Imperial College London

Projects

London Health Burden of Current Air Pollution and Future Health Benefits of Mayoral Air Quality Policies

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Key Findings

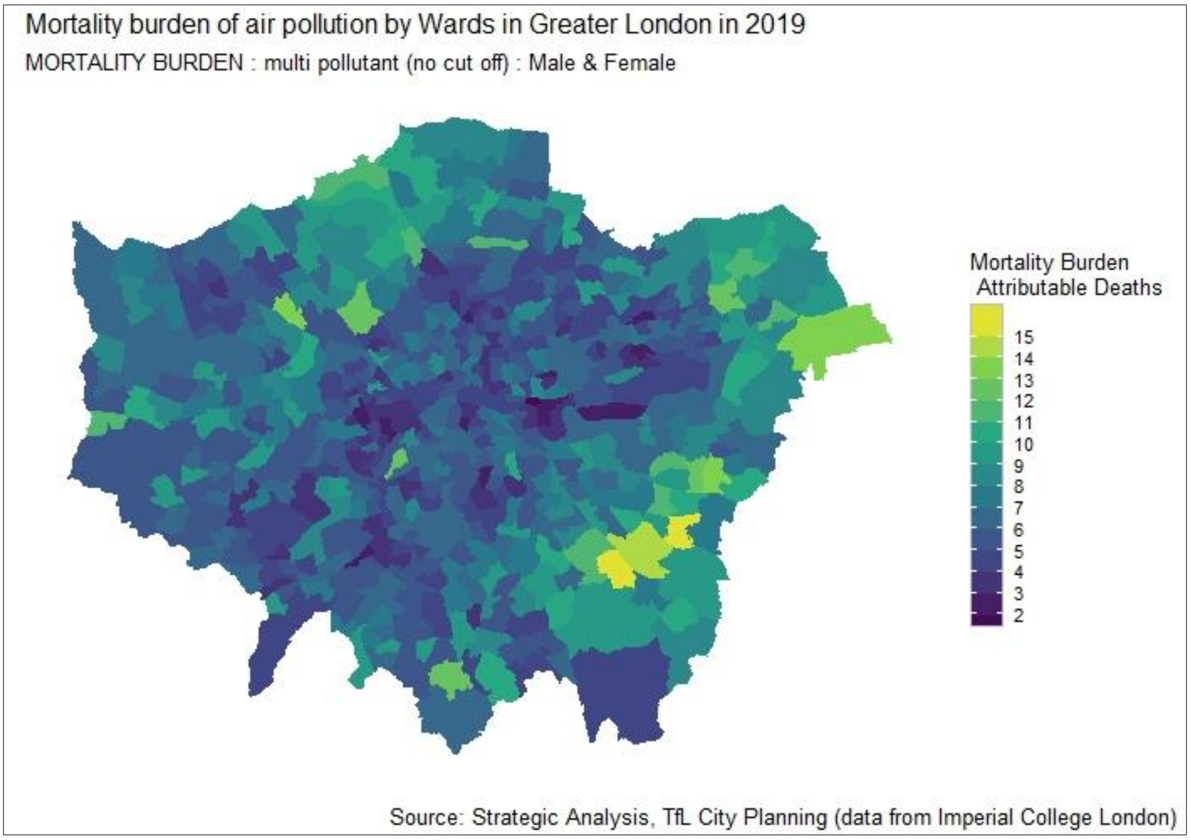
Transport for London (TfL) and the Greater London Authority (GLA) commissioned researchers from the Environment Research Group (ERG) at Imperial College London to assess the impact on health of the mayoral air quality policies, and air pollution in London, using current (2019) and future levels of air pollution up to 2050 (projected from 2013).

Key findings include:

- In 2019, in Greater London, the equivalent of between 3,600 to 4,100 deaths (61,800 to 70,200 life years lost[1]) were estimated to be attributable to human-made $PM_{2.5}$ and NO_2, considering that health effects exist even at very low levels. This calculation is for deaths from all causes including respiratory, lung cancer and cardiovascular deaths.
- With the adoption of the Mayor's air quality policies and taking into account general air pollution trends, the average life expectancy of a child born in London in 2013 would improve by around 5 to 6 months.
- Without the Mayor's air quality policies and other general air pollution trends, a child born in 2013 would lose 7 to 11 months life expectancy due to air pollution.
- The mortality burden in 2019 was affected by a number of factors (population size, pollution, deprivation, age of population (as baseline mortality increases with age)):
    - The greatest burden, as a proportion of the population, falls in Outer London boroughs, even though pollution levels there are relatively lower, mainly due to the higher proportion of the elderly in these areas.
    - Conversely, Inner London boroughs had a lower burden of air pollution related mortality due to their younger age profile. However, for other air quality related health outcomes such as asthma admissions in children, boroughs with younger populations will be more affected.
- The team also found that London's population would gain around 6.1 million life years if air pollution concentrations improved, per the Mayor's air quality policies scenario, from 2013 to 2050, following up the population exposed for a lifetime up to 105 years after 2050 (2154[2]). This gain was in comparison to pollution levels remaining at 2013 concentrations.
- The gain in life expectancy from the projected future air pollution changes is less influenced by population size than the gain in life years. The life expectancy gains were larger in Inner London, including some more deprived boroughs, probably due to the greater concentration reductions in Inner London and to variations in baseline mortality rates.
- If London is enabled to meet the WHO guideline for $PM_{2.5}$ by 2030, the population in London would gain a 20% increase in life years saved over the next 20 years.
- The report does not cover effects on illness, such as hospital admissions and asthma exacerbations that are also affected by air pollution.

