2009-2017 average of all days and of all low or moderate days.

4.3 Increments (delta) between moderate, high and very high days and the average of all low days

Table 13 shows that, as expected, the difference (delta) between concentrations on specific high or very high days and the 2009-2017 average of days when all pollutants are low can be quite large (27 to 52 µg m^{-3}across nitrogen dioxide and $PM_{2.5}$). The largest concentration increments were generally for $PM_{2.5,}$ except for moderate days where the largest average increment was for ozone. It also illustrates that ozone can be particularly low on days when $PM_{2.5}$ is high, as explained earlier, giving a negative concentration difference for the delta. The range in the concentration differences can be quite wide, partly because these include differences when the specific pollutant is not particularly high, because the episode day has been defined by a different pollutant. Note that the moderate, high and very high days are days on which any pollutant is moderate, high or very high. Note also that it is possible to have deltas for low days because this is the difference between the concentration on a specific low day and the average of all low days across 2009-2017. The delta for low days averages out to zero for $PM_{2.5}$ and nitrogen dioxide but not for ozone. The reason for this is that all the days that are low for $PM_{2.5}$ or nitrogen dioxide specifically are also low days for all the other pollutants. Therefore, the average of the specific pollutant low days is the same as the average all pollutant low days, giving an average difference of zero. Days that are low for ozone specifically, in contrast, are not always low for other pollutants as well. The net positive average delta suggests there are many days where ozone is the high end of the range of low day concentrations, when the other pollutants have just tipped into moderate.

Pollutant		Low days	Moderate days	High days	Very high days
O_3	Average	16.59	27.51	4.39	-2.67
	Range	-45.15 to 69.91	-44.09 to 117.8	-43.49 to 87.05	-43.92 to 87.05
	Number of days	2881	358	40	8
$PM_{2.5}$	Average	0	14.99	38.7	51.46
	Range	-9.5 to 21.59	-4.48 to 39.63	6.13 to 51	28.85 to 70.32
	Number of days	2881	358	40	8
NO_2	Average	0	13.36	27.25	28.42
	Range	-24.88 to 44.7	-19.91 to 66.2	-16.56 to 78.59	12.25 to 48.64
	Number of days	2881	358	40	8

Table 13 The increments ('deltas') µg m^{-3} between low, moderate, high and very high days and the average of all days when all pollutants were low.

4.4 Increments (delta) between moderate, high and very high days and the average of all low and moderate days

Table 14 shows the differences for the comparison with the average of all low and moderate days. The average differences are smaller than those in Table 13 but not by that much as there are more low days than moderate days.

Pollutant		Low days	Moderate days	High days	Very high days
O_3	Average	6.73	17.65	-5.47	-12.53
	Range	-55.01 to 60.06	-53.96 to 107.94	-53.35 to 122.5	-53.78 to 77.19
	Number of days	2881	358	40	8
$PM_{2.5}$	Average	-1.66	13.34	37.04	49.81
	Range	-11.16 to 19.93	-6.13 to 37.98	4.48 to 49.34	27.19 to 68.66
	Number of days	2881	358	40	8
NO_2	Average	-1.47	11.89	25.78	26.95
	Range	-26.35 to 43.23	-21.38 to 64.73	-18.03 to 77.12	11.89 to 47.17
	Number of days	2881	358	40	8

Table 14 The increments ('deltas') µgm^{-3} between low, moderate, high and very high days and the average of all days when all pollutants were low or moderate.

The next few sections address the health impacts. These are arranged as follows:

- An overview of results for health impacts of broad health outcome categories summed across pollutants for moderate, high and very high days compared with the average of all **low** days (section 4.5).
- An overview of results for health impacts of more specific hospital admission categories summed across pollutants for moderate, high and very high days compared with the average of all **low** days (section 4.6).
- Results by pollutant for selected health outcomes for moderate, high and very high days compared with the average of all **low** days (section 4.7).
- Results by pollutant for selected health outcomes for high and very high days compared with the average of all **low or moderate** days (section 4.8) (further results in Appendix 1).
- Variation and uncertainties in results above (section 4.9).

4.5 *Overall health impacts (deaths brought forward, all respiratory and all cardiovascular admissions) - comparison of moderate, high and very high days with low days*

While later sections break the results down by types of respiratory and cardiovascular admissions and by pollutants, this section considers the overall results.

The health impacts over the period 2009-2017 for the broad health outcome categories of moderate, high and very high days compared with the average of all low days 2009-2017 are shown in Figure 1. It can be seen that there are health impacts on deaths brought forward, all respiratory hospital admissions and all cardiovascular hospital admissions, with the greatest impact from respiratory hospital admissions. There are greater impacts from moderate days, followed by high and very high days, despite the ranking of concentration differences for nitrogen dioxide and $PM_{2.5}$ being in the other direction (Table 13). This is because there are much larger numbers of moderate days and much smaller numbers of very high days (Table 11). Of course, there are still more health impacts per day on very high and high days than on moderate days as shown in Table 15, along with the figures for the totals as shown in Figure 1. The range given for the totals is for results using the lower or higher 95% confidence interval of the concentration-response function for each pollutant. Variation and uncertainty are discussed more in section 4.9.

The term 'deaths brought forward' is used to express the fact that some of these deaths may have occurred just a short time earlier than would otherwise have been the case, as those who are severely ill may be particularly susceptible. While this is true for some of the deaths, it is known that for others the deaths are brought forward by several months at least and probably longer (the method of analysis does not allow this to be determined). The term is also used to distinguish it from the results of studies of long-term exposure and mortality. The latter come from cohort studies followed up over many years and the method of analysis allows both calculation of effects on numbers of deaths and on loss of life-expectancy. The loss of life expectancy is unknown for 'deaths brought forward'.

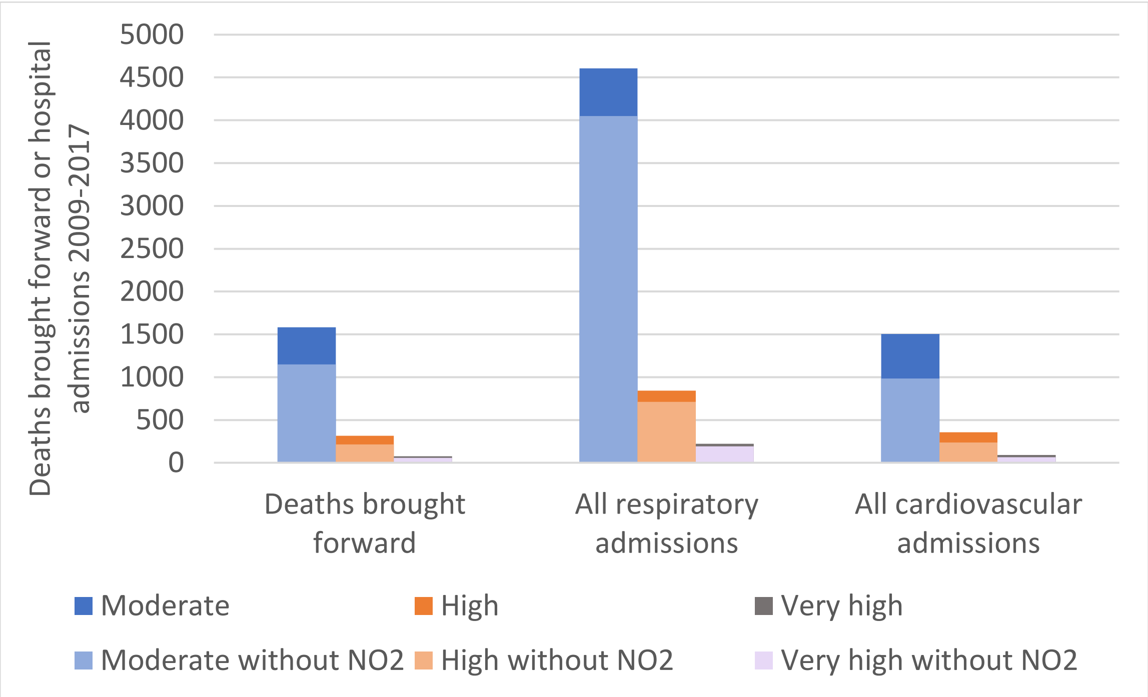

Figure 1 Total deaths brought forward, all respiratory admissions and all cardiovascular admissions, all ages, in London 2009-2017 for moderate, high and very high days compared with low days, $PM_{2.5}$ plus O_3 ***with and without NO_2.***

	Total 2009-2017 without NO_2 (range)[a]	Total 2009-2017 with NO_2 (range)	Average per day ± SD[b] (without NO_2)	Average per day ± SD (with NO_2)
Deaths brought forward				
Moderate	1150 (480, 1713)	1584 (742, 2325)	3 ± 2	4 ± 2
High	215 (103, 218)	314 (162, 458)	5 ± 2	8 ± 2
Very high	77 (40, 114)	56 (28, 84)	7 ± 2	10 ± 3
All respiratory admissions				
Moderate	4050 (474, 8093)	4608 (575, 9162)	11 ± 6	13 ± 6
High	710 (-52[c], 1615)	843 (-29, 1861)	18 ± 8	21 ± 8
Very high	191 (-19, 420)	220 (-14, 471)	23 ± 9	26 ± 10
All cardiovascular admissions				
Moderate	985 (134, 1818)	1505 (385, 2619)	3 ± 1	4 ± 3
High	236 (65, 408)	357 (123, 593)	6 ± 1	9 ± 2
Very high	63 (18, 109)	89 (31, 149)	8 ± 2	11 ± 4

Table 15 Total 2009-2017 and average events per day for deaths brought forward, respiratory hospital admissions and cardiovascular hospital admissions in London for air pollution concentrations on moderate, high and very high days compared with the average of all low days (with and without NO_2).

[a] *Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.*

[b] Sample standard deviation

[c] Negative values in this case are a results of a lower confidence interval below zero for the concentration-response function for $PM_{2.5}$ (Table 3). Totals without PM were moderate 2276 (800, 3971); high 162 (36, 310); very high 22 (3, 47).

4.6 *Overall health impacts for specific types of respiratory and cardiovascular hospital admissions - comparison of moderate, high and very high days with low days*

The following two sections consider the numbers of hospital admissions for selected specific types of respiratory and cardiovascular hospital admissions.

4.6.1 Results summed across pollutants for all respiratory, asthma and COPD admissions – comparison of moderate, high and very high days with low days

The results for specific types of respiratory admissions are shown in Figure 2 and Table 16. COPD admissions make the largest contribution to the results for all respiratory admissions, followed by asthma admissions in children and then asthma admissions in adults. The results for COPD admissions are in line with the higher baseline numbers and reasonably large concentration-response functions.