[1] The original studies were analysed in terms of 'time to death' aggregated across the population. Strictly, it is unknown whether this total change in life years was from a smaller number of deaths fully attributable to air pollution or a larger number of deaths to which air pollution partially contributed. The former is used with the phrase 'equivalent' to address this issue. See COMEAP (2010) for a fuller discussion.

[2] It is not possible to calculate the full result for gains in life expectancy until everyone in the initial population has died (105 years from 2050), necessitating follow-up for a life-time even if the pollution changes are only for the next decade or so.



Mortality burden of air pollution by Wards in Greater London in 2019
MORTALITY BURDEN : multi pollutant (no cut off) : Male & Female
Mortality Burden
Attributable Deaths
15
14
13
12
11
10
9
8
7
6
5
4
3
2
Source: Strategic Analysis, TfL City Planning (data from Imperial College London)

1.0 Executive Summary

Transport for London (TfL) and the Greater London Authority (GLA) commissioned researchers from the Environment Research Group (ERG) at Imperial College London to assess the impact on health of the mayoral air quality policies, and air pollution in London, using current (2019) and future levels of air pollution up to 2050 (projected from 2013).

This is the first time that the new health impact recommendations (COMEAP, 2018a)[3] have been applied in practice to London's $PM_{2.5}$ and NO_2 concentrations. The Committee on the Medical Effects of Air Pollutants (COMEAP) recommendations included quantifying the burden of $PM_{2.5}$ and NO_2 jointly rather than separately. This report is also the first time the COMEAP recommendations have been applied to projected levels to 2050, using mayoral air quality policies (including Low Emission Zones for Heavier vehicles in 2020, Ultra Low Emission Zones (brought forward in central London in 2019 and expansion to the inner area within the north and south circular roads in 2021) and London Environmental Strategy in 2025/2030/2050) and additional policies for meeting the (2005) WHO $PM_{2.5}$ air quality guidelines[4] by 2030[5].

Mortality burden (long–term exposure) of current (2019[6]) air pollution levels in London

Mortality burden calculations are not suitable for year on year analysis because they do not allow for the number of deaths the year before to influence the age and population size in the following year (lifetables and impact calculations do). Nonetheless, they provide a useful feel for the size of the burden of air pollution on health at a single point in time.

The team found that **in 2019, in Greater London**, 61,800 to 70,200 life years lost[7] (the equivalent of between **3,600 to 4,100 attributable deaths**) were estimated to be attributable to anthropogenic $PM_{2.5}$ and NO_2, assuming health effects exist even at very low levels[8]. These deaths occur mostly amongst older age groups, as is typical for deaths in the general population. We have used multi-pollutant model estimates as these provide a better representation of the air pollution mixture overall than calculations using each individual pollutant alone[9].

The health impacts (burden) of air pollution results for 2019 is also available by gender, borough and ward across Greater London. Many factors contribute to higher mortality burdens from air pollution. Whilst some outer London local authorities have lower pollution levels, they have higher mortality burdens due to a higher proportion of older people in the population.

[3] COMEAP – the Committee on the Medical Effects of Air Pollutants is a national expert Committee advising Government on the health effects of air pollution. Their recommendations for quantification are usually used in Government cost-benefit analysis of policies to reduce air pollution.

[4] https://www.who.int/airpollution/publications/aqg2005/en/ (Accessed 13 October 2020)

[5] https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/pm25-london-roadmap-meeting-who-guidelines-2030 (Accessed 22 September 2020).

[6] Represented by a snapshot view of 2019 (see further details in section 4.1)

[7] The original studies were analysed in terms of 'time to death' aggregated across the population. Strictly, it is unknown whether this total change in life years was from a smaller number of deaths fully attributable to air pollution or a larger number of deaths to which air pollution partially contributed. The former is used with the phrase 'equivalent' to address this issue. See COMEAP (2010) for a fuller discussion.

[8] The results omitting concentrations below which there are very few data points (cut-offs) were 38,300 to 45,300 life years lost (the equivalent of between 2200 and 2600 attributable deaths).

[9] The central estimate results using the largest single pollutant model result were 42,900 to 51,600 life years lost (the equivalent of between 2,500 to 3000 attributable deaths) using NO_2 as an indicator. Results using $PM_{2.5}$ as an indicator are given in Table 5.

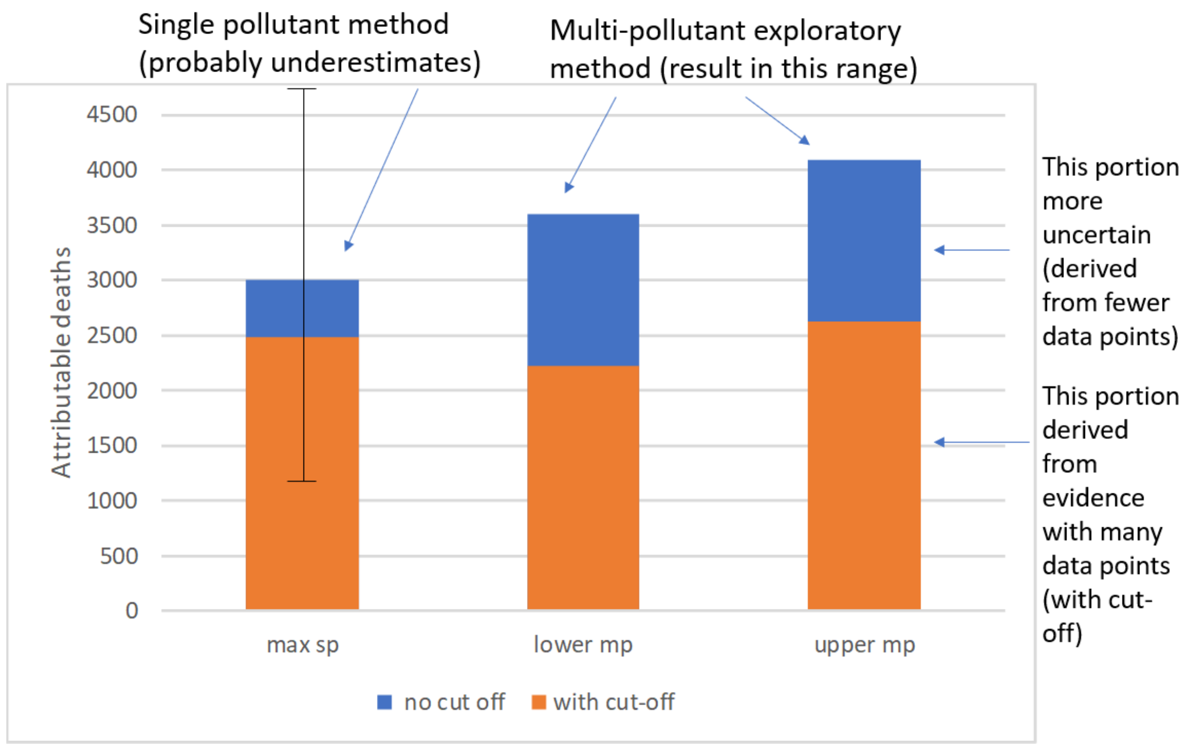


Figure 1 Mortality burden of air pollution in Greater London in 2019 – Attributable deaths

Mortality impact (long–term exposure) of Mayoral Air Quality Policies (MAQP) in London

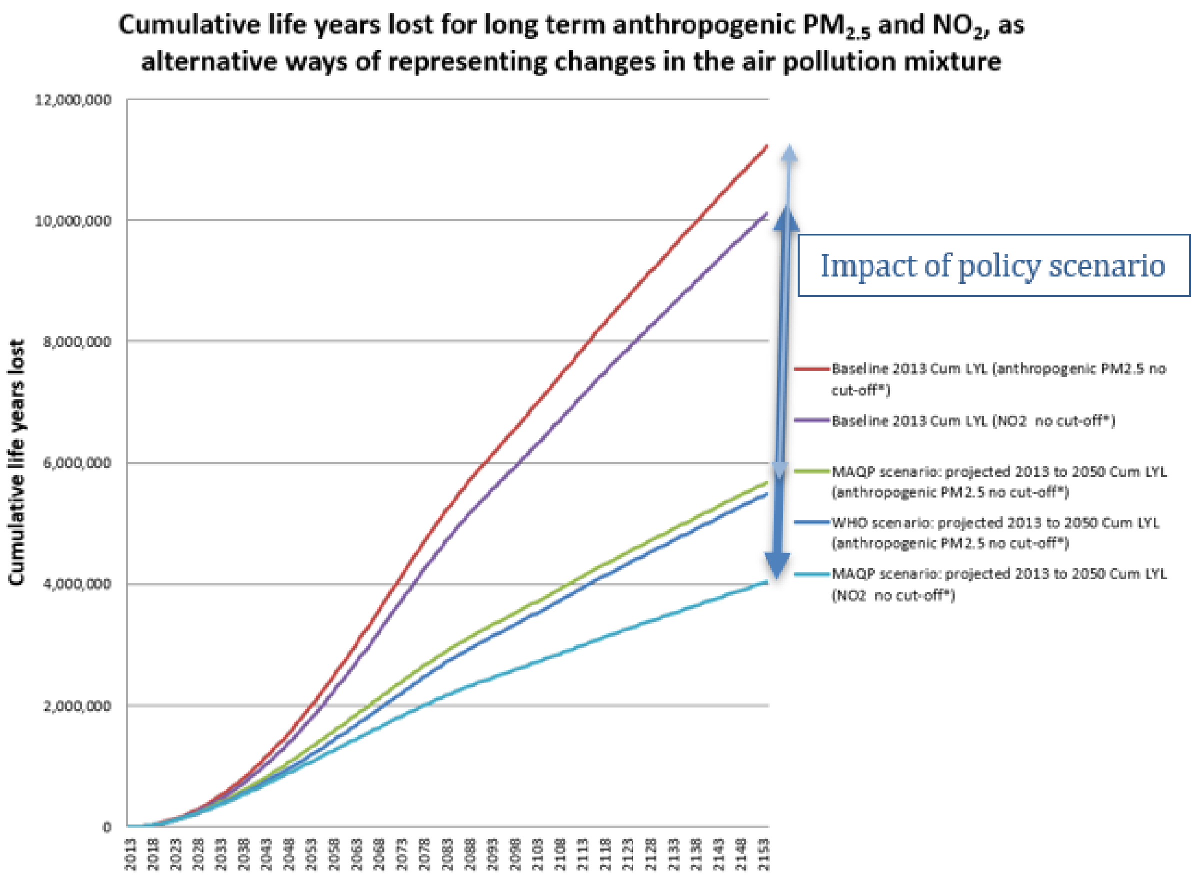


*Figure 2 Cumulative life years lost per year from long-term exposure of anthropogenic $PM_{2.5}$ and NO_2 pollution across London (** Cut-off results not shown)