For asthma in adults and children, the numbers are smaller than for all respiratory admissions not only because asthma is just one of the causes of respiratory admissions but also because the results are for only one part of the population (children or adults). Total numbers of asthma admissions in adults are smaller than in children.

Not all types of respiratory admissions were analysed, for example, there is some evidence of an effect on pneumonia admissions (Nhung et al 2017) which has not been considered here.

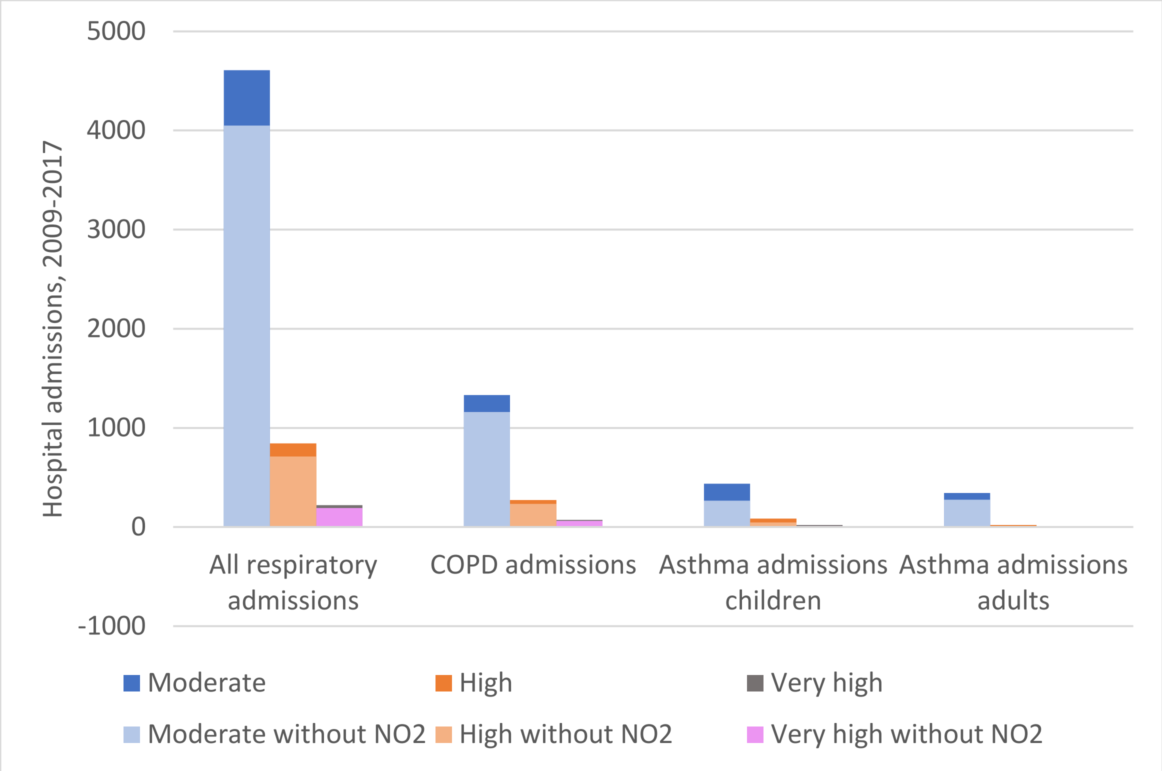

Figure 2 All respiratory admissions, all ages; COPD admissions, all ages; asthma admissions, children and asthma admissions, adults in London 2009-2017 for moderate, high and very high days compared with low days, $PM_{2.5}$ plus O_3 ***with and without*** NO_2.

	Total types of respiratory admissions 2009-2017[a]	
Outcome	**Total 2009-2017 without NO_2 (range)[b]**	**Total 2009-2017 with NO_2 (range)**
All respiratory admissions		
Moderate	4050 (474, 8093)	4608 (575, 9162)
High	710 (-52[c], 1615)	843 (-29, 1861)
Very high	191 (-19, 420)	220 (-14, 471)
COPD admissions, all ages		
Moderate	1161 (409, 1964)	1330 (577, 2135)
High	234 (62, 427)	273 (101, 467)
Very high	62 (15, 117)	70 (24, 427)
Asthma admissions in children		
Moderate	266 (10, 554)	436 (92, 814)
High	46 (23, 74)	85 (42, 134)
Very high	12 (7, 18)	20 (11, 30)
Asthma admissions in adults		
Moderate	274 (21, 622)	344 (37, 758)
High	6 (-0.3, 18)	22 (13, 49)
Very high	-0.6 (0.1, 0.5)	2.8 (3, 6)

Table 16 Total 2009-2017 for all respiratory hospital admissions, COPD admissions and asthma admissions in children and adults in London for air pollution concentrations on moderate, high and very high days compared with the average of all low days (totals summed across pollutants with and without NO_2)

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

4.6.2 Results summed across pollutants for all cardiovascular, cardiac (age 65+) and stroke admissions – comparison of moderate, high and very high days with low days

The results for specific types of cardiovascular admissions are shown in Figure 3 and Table 17. This example illustrates some of the uncertainties in such calculations, in that the numbers of cardiac admissions in the elderly actually exceeds those for all cardiovascular admissions all ages. This should not be the case as it is only a subset of the wider diagnoses for all types of heart and circulatory disease and the wider age range. It is most likely a reflection of the fact that the concentration-response functions are drawn from different groups of studies, that themselves show heterogeneity in the size of the effect. Nonetheless, this broadly indicates that cardiac admissions are likely to be a more significant contributor to the results for all cardiovascular admissions than stroke. (This issue is discussed further with the results for specific pollutants). Stroke admissions make a much smaller contribution.

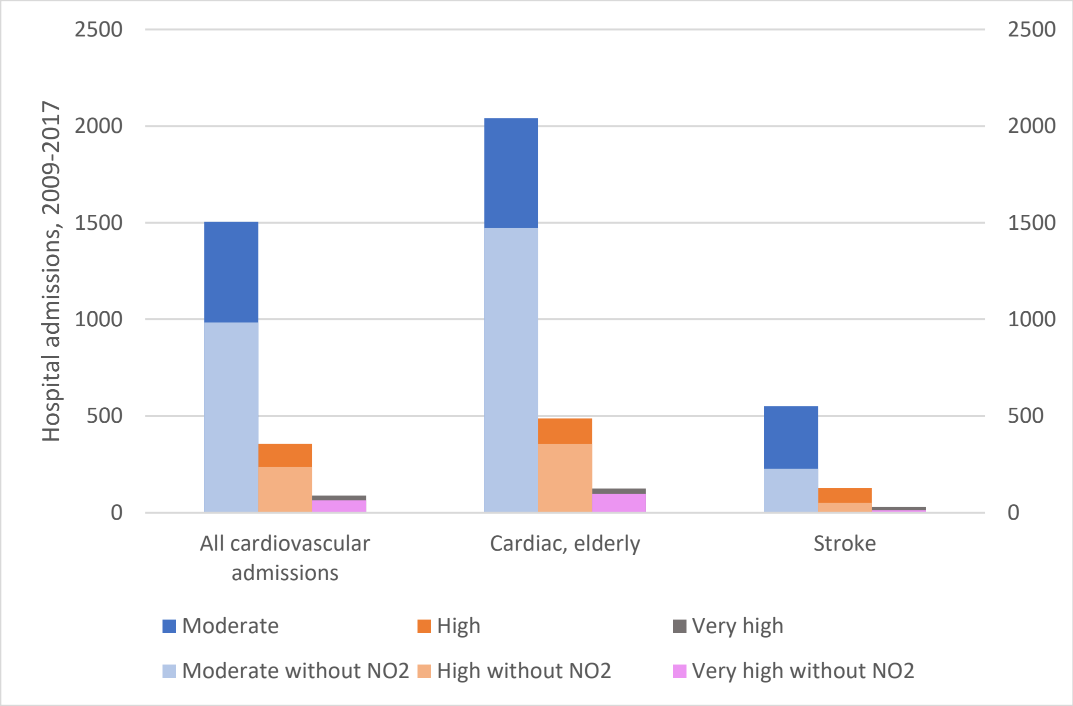

*Figure 3 All cardiovascular admissions, all ages; cardiac admissions 65+; and stroke admissions, all ages in London 2009-2017 for moderate, high and very high days compared with low days, $PM_{2.5}$ plus O_3 **with and without NO_2**.*

	Total types of cardiovascular admissions 2009-2017[a]	
Outcome	**Total 2009-2017 without NO_2 (range)[b]**	**Total 2009-2017 with NO_2 (range)**
All cardiovascular admissions, all ages		
Moderate	985 (134, 1818)	1505 (385, 2619)
High	236 (65, 408)	357 (123, 593)
Very high	63 (18, 109)	89 (31, 149)
Cardiac admissions, 65+		
Moderate	1473 (358, 2650)	2040 (707, 3444)
High	356 (180, 546)	488 (261, 730)
Very high	97 (52, 147)	126 (69, 186)
Stroke admissions		
Moderate	229 (156, 303)	551 (287, 800)
High	51 (46, 57)	127 (76, 174)
Very high	14 (12, 15)	29 (19, 39)

Table 17 Total 2009-2017 for all cardiovascular hospital admissions, cardiac admissions, age 65s and stroke admissions in London for air pollution concentrations on moderate, high and very high days compared with the average of all low days (totals summed across pollutants with and without NO_2)

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

4.7 Health impacts comparison of moderate, high and very high episode days with low days – results by pollutant

Sections 4.5 and 4.6 gave results summed across the pollutants. This section gives results for each pollutant separately.

4.7.1 Deaths brought forward comparison with low days

The results for deaths brought forward are shown in Figure 4 and Table 18. This shows the largest effect for $PM_{2.5}$ as $PM_{2.5}$ has the largest increments and also the largest concentration-response functions. There is only a small result for ozone (due to some of the concentration differences actually being negative giving only a small net answer). Nitrogen dioxide results are between the two.