The team also found that London's population would **gain** around **6.1 million life years*** if air pollution concentrations improved, per the Mayor's air quality policies scenario, from 2013 to 2050, following up the population exposed for a lifetime up to 105 years after 2050 (2154[10]). The gain was in comparison to pollution levels remaining at 2013 concentrations. By adopting the Mayor's air quality policies scenario, the average **life expectancy** of **a child born in London in 2013** would **improve** by around **5 to 6 months (53 to 76%)**.

*(a life year is one person living for one year)

However, Imperial's researchers also found that, despite the mayoral air quality policies, London's population would still be **losing** between **2.6 to 5.7 million life years** compared with no human-made pollution. Put another way, **children born in 2013, in London,** are still estimated to **die 2-5 months earlier[11]** on average**, if exposed over their lifetimes to the projected future air pollution concentrations[12] in London**.

The report provides figures for both $PM_{2.5}$ and NO_2 separately but then uses one or the other as the best indicator pollutant rather than adding results together to avoid large overestimation of the mortality impact of air pollution (details in the report below). This follows methodology included within a recent COMEAP report. The 'best indicator' approach may result in a small underestimate[13].

Mortality impact (long–term exposure) of additional policies[14] for meeting $PM_{2.5}$ WHO (2005) guidelines by 2030 in London

As a result of **meeting $PM_{2.5}$ WHO (2005) guidelines by 2030**, ERG's researchers found that between 2020 to 2049, London's population would **gain** a **20% increase in life years** saved (600,000 life years saved – compared with around 500,000 life years gained during the same period for the Mayor's air quality policies scenario)[15].

The mortality impact of the MAQP and WHO scenarios is also available by gender, borough and ward. The benefits were generally greatest in Inner London, including in some deprived areas. Several factors influence the pattern of results across boroughs including population size, concentration change, baseline mortality rate, age distribution and the timing of the pollution changes.

[10] It is not possible to calculate the full result for gains in life expectancy until everyone in the initial population has died (105 years from 2050), necessitating follow-up for a life-time even if the pollution changes are only for the next decade or so.
[11] The range is according to whether the indicator pollutant is taken as $PM_{2.5}$ or NO_2, whether or not there is a cut-off concentration below which no effects are assumed and gender.
[12] The concentrations were projected from 2013. There are multiple factors contributing to the profile of projected concentration changes over time, including past policies back to 2013, and local, national and international policies.
[13] For technical reasons, the multi-pollutant model approach is not available for impact calculations. See section 3.2 for more details and COMEAP (2018) for a full explanation.
[14] Introduce a new twenty-first century Clean Air Act, revitalise smoke control zones, create zero emission zones, set tighter minimum emission standards for new wood burning stoves, provide new powers to control NRMM and river/maritime emissions (for more details see section 8.6 in the Appendix)
[15] The results for life-expectancy are very similar to those for the MAQP scenario (to within fractions of a day) so are not described separately here. Further explanation can be found in section 6.4.

Limitations

For clarity, the executive summary presents only the central estimate of the results. However, a wider range of uncertainty around the results for the mortality burden[16] (see Figure 1, section 5 and 7.1) and impacts[17] (see section 6) can be found in the main report.

The study was focused on air pollution changes within London. Reductions in emissions will also have benefits for air pollution concentrations in the wider region. For example, reductions in NO_x emissions will reduce nitrate concentrations and thus $PM_{2.5}$ concentrations in the South East region. The health benefits of this are not reflected here, although they are likely to be smaller than those in London itself.

There will be further impacts from ozone concentrations out to 2030 and beyond. The long-term ozone exposure (representative of the summer smog ozone concentrations metric) is projected to decrease over time compared with 2013, but less than other pollutants such as NO_2 and $PM_{2.5}$. This impact of ozone needs to be investigated further, while it is currently regarded as having smaller and more uncertain effects on life-expectancy than $PM_{2.5}$, for example, there is the possibility that effects are being masked in the original studies due to negative correlations with other pollutants (COMEAP, 2015; WHO, 2013b). Ozone also has other health effects such as effects on respiratory disease.

This study addressed the effect of air pollution on deaths and loss of life-expectancy. This included all causes of death grouped together so covers, for example, respiratory, lung cancer and cardiovascular deaths for which there is good evidence for an effect of air pollution. It does not, however, cover the effect of air pollution on health where this does not result in death. So well established effects (such as respiratory and cardiovascular hospital admissions, effects on asthma, low birth weight etc.) and other outcomes more recently potentially linked with air pollution (such as dementia) are not included. This was addressed to some extent in a previous study commissioned by the GLA, although the uncertainties and need for further work were acknowledged for some of these outcomes.[18]

In summary, we have presented the burden of air pollution on mortality in 2019 but also shown that air pollution concentrations are projected to reduce over time as a result of various policies including the Mayor's Environment and Transport Strategy, bringing health benefits across London.