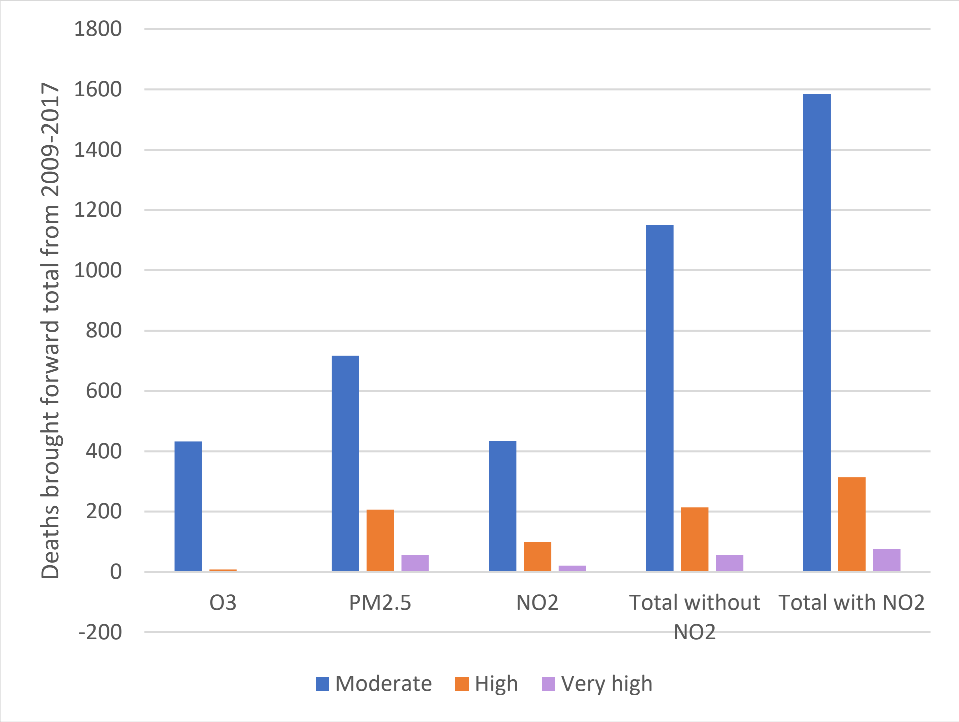

*Figure 4 Total additional premature deaths in London 2009-2017 for moderate, high and very high days compared with **low** days.*

Pollutant	Total premature deaths 2009-2017[a]		
	Moderate (range[b])	High (range)	Very high (range)
$PM_{2.5}$	717 (329, 993)	207 (100, 305)	57 (28, 86)
NO_2	434 (262, 434)	99 (60, 140)	21 (13, 30)
O_3	433 (152, 719)	8 (3, 14)	-1 (0, -2)
Total without NO_2	1150 (480, 1713)	215 (103, 318)	56 (28, 84)
Total with NO_2	1584 (742, 2325)	314 (162, 458)	77 (40, 114)

*Table 18 Total additional premature deaths in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days, by pollutant*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range,

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

4.7.2 All respiratory admissions, comparison with low days

Again, for all respiratory hospital admissions, all ages, the result is largest for $PM_{2.5}$ (Figure 5 and Table 19) in line with the largest increment and largest concentration-response function). It is smallest for ozone. While the concentration-response function for ozone is larger than that for nitrogen dioxide, the often negative increments for ozone counteracts this. As a general point applying to all the hospital admission calculations, it is unknown whether the air pollution associated hospital admissions are additional or brought forward, perhaps accelerating a decline in disease status that was happening anyway.

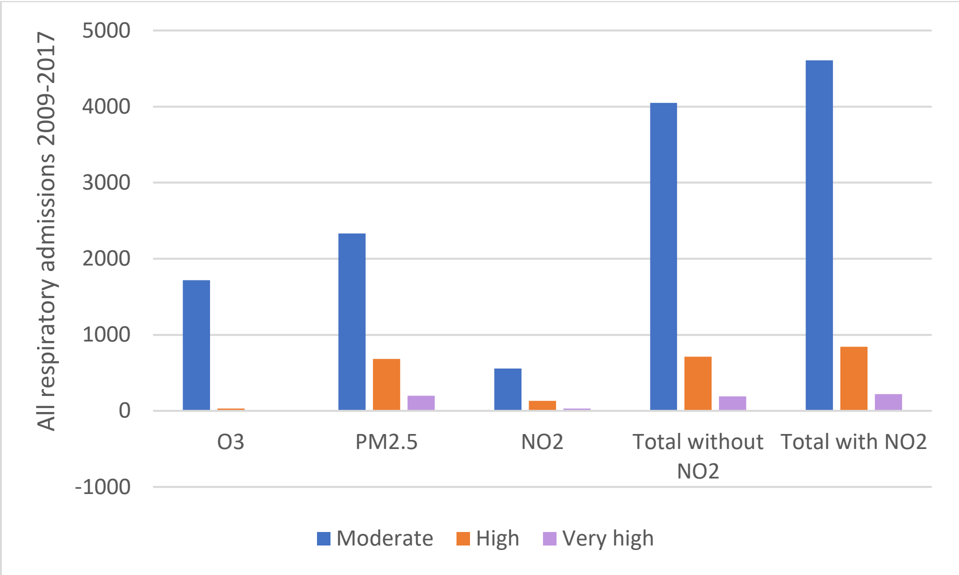

*Figure 5 Total respiratory admissions, all ages, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days by pollutant and totals with and without NO_2.*

Pollutant	Total respiratory admissions 2009-2017[a]		
	Moderate (range[b])	High (range)	Very high (range)
$PM_{2.5}$[c]	2331 (-226, 5192)	681 (-65, 1551)	199 (17, 424)
NO_2	558 (100, 1068)	133 (23, 246)	29 (5, 51)
O_3	1718 (701, 2902)	29 (13, 64)	-8 (1, -4)
Total without NO_2	4050 (474, 8093)	710 (-52[c], 1615)	191 (-19, 420)
Total with NO_2	4608 (575, 9162)	843 (-29, 1861)	220 (-14, 471)
Total without $PM_{2.5}$	2276 (800, 3971)	162 (36, 310)	22 (3, 47)

*Table 19 Total respiratory admissions in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days, by pollutant*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] Negative values in this case are a result of a lower confidence interval below zero for the concentration-response function for $PM_{2.5}$ (Table 3). Totals without PM are shown in the last row.

4.7.3 COPD admissions, all ages, comparison with low days

The picture for COPD admissions, all ages is quite similar to that for all respiratory admissions (COPD admissions are a significant contributor to all respiratory admissions) (Figure 6 and Table 20). The concentration-response function for $PM_{2.5}$ is proportionately greater compared with the other pollutants than for all respiratory admissions. The concentration-response functions for nitrogen dioxide and ozone are more similar to each other. Nonetheless, the ranking of the results is the same as for all respiratory admissions.

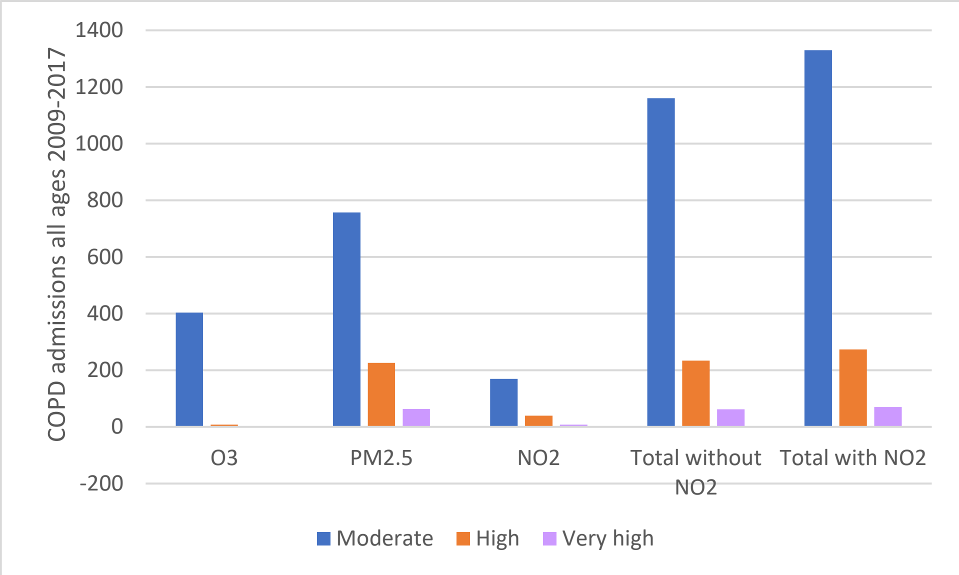

Figure 6 Total COPD admissions, all ages, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low*** *days by pollutant and totals with and without* NO_2.

	Total COPD admissions 2009-2017[a]		
Pollutant/Banding	**Moderate (range[b])**	**High (range)**	**Very high (range)**
$PM_{2.5}$	757 (201, 1353)	226 (58, 414)	63 (16, 118)
NO_2	170 (168, 171)	39.3 (38.9, 39.7)	8.3 (8.2, 8.4)
O_3	404 (208, 611)	8 (4, 13)	-0.9 (-0.5, -1.1)
Total without NO_2	1161 (409, 1964)	234 (62, 427)	62 (15, 116)
Total with NO_2	1330 (577, 2135)	273 (101, 467)	70 (24, 125)

Table 20 Total COPD admissions, all ages, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low*** *days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

4.7.4 Asthma admissions in children, comparison with low days

The pattern across pollutants for asthma admissions in children is a bit different (Figure 7 and Table 21). For moderate days, nitrogen dioxide accounts for the greatest proportion of admissions. It has the largest concentration-response function. The larger deltas for $PM_{2.5}$ outweigh this for high and very high days. Ozone has the smallest concentration-response function so, in this case, is not the largest contributing pollutant on moderate days.

The result for nitrogen dioxide is much closer to that for $PM_{2.5}$ than it was for the previous analyses, in keeping with the stronger evidence amongst nitrogen dioxide related health outcomes for a link with airway hypersensitivity (although nitrogen dioxide is generally less well studied in terms of causal mechanisms than $PM_{2.5}$).

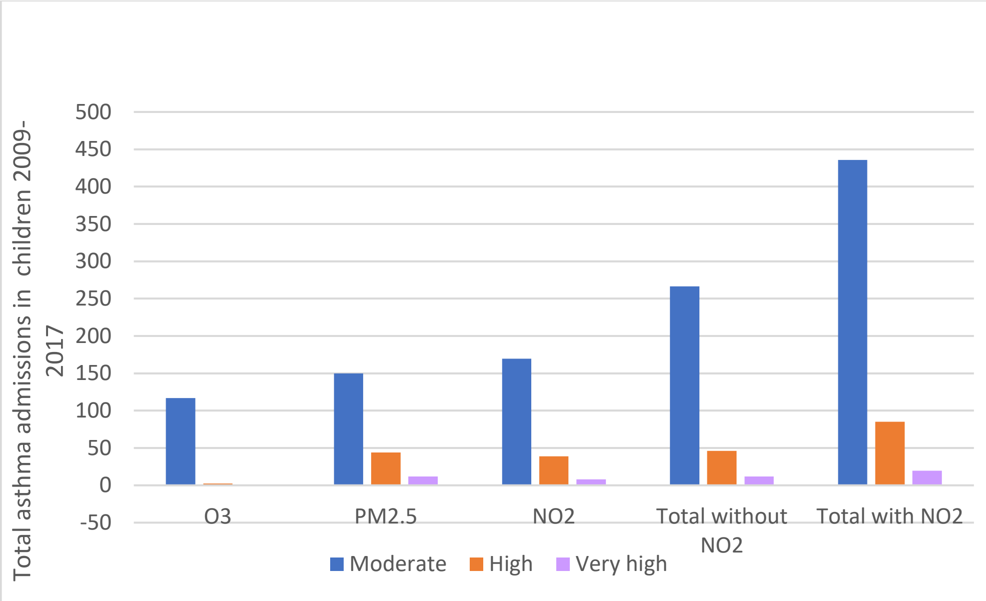

*Figure 7 Total asthma admissions in children, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days by pollutant and totals with and without NO_2.*

	Total asthma admissions in children 2009-2017[a]		
Pollutant/Banding	**Moderate (range[b])**	**High (range)**	**Very high (range)**
$PM_{2.5}$	150 (82, 219)	44 (24, 65)	39 (6, 18)
NO_2	169 (83, 260)	39 (19, 60)	8 (4, 12)
O_3[c]	117 (-72, 336)	2 (-1, 9)	-0.21 (0.23, -0.22)
Total without NO_2	266 (10, 554)	46 (23, 74)	12 (7, 18)
Total with NO_2	436 (93, 814)	85 (42, 134)	20 (11, 30)
Total without ozone	319 (165, 478)	83 (43, 125)	20 (10, 30)

*Table 21 Total asthma admissions in children in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days, by pollutant*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] The lower confidence interval for ozone is negative. Totals therefore shown without ozone (but with potential overlap between $PM_{2.5}$ and NO_2)..

4.7.5 Asthma admissions in adults, comparison with low days

The results for asthma admissions in adults (Figure 8,Table 22) do not show a typical pattern. On the evidence described in section 3.3, there is no association of asthma admissions in adults with $PM_{2.5}$. Nitrogen dioxide has the largest concentration-response function leading to the largest impacts on high and very high days. This is outweighed by the larger deltas for ozone on moderate days. The concentration-response function for ozone has a marginally negative lower confidence interval. The combination of this with negative deltas on very high days leads to a range not encompassing the central estimate. This is due to some days with negative deltas switching signs with others remaining positive, and the relative size of the effect on each of these days determining the sign and size of the overall total. But this all occurs with small numbers overall and is best taken to mean that the impact is essentially negligible.

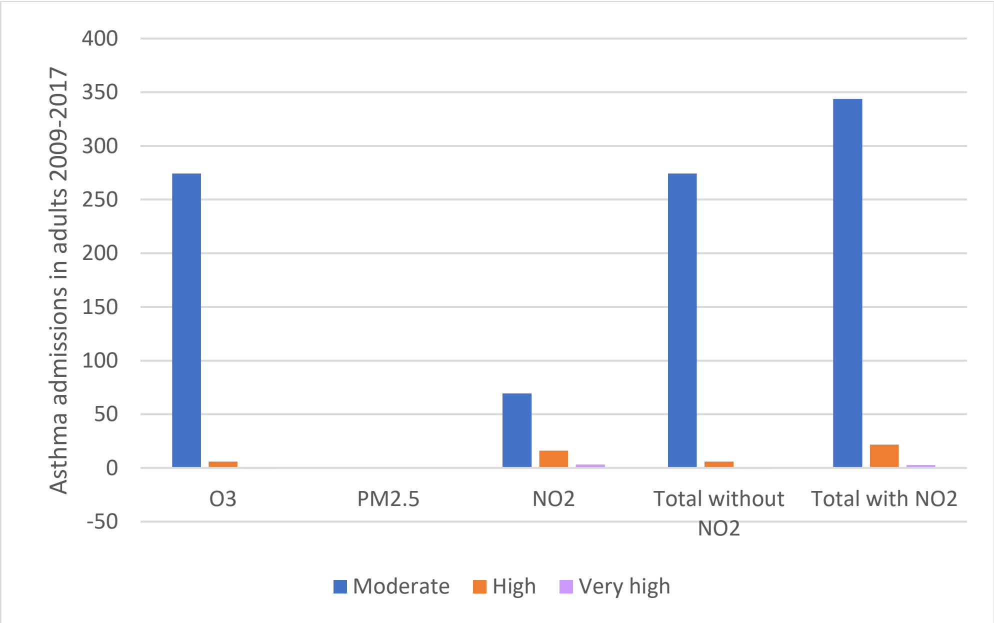

*Figure 8 Total asthma admissions in adults, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days by pollutant and totals with and without NO_2.*

	Total asthma admissions in adults 2009-2017[a]		
Pollutant/Banding	**Moderate (range[b])**	**High(range)**	**Very high (range)**
$PM_{2.5}$	-	-	-
NO_2	70 (58, 135)	16 (13, 31)	3.4 (2.8, 7)
O_3[c]	274 (21, 622)	6 (-0.3, 18)	-0.6 (0.1, -0.5)
Total without NO_2	274 (21, 622)	6 (-0.3, 18)	-0.6 (0.1, -0.5)
Total with NO_2	344 (37, 758)	22 (13, 49)	2.8 (3, 6)
Total without ozone	70 (58, 135)	16 (13, 31)	3.4 (2.8, 7)

Table 22 Total asthma admissions in adults in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low*** *days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] The lower confidence interval for ozone is just negative. As there is no association for $PM_{2.5}$, the total without ozone is just that for NO_2.

4.7.6 All cardiovascular admissions, comparison with low days

The results for admissions for heart and circulatory disease are shown in Figure 9 and Table 23). The result for ozone is not missing, it is just very small. The concentration-response function of ozone and cardiovascular admissions is much smaller than that for respiratory admissions, so, together with the occurrence of negative increments, this is not surprising. The concentration-response function for $PM_{2.5}$ is larger than for the other pollutants, as was also seen for deaths brought forward and all respiratory admissions. The number of air pollution associated admissions for heart and circulatory disease is smaller than that for respiratory disease but is still substantial.

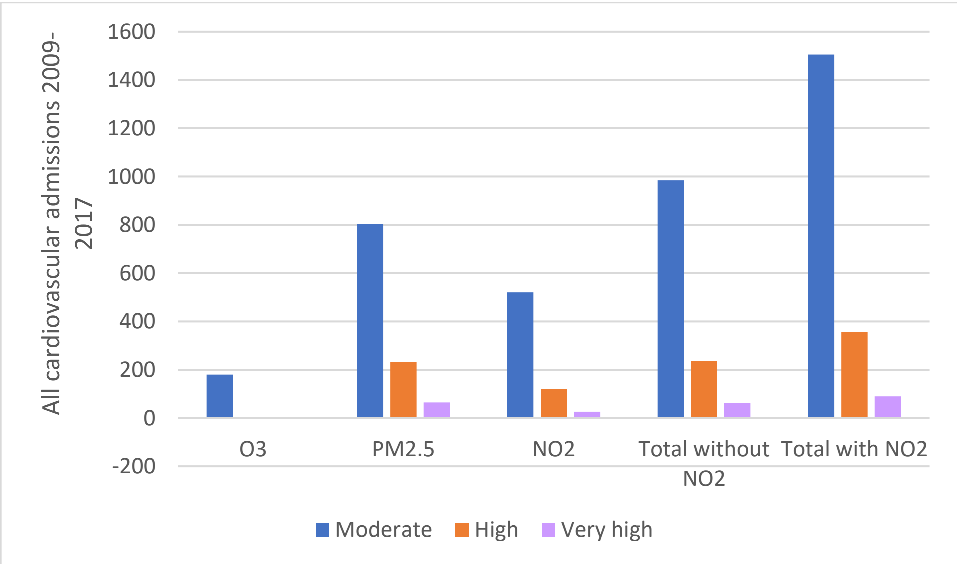

Figure 9 Total cardiovascular admissions all ages, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low*** *days by pollutant and totals with and without NO_2.*

	Total cardiovascular admissions all ages 2009-2017[a]		
Pollutant/Banding	**Moderate (range)[b]**	**High (range)**	**Very high (range)**
$PM_{2.5}$	805 (231, 1373)	233 (67, 400)	64 (18, 110)
NO_2	521 (252, 801)	121 (58, 185)	26 (12, 40)
O_3[c]	180 (-98, 445)	3 (-2, 8)	-1 (0, -1)
Total without NO_2	985 (134, 1818)	236 (65, 408)	63 (31, 109)
Total with NO_2	1505 (385, 2619)	357 (123, 593)	89 (19, 149)
Total without ozone	1325 (483, 2174)	354 (125, 585)	90 (31, 150)

*Table 23 Total cardiovascular admissions all ages in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] Negative values for moderate and high days are a result of a lower confidence interval below zero for the concentration-response function for ozone (Table 6). (For very high days, negative deltas also contribute). Totals without ozone are shown in the last row.

4.7.7 Cardiac admissions in the elderly, comparison with low days

The results for admissions for cardiac admissions in the elderly are shown in Figure 10 and Table 24. It is expected that the concentration-response function for e.g. $PM_{2.5}$ is slightly larger for cardiac admissions in the elderly than for all cardiovascular admissions, all ages. This is because the elderly are more susceptible and it is thought that $PM_{2.5}$ has specific effects on the heart (as opposed to, say, diseases of the peripheral circulation, which are included in all cardiovascular admissions). Nonetheless, in combination with the lower baseline numbers of admissions it should be less than the result for all cardiovascular admissions.

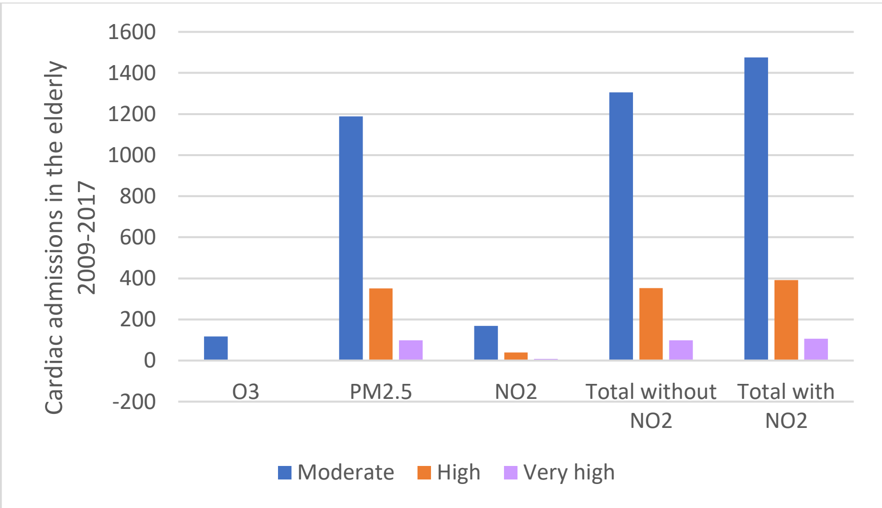

*Figure 10 Total cardiac admissions age 65+, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days by pollutant and totals with and without NO_2.*

	Total cardiac admissions age 65+ 2009-2017[a]		
Pollutant/Banding	**Moderate (range)**[b]	**High (range)**	**Very high (range)**
$PM_{2.5}$	1189 (634, 1763)	351 (185, 527)	98 (51, 149)
NO_2	568 (348, 794)	132 (81, 185)	28 (17, 39)
O_3[c]	284 (-275, 887)	5 (-4, 19)	-0.8 (1, -2)
Total without NO_2	1473 (358, 2650)	356 (180, 546)	97 (52, 147)
Total with NO_2	2040 (707, 3444)	487 (261, 730)	125 (69, 186)
Total without ozone	1756 (982, 2556)	482 (265, 711)	126 (68, 188)

*Table 24 Total cardiac admissions age 65+ in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] Negative values for moderate and high days are a result of a lower confidence interval below zero for the concentration-response function for ozone. (For very high days, negative deltas also contribute). Totals without ozone (but including overlap between $PM_{2.5}$ and NO_2) are shown in the last row.