[16] One reasonable range is 2,000 to 4,000 attributable deaths (38,000 to 70,000 life years lost), depending on assumptions considered (see section 7.1).
[17] 3.8 to 9.7 million life years gained for the pollution changes from 2013-2050, followed up to 2154, including those from Mayoral Air Quality policies, compared with 2013 concentrations remaining unchanged (see Table 8).
[18] Modelling the long-term health impacts of air pollution in London, Health Lumen, 2020

2.0 Introduction

Transport for London (TfL) and the Greater London Authority (GLA) commissioned researchers from the Environmental Research Group (ERG) at Imperial College London to produce a mortality burden impact assessment associated with current air pollution levels in London for the year 2019 (represented by a snapshot view of 2019) and estimate the health benefits of specific policies over time (impact calculations). The impact calculations used current (2019) and future levels of air pollution up to 2050 (projected from 2013) from the mayoral air quality policies (MAQP) (including the Low Emission Zones, the Ultra Low Emission Zones and the London Environmental Strategy) and an alternative scenario with additional policies (the London Environmental Strategy Plus) for meeting $PM_{2.5}$ WHO (2005) guidelines[19] by 2030.

In order to do that, the team first compiled air pollution data for every Output Area (OA) in London, which then, combined with relationships between concentrations and health outcomes, were used to calculate the mortality burden and impacts on health from the air pollution levels estimated in each London ward and borough. The experts from the ERG produced the mortality burden and impacts methodology and calculations in the 2015 report (Walton et al, 2015) 'Understanding the Health Impacts of Air Pollution in London'. The researchers from the ERG (now part of Imperial) updated this work using the following methodology (see next sections for further details):

- Use the new COMEAP recommended methodology for calculating impacts of anthropogenic $PM_{2.5}$ and NO_2 (COMEAP, 2018a)
- Use updated data inputs (population and deaths at OA and LSOA levels, respectively) to give the current mortality burden in the London population in 2019 at a finer spatial scale (at wards and local authority levels)
- Use updated data inputs such as population and deaths at wards levels (to create the lifetables) and the latest birth projection data and improved life table calculations at ward level (previously at local authority level) with the new incorporation of the mortality rate improvements to give the mortality impact in the London population for current and future years at a finer spatial scale (at wards and local authority levels)
- Use updated air pollution data inputs to give the current mortality burden in the London population for the current levels of air pollution in 2019
- Use updated air pollution data inputs between 2013 and 2050 to give the mortality impacts in the London population

[19] https://www.who.int/airpollution/publications/aqg2005/en/ (Accessed 13 October 2020)

3.0 Method

3.1 Air Quality data

From 20m grid data to OA concentration

Particulate matter with diameter <2.5 µm ($PM_{2.5}$) and nitrogen dioxide (NO_2) annual mean concentrations across Greater London were predicted for a range of years between 2013 and 2050 using the London Air Quality Toolkit (LAQT) model as part of previous studies commissioned and undertaken in partnership with TfL and GLA. These included the "LAEI 2013"[20], "LAEI 2016"[21], "2019 snapshot (Dajnak et al., 2020b)", "Low Emission Zone (LEZ) Scenarios", "Ultra Low Emission Zone (ULEZ)"[22], "London Environment Strategy (LES)"[23] and "$PM_{2.5}$ in London: Roadmap to meeting WHO (2005) guidelines by 2030"[24] $PM_{2.5}$ and NO_2 annual mean concentrations air pollution data were extracted at 20m grid resolution and intersected with the latest Output Area (OA) layer from the Office of National Statistics (ONS)[25] for the Greater London area (a total of 25,053 OAs). Each concentration grid point within each OA was further averaged at OA level.

From OA to population-weighted LSOA and Ward concentration

Population-weighted average concentration (PWAC): Population-weighting was done at LSOA (Lower Super Output Area) and Ward level in the case of the mortality burden and impact calculations, respectively. The OA averaged concentrations were multiplied by the population aged 30 plus for each gender and the resulting population-concentration product summed across all OAs in each LSOA and Ward and then divided by the LSOA and Ward population, respectively. The LSOA and Ward population-weighted means were then used directly in the health impact calculations across all LSOA and Wards in London (This process allows one health calculation per LSOA or Ward rather than calculations in each separate OA).

3.2 Health assessment

It is now well established that adverse health effects, including mortality, are statistically associated with outdoor ambient concentrations of air pollutants. Moreover, toxicological studies of potential mechanisms of damage have added to the evidence such that many organisations (e.g. US Environmental Protection Agency (https://www.epa.gov/isa); World Health Organization (WHO, 2013a), COMEAP www.comeap.org.uk) consider the evidence strong enough to infer a causal relationship between the adverse health effects and the air pollution concentrations.

The concentration-response functions used and the spatial scales of the input data is given in Table 15, Table 16, Table 17 and Table 18 in the Appendix. The concentration-response functions are based on the latest advice from the Committee on the Medical Effects of Air Pollutants in 2018

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[20] https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013 (Accessed 22 September 2020)
[21] https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory--laei--2016 (Accessed 22 September 2020)
[22] https://consultations.tfl.gov.uk/environment/air-quality-consultation-phase-3b/user_uploads/supporting-information-document-updated-12.12.17.pdf (Accessed 23 October 2020)
https://www.london.gov.uk/sites/default/files/air_quality_in_london_2016-2020_october2020final.pdf (Accessed 16 November 2020)
[23] https://www.london.gov.uk/sites/default/files/london_environment_strategy-_draft_for_public_consultation.pdf (Accessed 23 October 2020).
[24] https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/pm25-london-roadmap-meeting-who-guidelines-2030 (Accessed 22 September 2020).
[25] https://data.london.gov.uk/dataset/statistical-gis-boundary-files-london. (Accessed 21 July 2020).