4.7.8 Stroke admissions, all ages, comparison with low days

In this example (Figure 11 and Table 25), the nitrogen dioxide associated stroke admissions appear to exceed those for $PM_{2.5}$ in line with the larger concentration-response function. How conclusive this might be is unclear as there are still relatively few studies of stroke admissions and earlier meta-analyses did not find associations with stroke for ozone (Walton *et al* 2014a) or $PM_{2.5}$ (Atkinson *et al* 2014) and a smaller association for nitrogen dioxide (Mills *et al* 2015).

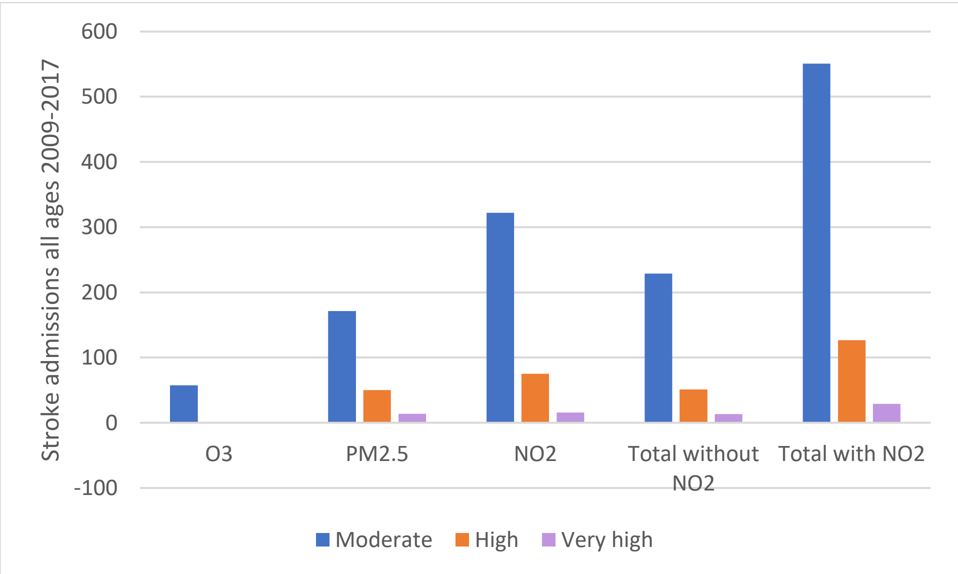

*Figure 11 Total stroke admissions, in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days by pollutant and totals with and without NO_2.*

	Total stroke admissions all ages 2009-2017[a]		
Pollutant/Banding	**Moderate (range)[b]**	**High (range)**	**Very high (range)**
$PM_{2.5}$	171 (157, 187)	50 (46, 55)	14 (12, 15)
NO_2	322 (131, 497)	75 (31, 117)	15 (6, 24)
O_3	57 (0, 116)	1 (0, 2)	-0.1 (0, -0.2)
Total without NO_2	229 (156, 303)	51 (46, 57)	14 (12, 15)
Total with NO_2	550 (287, 800)	126 (76, 174)	29 (19, 39)

*Table 25 Total stroke admissions all ages in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low** days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b] Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

4.8 Comparison of high and very high episode days with low or moderate days

Section 4.5 to 4.7 relates to the inherent impact of high and very high episode days assuming an abstract counterfactual of the average of all low days across the time period. It could be argued that to avoid an episode day (high or very high day), it would only be necessary to reduce levels to that of a moderate day. It was also thought to be useful to do calculations related to smaller air pollution reductions that might more likely represent achievable reductions. In the absence of examples of specific measures and what they can achieve, and still wishing to show a level of ambition towards pollution improvement, we show the health impacts of the difference in the concentrations on high and very high days with the average of all low or moderate days over the time period. These calculations were designed ahead of analysis of what the review of schemes report suggested had actually been achieved by emergency measures in other cities. A comparison between the air pollution reductions in each case is given in the overview report.

Overall (Figures 12-19), results are a little smaller than for the comparison with days when all pollutants are low, in keeping with the slightly smaller increments. The greater negative concentration increments for ozone can affect the totals. For asthma admissions in adults (Figure 16), the absence of an association with $PM_{2.5}$ gives a negative total when nitrogen dioxide is omitted, given the greater negative impact for ozone. An example table (Table 26Table 26) is given towards the end of the section, to show the comparison between results for the two different baselines more clearly. Tables showing the numerical figures relating to the histograms and the ranges are included in Appendix 1.

4.8.1 Deaths brought forward, comparison with low or moderate days

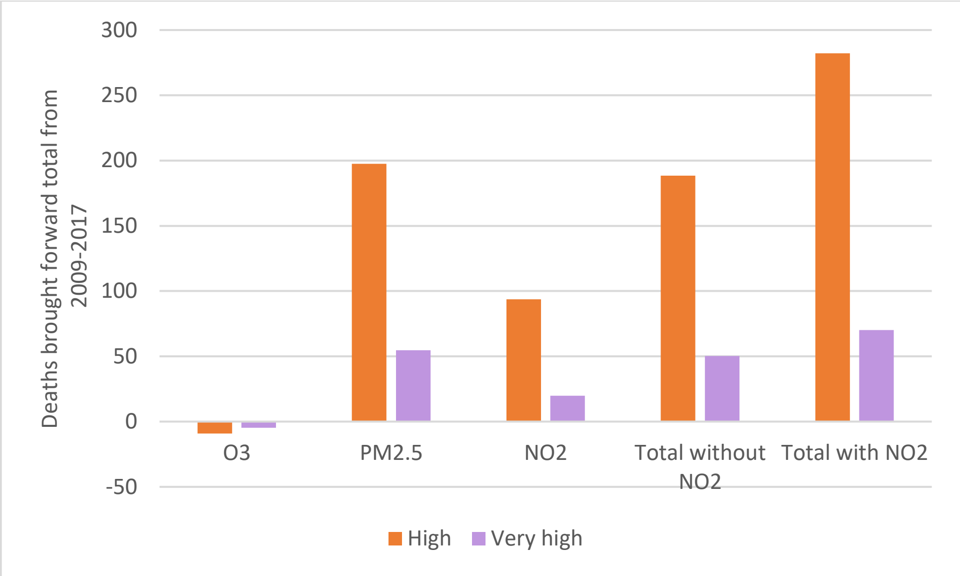

Figure 12 Total additional premature deaths in London 2009-2017 for high and very high days compared with low or moderate days.

4.8.2 All respiratory hospital admissions, comparison with low or moderate days

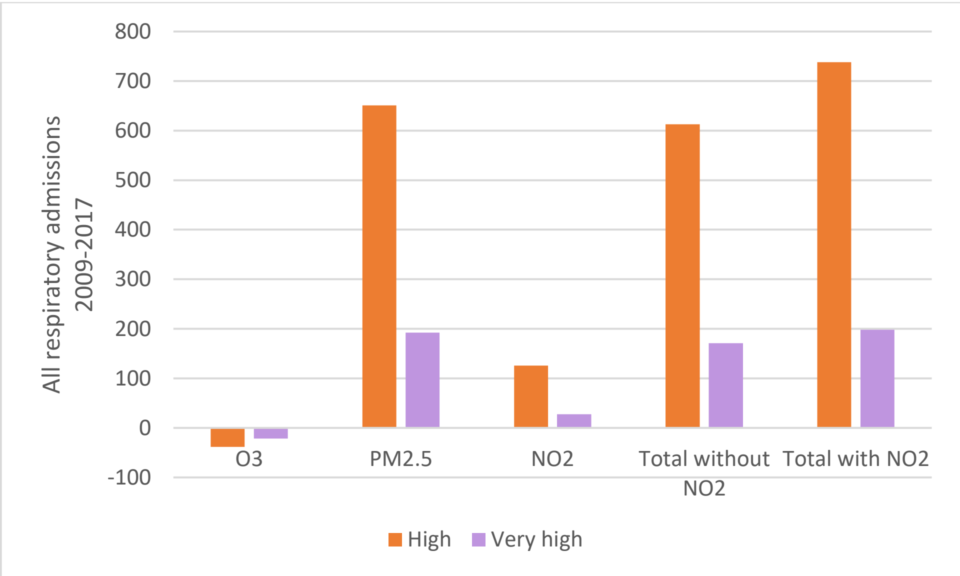

Figure 13 Total all respiratory admissions, all ages, in London 2009-2017 for high and very high days compared with low or moderate days.

4.8.3 COPD admissions all ages, comparison with low or moderate days

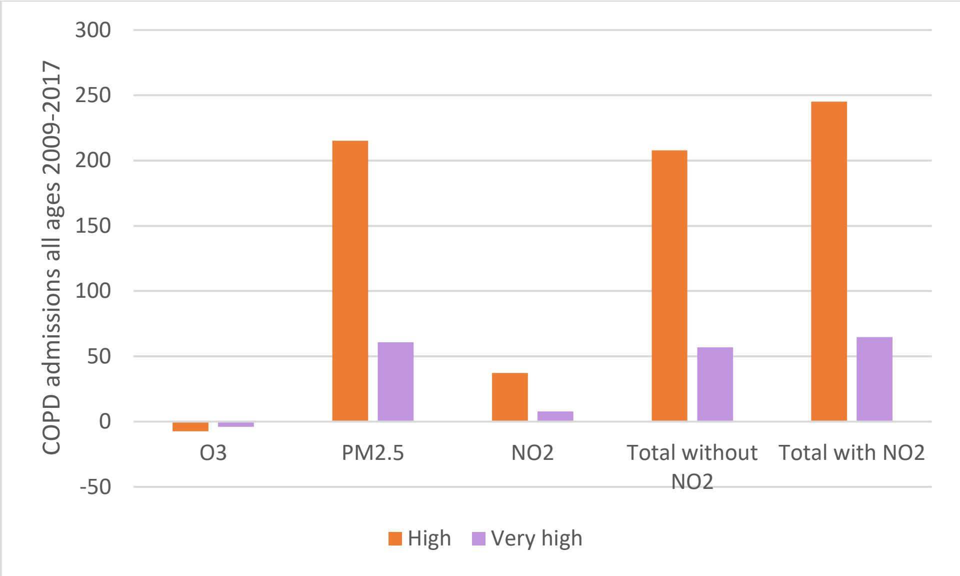

Figure 14 Total COPD admissions, all ages, in London 2009-2017 for high and very high days compared with ***low and moderate*** *days.*

4.8.4 Asthma admissions in children, comparison with low or moderate days

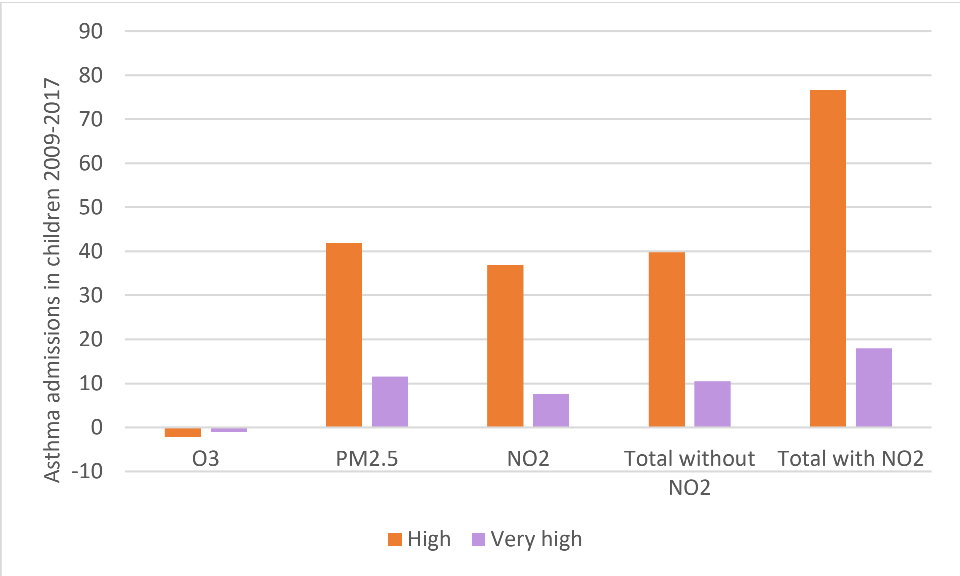

Figure 15 Total asthma admissions, in children, in London 2009-2017 for high and very high days compared with ***low and moderate*** *days.*

4.8.5 Asthma admissions in adults, comparison with low or moderate days

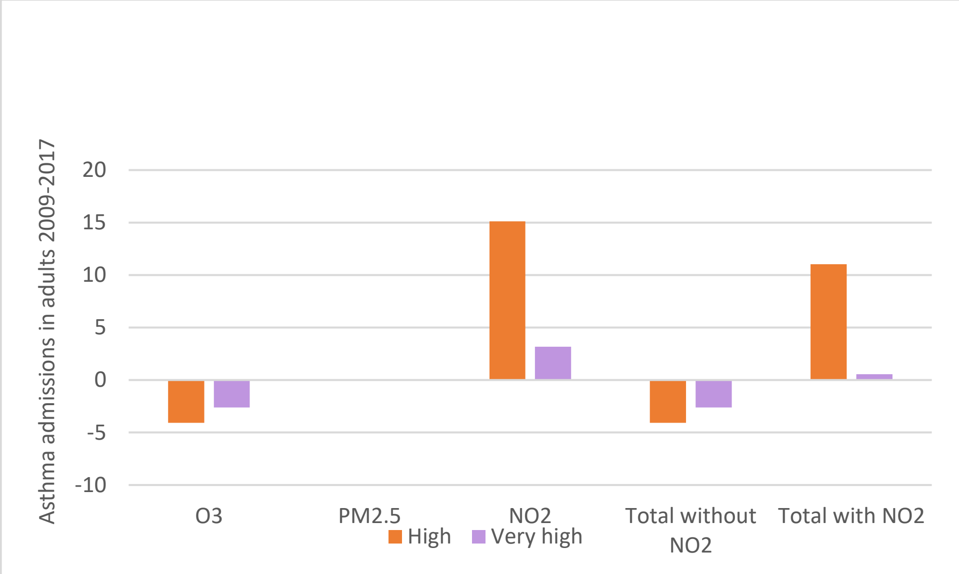

*Figure 16 Total asthma admissions in adults 15-64 in London 2009-2017 for high and very high days compared with **low and moderate** days.*

4.8.6 All cardiovascular admissions, all ages, comparison with low or moderate days

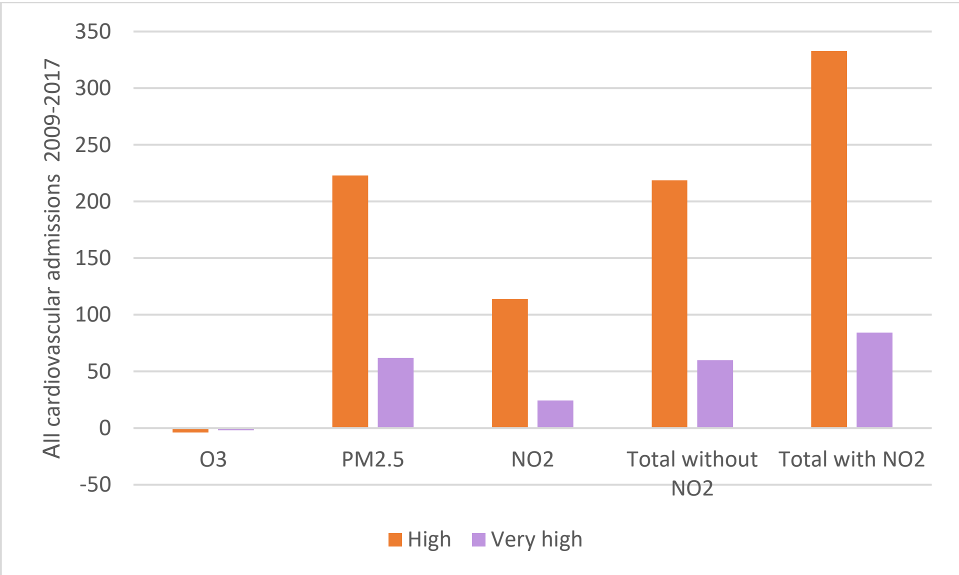

*Figure 17 Total all cardiovascular admissions, all ages, in London 2009-2017 for high and very high days compared with **low and moderate** days.*

4.8.7 Cardiac admissions in the elderly, comparison with low or moderate days

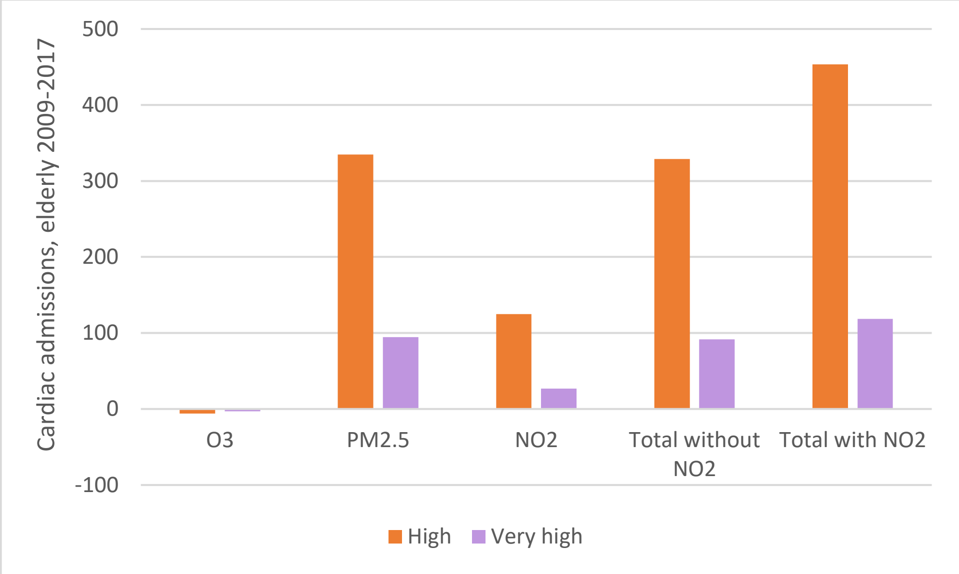

*Figure 18 Total cardiac admissions, 65+, in London 2009-2017 for high and very high days compared with **low and moderate** days.*

4.8.8 Stroke admissions all ages, comparison with low or moderate days

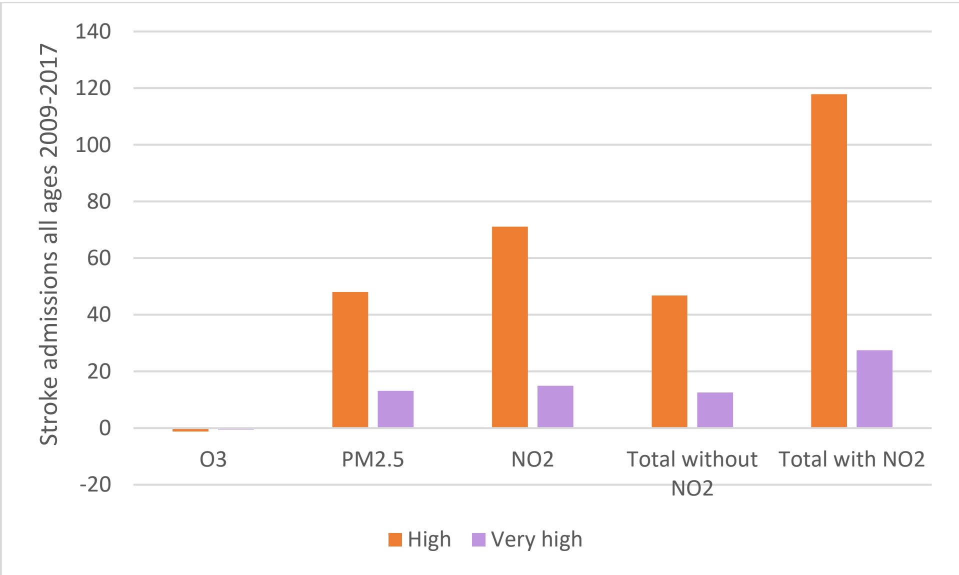

*Figure 19 Total stroke admissions all ages in London 2009-2017 for high and very high days comparied with the average of all **low and moderate** days .*