(COMEAP, 2018a). Results are given with and without a cut-off[26] of 7 µg m^{-3} for $PM_{2.5}$ and 5 µg m^{-3} for NO_2.

Mortality burden calculations

Previously, burden calculations were based only on concentrations of $PM_{2.5}$ (COMEAP, 2010). The new COMEAP report considers whether there is an additional burden or impact from nitrogen dioxide or other pollutants with which it is closely correlated. The method considers both pollutants together, as correlations between the pollutants mean that health studies in the population for either pollutant alone, actually overlaps with the effects of the other pollutant.

Further mortality burden, impacts and air quality (anthropogenic source data) methodology details and health inputs such as population and death data, expected remaining life-expectancy and population at risk can be found in Appendix section 8.5.

Mortality impact calculations

The 2018 COMEAP report includes two options for concentration-response functions for use in impact calculations according to whether the analysis is for a policy or mixture of policies that reduces air pollution (NO_2 and $PM_{2.5}$) as a whole[27] or is for NO_2 specific policy. We considered that the former was more appropriate since the range of policies considered in this study (MAQP -see section below) have an impact on both NO_2 and $PM_{2.5}$ overall. There is no multi-pollutant option for impact calculations because the multi-pollutant model method relies on the balance between the pollutants being similar to that in the original studies. Because specific policies as analysed in impact calculations may change one pollutant much more than another, it was not regarded as appropriate.

A full health impact assessment requires a follow-up of the initial population for a life-time even if the pollution changes are only for the next decade or so. In this study, the health benefits of pollution changes over the period 2013-2050 have been calculated using the full result for gains in life expectancy until everyone in the initial population has died by 2154 (i.e. 105 years from 2050).

This study uses this epidemiological evidence to estimate the health burden of the current (2019) levels of air pollution and the health impacts of the changes in air pollutant concentrations discussed in the air quality modelling section below.

[26] Cut-off is a term used for the concentration below which it is unclear whether or not epidemiological evidence supports the existence of an effect. This does not mean there is no effect below the cut-off, just that the numbers of data points are too small to be sure one way or the other. In addition, this cut-off is based on Pope et al (2002) which in turn used particulate concentrations from many years earlier. As concentrations reduce and newer studies are completed, it is often found that the health effects at lower concentrations become clearer as there are more data points available for analysis at these lower concentrations.

[27] Excluding ozone – COMEAP (2015) concluded there was insufficient information for quantification of effects of long-term exposure to ozone on mortality.

4.0 Results: Air Quality modelling

Epidemiological evidence shows that health impacts are still seen at concentrations below the limit values and WHO guidelines. Tackling pollutant emission sources is therefore essential to improve air quality to meet both the UK limit values and the WHO guidelines, and ultimately to achieve the lowest possible levels of pollution.

4.1 Current Air Quality in 2019 (for Burden calculations)

Analysis of ambient measurements of the central ULEZ, implemented in April 2019, has shown significant air quality improvements within and outside the ULEZ zone[28]. In January 2020, TfL commissioned ERG to provide an estimate of emissions and air quality in 2019 across Greater London (Dajnak et al., 2020b). The dispersion modelling represented a snapshot for 2019 based on provisional measurements data but provided an initial view of air quality in London with the central ULEZ in operation.

A summary of the population weighted average concentration (PWAC from OA to LSOA level) annual mean average concentration in 2019 in London is shown in *Table 1* for anthropogenic $PM_{2.5}$ and NO_2, respectively, with and without the cut-off. The PWAC by borough varied from 10 to 12.6 µg m^{-3} and from 23 to 37.2 µg m^{-3} for anthropogenic $PM_{2.5}$ and NO_2 (without cut-off), respectively (see *Table 20* in Appendix).

Table 1 2019 Anthropogenic $PM_{2.5}$ and NO_2 concentration (in µg m^{-3}) (PWAC annual mean)

Zone	Anthropogenic $PM_{2.5}$ 2019 (Above 7)	NO_2 2019 (Above 5)
Greater London	10.9 (4.2)	28.8 (23.9)

Note the figure in brackets represent the population weighted average concentration (PWAC) annual mean average concentration in 2019 with the cut-off

4.2 Current and future levels of air pollution (2013-2050) (for Impact calculations)

Over the last decade, working with TfL and GLA, ERG have provided estimates of air quality across Greater London area for a range of years and scenarios. In this study, Imperial's experts estimated the health benefits of specific policies over time in London using a range of modelled concentrations scenario profiles over the period 2013-2050 (a baseline and two scenarios (MAQP and WHO), as described in detail below). Note that all air pollution predictions were done pre-COVID-19. This means that it does not take into account the air pollution changes from COVID-19 in 2020. We considered that any analysis taking this into account was best done after the pandemic when a full update could be completed.

Baseline scenario

Mortality impact calculations (in London) in which 2013 modelled concentrations of anthropogenic $PM_{2.5}$ and NO_2 using LAEI 2013 are maintained to 2050

[28] https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/central-london-ulez-six-month-report
https://www.london.gov.uk/sites/default/files/air_quality_in_london_2016-2020_october2020final.pdf

- 2013 (LAEI2013)

Note that 2013 was chosen as a baseline and a start for the impact calculations in this study because it was used in the original MAQP study to project forward all future years up to 2050

Mayor's air quality policies - MAQP scenario

Mortality impact calculations (in London) for a scenario for the projected concentrations of anthropogenic $PM_{2.5}$ and NO_2 over the period 2013-2050 as a result of mayoral air quality policies (including LEZ, ULEZ and LES policies)

- 2013 (LAEI2013)
- 2016 (LAEI2016)
- 2019 Snapshot (including ULEZ brought forward in central London)
- 2020 LEZ for Heavier vehicles London wide (projected from 2013)
- 2021 ULEZ expansion (to inner (north and south circular) area) (projected from 2013)
- 2025 LES (projected from 2013)
- 2030 LES (projected from 2013)
- 2050 LES (projected from 2013)

WHO scenario

Mortality impact calculations (in London) of anthropogenic $PM_{2.5}$ concentrations[29] over the period 2013-2050 as a result of the additional policies[30] to the LES (referred to as LES Plus) designed to meet the WHO (2005) Guideline of 10 µg m^{-3} by 2030

- 2013 (LAEI2013)
- 2016 (LAEI2016)
- 2019 Snapshot (including ULEZ brought forward central)
- 2030 LES (Plus) - $PM_{2.5}$ roadmap to meeting WHO (2005) guidelines by 2030 (projected from 2016)
- 2050 LES (projected from 2013)

Note that the impact of the WHO scenario on other pollutants such as NO_2 was not estimated; the WHO scenario modelling focused solely on predicting $PM_{2.5}$ concentration in London

Note that an alternative 2050 projection based on $PM_{2.5}$ meeting WHO (2005) guidelines by 2030 was not available thus the 2050 LES prediction (from MAQP scenario, above) was used.

Imperial's academics reviewed the regional background $PM_{2.5}$ concentration used in this study based on measurements time-series collected between 2010 and 2019 (See Appendix section 8.4 for more details). Background concentration used in the projected years 2020 to 2050 was estimated using the most recent years available and projected forward (beyond 2019) using the most appropriate (CMAQ-urban) modelling available (See Appendix section 8.4 for more details).

A summary of the population-weighted average concentration (PWAC from OA to Ward level) annual mean average concentration in 2013 to 2050 in London is shown in *Table 2* for anthropogenic $PM_{2.5}$ and NO_2, respectively, with and without the cut-off.

[29] Only $PM_{2.5}$ was commissioned as part of the study "$PM_{2.5}$ in London: roadmap to meeting WHO guidelines by 2030"; NO_2 was not estimated

[30] Introduce a new twenty-first century Clean Air Act, revitalise smoke control zones, create zero emission zones, set tighter minimum emission standards for new wood burning stoves, provide new powers to control NRMM and river/maritime emissions (for more details see section 8.6 in the Appendix)

Table 2 Anthropogenic $PM_{2.5}$ and NO_2 concentration (in µg m^{-3}) (PWAC annual mean)

Zone Greater London	**Anthropogenic $PM_{2.5}$ (Above 7)**	**NO_2 (Above 5)**
2013 (LAEI2013)	15.7 (9.0)	36.2 (31.2)
2016 (LAEI2016)	13.0 (6.3)	36.3 (31.3)
2019 (2019) Snapshot)	11.0 (4.3)	29.2 (24.2)
2020 LEZ	11.8 (5.0)	27.7 (22.7)
2021 ULEZ expansion	11.6 (4.8)	26.3 (21.3)
2025 LES	10.8 (4.0)	21.7 (16.7)
2030 LES	9.8 (3.0)	18.3 (13.3)
2030 LES Plus	7.8 (1.0)	N/A
2050 LES	7.2 (0.4)	12.4 (7.4)

Note that the percentage change of Anthropogenic $PM_{2.5}$ concentration in 2030 LES, 2030 LES Plus (WHO scenario) and 2050 LES (when compared with 2013) is equivalent to 38%, 50% and 54%, respectively. The percentage change of NO_2 concentration in 2030 LES and 2050 LES (when compared with 2013) is equivalent to 49% and 66%, respectively.

Boroughs

PWAC by borough can be found in *Table 23*, *Table 24*, *Table 25* and *Table 26* in the appendix (with further data available on request). The PWAC by borough varied from 14.6-17.9 (7.9-11.2) µg m^{-3} (in 2013) to 6.7-8.6 (0.03-1.8) µg m^{-3} (in 2050) and from 26.8-52.3 (21.8-47.3) µg m^{-3} (in 2013) to 11.5-14.4 (6.5-9.4) µg m^{-3} (in 2050) for anthropogenic $PM_{2.5}$ and NO_2 without cut-off (with cut-off), respectively. The modelled pollution changes evolve with a different time profile in different places and to illustrate the range of the change, we have chosen the difference between pollutant concentrations in 2030 (for both LES (MAQP) and LES Plus (WHO) scenarios) compared with 2013. The change in PWAC (without cut-off) by borough varied by between -11.9 to -28.7 µg m^{-3} (2030 LES compared with 2013) for NO_2 and, for anthropogenic $PM_{2.5}$ between -5.4 to -6.6 µg m^{-3} and between -7.3 to -9.3 µg m^{-3} for both scenarios 2030 LES and 2030-LES Plus compared with 2013, respectively.