	Compared with low days		**Compared with low or moderate days**	
	Total 2009-2017 without NO_2 (range)[a]	**Total 2009-2017 with NO_2 (range)**	**Total 2009-2017 without NO_2 (range)[a]**	**Total 2009-2017 with NO_2 (range)**
Deaths brought forward				
Moderate	1150 (480, 1713)	1584 (742, 2325)	916 (415, 1424)	1302 (648, 1969)
High	215 (103, 218)	314 (162, 458)	189 (95, 284)	282 (151, 417)
Very high	77 (40, 114)	56 (28, 84)	50 (25, 76)	70 (37, 104)
All respiratory admissions				
Moderate	4050 (474, 8093)	4608 (575, 9162)	3305 (250, 6498)	3823 (339, 7449)
High	710 (-52[c], 1615)	843 (-29, 1861)	646 (-77, 1433)	772 (-55, 1666)
Very high	191 (-19, 420)	220 (-14, 471)	168 (-24, 383)	195 (-19, 432)
All cardiovascular admissions				
Moderate	985 (134, 1818)	1505 (385, 2619)	831 (143, 1507)	1295 (367, 2219)
High	236 (65, 408)	357 (123, 593)	219 (66, 373)	333 (121, 548)
Very high	63 (18, 109)	89 (31, 149)	60 (19, 102)	84 (31, 139)

Table 26 Comparison of results using a baseline of the average of concentrations on days when all pollutants were low compared with results using a baseline of the average of concentrations on days when all pollutants were low or moderate. Results for deaths brought forward; all respiratory admissions and all cardiovascular admissions

4.9 Uncertainty

The previous sections have represented uncertainty by doing calculations three times for the central estimates, upper and lower confidence intervals around the concentration-response function. For each pollutant this covers one aspect of uncertainty. Summing across pollutants, we used the lower limit of the confidence interval for each pollutant, the central estimate for each or the upper limit for each. This almost certainly over-estimates the uncertainty for the concentration-response function aspect as it is increasingly unlikely that the true concentration-response function falls at the lower end for all of the pollutants simultaneously. We therefore investigated how the uncertainties in the inputs propagate through the calculations. This is, however, a complex undertaking and could not be fully pursued in the context of this relatively small project. Some observations are included below to aid further development of uncertainty approaches in future projects.

One aspect for discussion before deciding on a statistical method for exploring uncertainty is deciding the exact purpose of the calculations and what aspects of the calculations are of particular interest. This is not necessarily as obvious as it seems. Some points relating to this are given below:

a) One could be reporting on the actual variation of the difference between the concentration on specific days and the average of all days for the period 2009-2017 and the consequent predicted health impacts or one could be predicting ‘typical’ health impacts for high and very high days in general. The statistical approach would be different in each case.

b) Some aspects could be regarded as fixed once a particular assumption had been chosen or a particular value of an uncertain input became defined. For example, if the true concentration-response function turned out to be close to the lower confidence interval, this would not change from day to day.

c) Apparently closely related variables can vary in different dimensions. On a specific day, there is only one value for the concentration of a particular pollutant on that day, but the delta has variation because it subtracts the average concentration of the days on which all pollutants are low across 2009-2017. Across days the specific concentration of pollutants vary but the average and variance of the average concentration of the days on which all pollutant are low does not change further across days.

We explored one approach as a way to achieve further insight and concluded that more thinking is needed. This looked at combining the variation in the deltas across the days and the variation in the concentration-response function. It did not include the variation around the average concentration of the days on which all pollutants are low across 2009-2017. It was assumed that since this was averaged over a large number of days, the variation would be smaller and contribute less to overall uncertainty than the variation in the concentration-response functions and the deltas.

We repeat here the equation for the calculations:

The calculation was (equation 1)

Additional Admissions =
```
(EXP(((LOG((ConcResponseFunction/100)+1)/10)*Pollution Delta))-1)*Admissions/365
```
Where

'ConcResponseFunction' is the relative risk per 10 µgm^{-3};

'Pollution Delta' is the difference between the pollutant concentration on the specific day and the average of all low days;

'Admissions' is the annual number of hospital admissions for the relevant cause.

Admissions was used as a single number without variation for each year, so there are two inputs with variation around them – the concentration-response function and the pollution delta. The approach we initially took was to combine the variances of these two parameters using the following equation 2 for the variance of a product.

Let V(x) and V(y) be the variance of X and Y respectively
Let C(x,y) be the covariance of X and Y

then the variance of the product XY, is

V(xy)=[E(x)]^2*V(y)+[E(y)]^2*V(x)+2*E(x)*E(y)*C(x,y)+V(x)*V(y)+C(x,y)^2

(E(x) is the expected value of x approximated by the mean of x)

(This approach assumes x and y are normally distributed).

In the particular case here, we considered that there was unlikely to be a correlation and thus covariance between the pollution delta and the original concentration-response function so equation 2 reduces to the following (equation 3).

V(xy)=[E(x)]^2*V(y)+[E(y)]^2*V(x)

This was applied to the term of equation 1 containing the concentration-response

function and pollution delta: ((LOG((ConcResponseFunction/100)+1)/10)*Pollution Delta)) specifying x as (LOG((ConcResponseFunction/100)+1)/10) and y as Pollution Delta giving equation 4:

Variance (((LOG((ConcResponseFunction/100)+1)/10)*Pollution Delta)))= (((LOG((central estimate ConcResponseFunction/100)+1)/10))^2*variance Pollution Delta) + ((mean Pollution Delta)^2 * variance ((LOG((ConcResponseFunction/100)+1)/10))

The variance of the concentration-response function term was calculated as the square of the difference between ((LOG((upper 95% confidence interval of ConcResponseFunction/100)+1)/10)) and ((LOG((lower 95% confidence interval of ConcResponseFunction/100)+1)/10)) divided by 2*1.96.

Finally, the newly calculated variance of the product is further modified to give the variance of the results using the remainder of equation 1 (the variance of az is simply equal to a-squared times the variance of z, where a is a constant i.e. one can take the variance of the concentration-response function and delta term product and exponentiate, subtract 1 and multiply by the admissions/365.

This process was applied to each pollutant before summing the results.

As a result of finding unexpected negative values in the results, we realised that there were two issues with this approach. Firstly, it assumes a 'free' combination of values for deltas and concentration-response function values across days. In fact, whatever value of the concentration-response function happened to be true, it would be the same across days.

Secondly, the results once completed for individual pollutants need to be combined across pollutants. Here, there is an issue with the pollution deltas being correlated. The unexpected negative values in the results came from the fact that the process allowed low deltas for $PM_{2.5}$ to be combined with occasions with negative deltas for ozone. In practice, negative deltas for ozone are most likely to occur on days (such as still winter days) when both $PM_{2.5}$ and nitrogen dioxide accumulate. The accumulating nitrogen dioxide is accompanied by accumulating nitric oxide (NO, which destroys ozone. This means that ozone is even lower on those days than on the average of all days when all pollutants are low. It also means that negative deltas for ozone are most likely to be accompanied by large deltas for $PM_{2.5}$ (and often nitrogen dioxide). In turn, this gives a net positive sum for the results, not a negative one. This can be taken into account, but we did not pursue further due to time constraints.

The fact that the variance around the various inputs are most relevant at different points in the process, makes Monte-Carlo simulation analysis a more suitable approach in the future. Monte-Carlo analysis would sample from the relevant distribution assumed for the input variables at the appropriate point in the process and would end up with predictions for the health impacts of air pollution by repeated random sampling.

We reverted to the common practice of only incorporating the variation around the concentration-response function. This was done by redoing the calculations used for the central estimate using the lower 95% confidence intervals and again using the upper 95% confidence interval. For the results for each pollutant individually, this is a reasonable representation of this aspect of the uncertainty (but misses other aspects). When adding across the pollutants, we added the results using the lower 95% confidence interval for all the pollutants and then added the results using the upper 95% confidence interval for all the pollutants. This gives far too wide a range for this aspect of uncertainty, and possibly for uncertainty overall. This former point is because it is not likely that the true value of the concentration-response function would be near the lower 95% confidence interval, for example, for all the pollutants. This was the issue that the approach discussed at the beginning of this section was intended to solve. Work on this aspect needs to be further developed including checking whether the inputs are normally distributed and not correlated, as we have assumed so far.

5 Discussion

While relatively rare, high air pollution days were shown here to result in an estimated **210-310 deaths brought forward, 710-840 respiratory admissions and 240-360 cardiovascular admissions over the period 2009-2017** compared with the average of days when all pollutants are classified as 'low' according to the Daily Air Quality Index. The numbers of health outcomes for very high days were smaller than those for high days, as there are very few of them (8 days).

The range is from summing the results for ozone and $PM_{2.5}$ without nitrogen dioxide and summing all three pollutants. There is substantial overlap between the single pollutant model concentration-response functions for $PM_{2.5}$ and nitrogen dioxide due to their similar sources. For example, on days when still weather conditions lead to accumulation of pollutants, both nitrogen dioxide and $PM_{2.5}$ are likely to increase together. This makes them difficult to disentangle in the original health studies. This issue was discussed for effects of long-term exposure in a recent report (COMEAP, 2018). This concluded that the total deaths from combined exposure to nitrogen dioxide and $PM_{2.5}$ was likely to be similar to, but somewhat higher than the result for $PM_{2.5}$ alone. If this also applies to short-term exposure and to the inclusion of ozone, this implies that a single combined answer would be towards the lower end but not the bottom of the ranges given above. The results of single pollutant models are best regarded as markers for the specified pollutant and other pollutants with which it is closely correlated. So $PM_{2.5}$ is a partial marker for the regional pollution mixture and local sources whereas nitrogen dioxide is a good marker for traffic pollution but less so for other aspects of the air pollution mixture. Ozone is a marker for the photochemical pollution mixture and is generally regarded as independent from the effects of the other pollutants.

There are several uncertainties in the calculations of which the overlap between pollutants is one. There is substantial heterogeneity across the individual studies that are pooled to give the concentration-response functions resulting in reasonably wide 95% confidence intervals in some cases. There is also uncertainty around the average of the pollutant concentrations. This gives an error of around 10%. The baseline admissions inputs did not have uncertainty around them as they are actual counts[7]. It is complex to incorporate and combine these uncertainties in the inputs together. We started on a process of developing an approach to this and made some progress. In the end, however, we reverted to the standard practice of doing separate calculations for the lower and upper limits of the confidence interval. This does not cover every aspect of uncertainty into account and, if added across pollutants without taking pollutant correlation into account, gives ranges for this aspect that are too wide. Further work on approaches to evaluating uncertainty is recommended.

We also analysed the results for certain specific causes of hospital admissions that are included within the broader classes of all respiratory[8] and all cardiovascular (heart and circulatory disease) admissions. Cardiac (heart disease) admissions in the elderly and admissions for chronic obstructive pulmonary disease (COPD, a lung disease common in smokers) were significant contributors to the

[7] There may still be uncertainties in this data due to misdiagnosis across diagnostic categories and, potentially, in variations in hospital reporting (although hospital episode statistics are a well-established system).
[8] Note that, as the years were 2009-2017, this did not include any admissions for COVID-19.

total hospital admissions. Asthma admissions were smaller than for the above health outcomes, with children more affected than adults.

These estimates capture the most serious outcomes but do not include other health outcomes that are also likely to occur such as increases in symptoms.

Others have done health impact calculations for specific outcomes (e.g. Stedman et al 2003; McIntyre et al, 2014) but, so far as we are aware, this is the only health impact report of multiple episodes over an extended period apart from our own previous work in Sussex (Walton et al 2014b).

The intention of this report is to give an estimate of the health impact of episodes and, in turn, a sense of the size of the problem that potential emergency measures on episode days might address if implemented. However, this is not to say that the emergency measures would necessarily reduce air pollution concentrations to the baseline for all low days. To partially address this, we also did an analysis down to concentrations derived from the average of all days when all pollutants were either moderate or low. This gave slightly smaller results but is still derived from quite marked concentration differences. The results were **190 -280 deaths brought forward, 610 - 740 respiratory admissions and 220-330 cardiovascular admissions over the period 2009-2017.** In practice, what is actually achievable with emergency measures will vary and would need to be analysed using modelled concentration changes. The benefits of the achievable concentration reduction would then be compared with the costs. The methods used here could also be used to calculate the health benefits in such an analysis.

Note that to achieve benefits equivalent to the above impacts would require substantial reductions in concentrations (see deltas in Table 13 and Table 14) beyond those that might be achievable with the short-term emergency measures discussed in the overview report and report C.

We also analysed the health impacts of moderate days. These are much more substantial than for high or very high days because they occur much more frequently. This gives results of **1150 -1580 deaths brought forward, 4000-4600 respiratory admissions and 980-1500 cardiovascular admissions over the period 2009-2017** compared with low days. This emphasises the importance of either extending emergency measures to cover moderate days (if feasible) or of general measures to reduce concentrations of air pollution overall.

The same methods discussed in this report could be used for more detailed cost-benefit analysis of potential emergency measures to be implemented on episode days.

6 Conclusions and recommendations

We conclude that,

(i) There are increased health impacts on high and very high days, in terms of impact per day

(ii) Health impacts added up across 2009-2017 are ranked as moderate>high>very high despite the health impacts per day being ranked in the opposite direction. This is due to the greater frequency of moderate, compared with high and very high days

(iii) Across the broad health outcomes of deaths brought forward, respiratory and cardiovascular admissions, respiratory hospital admissions are most important in terms of numbers of admissions. Within respiratory admissions, COPD admissions are most important and within cardiovascular admissions, cardiac admissions in the elderly are most important.

(iv) Across pollutants and high and very high days, $PM_{2.5}$ is usually the most important in the size of the health impact. Nitrogen dioxide is usually second in importance on these days and sometimes close to (asthma admissions in children) or more than for $PM_{2.5}$ (asthma admissions in adults; stroke) Ozone is often most important on moderate days.

(v) The pattern of results is similar but smaller and with more frequent negative results for ozone, when using a baseline of the average of pollutants on all low or moderate days instead of a baseline of the average of pollutants on all low days.

Uncertainties remain about how best to deal with the overlap between the effects of different pollutant and how to propagate uncertainties through the whole calculation process. While the overall observation that the greatest health impact is from moderate days (and therefore probably better addressed by long-term measures), to increase overall understanding from a scientific point of view we recommend:

(i) Investigation of the health impact of more long-term policies compared with emergency measures. This should include the effects of the policies on frequency of episode days and on the concentrations and health impacts on moderate, high and very high days. Given the larger overall impact of moderate days, it seems likely that longer term policies might be a more effective approach overall.

(ii) Further work on methods to deal with overlap between pollutants including use of multi-pollutant models and correction for measurement error.

(iii) Further work on propagation of uncertainties.

7 Acknowledgements

This work was funded by Transport for London and the Greater London Authority.

Heather Walton's post was part funded by the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Health Impact of Environmental Hazards at King's College London in partnership with Public Health England (PHE) and Imperial College London. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, the Department of Health & Social Care or Public Health England.

We thank Anita Brock PHE for extracting hospital admissions data and Laura Buchanan, Environmental Research Group, Imperial College London for investigating alternative approximations for London specific data should it have been necessary.

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9 Appendix 1 Numerical values for deaths brought forward and admissions for moderate, high and very high days compared with the average concentration of pollutants on all days that are low or moderate

	Total deaths brought forward 2009-2017[a]	
Pollutant/Banding	**High (range)[b]**	**Very high (range)**
$PM_{2.5}$	198 (98, 299)	55 (27, 83)
NO_2	94 (57, 133)	20 (12, 28)
O_3	-9 (-3, -14)	-5 (-2, -8)
Total without NO_2	189 (95, 284)	50 (25, 76)
Total with NO_2	282 (151, 417)	70 (37, 104)
Total without ozone	291 (155, 431)	75 (39, 111)

Table A1 Total deaths brought forward in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low or moderate*** *days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

	Total respiratory admissions all ages 2009-2017[a]	
Pollutant/Banding	**High (range)[b]**	**Very high (range)**
$PM_{2.5}$	678 (-62, 1480)	185 (-17, 409)
NO_2	127 (22, 233)	26 (5, 49)
O_3	-33 (-14, -47)	-17 (-7, -26)
Total without NO_2	646 (-77, 1433)	168 (-24, 383)
Total with NO_2	772 (-55, 1666)	195 (-19, 432)
Total without O_3	805 (-41, 1713)	211 (-12, 458)
Total without PM	94 (7, 186)	10 (-2, 23)

Table A2 Total respiratory admissions all ages in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low or moderate*** *days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish rangex.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] Negative values in this case are a result of a lower confidence interval below zero for the concentration-response function for $PM_{2.5}$ (Table 3). Totals without PM are shown in the last row.

	Total COPD admissions all ages 2009-2017[a]	
Pollutant/Banding	**High (range)[b]**	**Very high (range)**
$PM_{2.5}$	215 (57, 394)	61 (15, 114)
NO_2	37.2 (36.8, 37.6).	7.85 (7.8, 7.9)8
O_3	-7 (-4, -10)	-4 (-2,-6)
Total without NO_2	208 (51, 384)	57 (13, 108)
Total with NO_2	245 (88, 422)	61 (21, 115)
Total without ozone	252 (93, 431)	69 (23, 122)

Table A3 Total COPD admissions all ages in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with low or moderate days, by pollutant.

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

	Total asthma admissions in children 2009-2017[a]	
Pollutant/Banding	**High (range)[b]**	**Very high (range)**
$PM_{2.5}$	42 (23, 62)	12 (6, 17)
NO_2	37 (18, 57)	8 (4, 12)
O_3[c]	-2 (2, -3.1)	-1 (1, -2.5)
Total without NO_2	40 (25, 59)	10 (7, 15)
Total with NO_2	77 (43, 116)	18 (11, 26)
Total without ozone	79 (41, 119)	19 (10, 29)

*Table A4 Total asthma admissions in children in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low or moderate** days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] Negative values for moderate and high days are a result of a lower confidence interval below zero for the concentration-response function for ozone (Table 6). (For very high days, negative deltas also contribute). Totals without ozone are shown in the last row.

	Total asthma admissions in adults 2009-2017[a]	
Pollutant/Banding	**High (range)[b]**	**Very high (range)**
$PM_{2.5}$	-	-
NO_2	15 (13, 29)	3 (2.6, 6)
O_3	-4 (1, -3)	-3 (0.3, -5)
Total without NO_2	-4 (1, -3)	-3 (0.3, -5)
Total with NO_2	11 (13,26)	1 (3, 2)
Total without ozone	15 (13, 29)	3 (2.6, 6)

Table A5 Total asthma admissions in adults in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low or moderate*** *days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

	Total cardiovascular admissions all ages 2009-2017[a]	
Pollutant/Banding	**High (range)[b]**	**Very high (range)**
$PM_{2.5}$	223 (64, 382)	62 (18, 107)
NO_2	114 (55, 175)	24 (12, 37)
O_3[c]	-4 (2, -9)	-2 (1, -5)
Total without NO_2	219 (66, 373)	60 (19, 102)
Total with NO_2	333 (121, 548)	84 (31, 139)
Total without ozone	337 (119, 558)	86 (29, 144)

Table A6 Total cardiovascular admissions all ages in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with ***low or moderate*** *days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] Negative values for moderate and high days are a result of a lower confidence interval below zero for the concentration-response function for ozone (Table 6). (For very high days, negative deltas also contribute). Totals without ozone are shown in the last row.

	Total cardiac admissions age 65+ 2009-2017[a]	
Pollutant/Banding	**High (range)**[b]	**Very high (range)**
$PM_{2.5}$	335 (176, 502)	95 (49, 144)
NO_2	125 (76, 175)	27 (16, 37)
O_3[c]	-6 (7, -15)	-3 (3, -9)
Total without NO_2	329 (183, 487)	92 (53, 135)
Total with NO_2	454 (260, 662)	118 (69, 172)
Total without ozone	460 (253, 677)	121 (66, 181)

*Table A7 Total cardiac admissions age 65+ in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low or moderate** days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.

[c] Negative values for moderate and high days are a result of a lower confidence interval below zero for the concentration-response function for ozone (Table 7). (For very high days, negative deltas also contribute). Totals without ozone are shown in the last row.

	Total stroke admissions all ages 2009-2017[a]	
Pollutant/Banding	**High (range)**[b]	**Very high (range)**
$PM_{2.5}$	48 (44, 53)	13 (12, 14)
NO_2	71 (29, 110)	15 (6, 23)
O_3	-1.3 (0, -2)	-0.6 (0, -1)
Total without NO_2	47 (44, 50)	13.1 (11.9, 13.2)
Total with NO_2	118 (72, 160)	28 (18, 36)
Total without ozone	119 (72, 163)	28 (18, 37)

*Table A8 Total stroke admissions all ages in London 2009-2017 for air pollution concentrations on moderate, high and very high days compared with **low or moderate** days, by pollutant.*

[a] Rounded to whole numbers, unless further decimal places needed to distinguish range.

[b]Range for the results using all lower or all higher 95% confidence intervals of the concentration-response functions for each pollutant. This is unlikely to represent the true concentration-response functions so the actual range is likely to be narrower. The range for the totals should not be regarded as a 95% confidence interval itself or a measure of statistical significance.