5.0 Results: Health Estimates of the mortality burden of air pollution

5.1 Burden background

Burden calculations are a snapshot of the burden in one specific year, assuming that concentrations had been the same for many years beforehand. They are not suitable for calculation in several successive years as they do not have a mechanism for allowing the number of deaths the year before to influence the age and population size the following year as the lifetables used in impact calculations do.

The current (2019) burden and mortality impacts calculations update the 2010 calculations in Walton et al (2015) with both the new methodology in COMEAP (2018a) and new input data for 2019. Similar burden calculations can be found elsewhere (COMEAP, 2010; COMEAP, 2018a; Walton et al., 2015; Dajnak et al., 2018/2019a/2019b/2020a). The concentration-response functions used for these calculations are evolving over time. Previous recommendations favoured methods similar to the single pollutant model approach presented below. The latest COMEAP (2018a) report shows that a majority of the committee supported a new approach using information from multi-pollutant model results but COMEAP (2018a) also recommended using a range to reflect the uncertainty.

The COMEAP (2018a) report explains that single pollutant models relate health effects to just one pollutant at a time, although because pollutants tend to vary together, they may in fact represent the effects of more than one pollutant. Single pollutant models for different pollutants cannot therefore be added together as there may be substantial overlap.

The report goes on to explain that multi-pollutant models aim to disentangle the effects of separate pollutants, but this is difficult to do. Despite the best attempts, it may still be the case that some of the effect of one pollutant 'attaches'[31] to the effects ascribed to another pollutant, leading to an underestimation of the effects of one pollutant and an overestimation of the effects of another. In this situation, the combined effect across the two pollutants should give a more reliable answer[32] than the answers for the individual pollutants that may be over- or under-estimated. This was the basis for the approach described below, including adding results derived from information within each of 4 separate studies first, before combining them as a range. The intention is not to present the individual pollutant results separately as final results, although the calculations for individual pollutants are done as intermediate stages towards the overall results.

Burden calculations include accompanying estimates of the burden of life years lost[33]. Life years lost calculations are based on the average loss of life expectancy by age (in this case by - year age group) and gender for calculations in each LSOA.

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[31] More formally this is known as 'effect transfer' and is usually caused by exposure measurement error. The direction of the transfer is from the more poorly to the better measured pollutant.

[32] This is certainly true for estimates based on the interquartile range within an individual study. However, application to situations where the ratio between the interquartile ranges for the two pollutants differs from that in the original study may exaggerate the contribution of one pollutant over another. The views of COMEAP members differed on how important this issue might be in practice, with the majority considering that a recommended approach on the basis of combined multi-pollutant model estimates could still be made provided caveats were given.

[33] Burden life years lost represent a snapshot of the burden in one year and are not to be confused with the full calculation of the life years lost for the health impact of air pollution concentration changes over time.

The calculations are based on deaths from all causes including respiratory, lung cancer and cardiovascular deaths, the outcomes for which there is strongest evidence for an effect of air pollution.

5.2 Combined estimate for $PM_{2.5}$ and NO_2 using multi-pollutant model results

Greater London

Using the exploratory new combined method (COMEAP, 2018a) gives an estimate for the 2019 mortality burden in London of 2019 levels of air pollution (represented by anthropogenic $PM_{2.5}$ and NO_2) to be equivalent to 3,600 to 4,100 attributable deaths (or 61,800 to 70,200 life year lost[34]) at typical ages. When cut-offs for each pollutant were implemented, the result was equivalent to 2,220 to 2,630 deaths (or 38,300 to 45,300 life years lost) (see Table 3). The results for males are somewhat greater than for females, due to the higher baseline mortality rate in males.

These results use recommendations from COMEAP, 2018a. For each of the four individual cohort studies that included multi-pollutant model results[35], the burden results were estimated separately using mutually adjusted summary coefficients for $PM_{2.5}$ and NO_2 and then the adjusted $PM_{2.5}$ and NO_2 results were summed to give an estimated burden of the air pollution mixture. Example of the calculations for each study for Greater London of 2019 levels of NO_2 and $PM_{2.5}$ can be found in the appendix in Table 30. The uncertainty of each separate study was not quantified (COMEAP, 2018a) but it is worth noting that each of the individual results also has uncertainty associated with it.

Table 3 Estimated burden (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies) of effects on annual mortality in 2019 of 2019 levels of anthropogenic $PM_{2.5}$ and NO_2 (without and with cut-off)

Zone **Greater London**	**Anthropogenic $PM_{2.5}$ and NO_2 (without cut-off)**	**Anthropogenic $PM_{2.5}$ and NO_2 (with cut-off)**
	Attributable deaths (using coefficients derived from information in 4 studies below*) (Life years lost)**	**Attributable deaths (using coefficients derived from information in 4 studies below*) (Life years lost**)**
Total (male and female)	3,598 - 4,096 (61,818 - 70,224)	2,220 - 2,627 (38,308 - 45,313)
Male	1,811 – 2,060 (32,731- 37,157)	1,119 - 1,324 (20,305 - 24,019)
Female	1,787 - 2,036 (29,087 - 33,067)	1,101 - 1,302 (18,002 - 21,294)

*Using COMEAP's recommended concentration-response coefficients of 1.029, 1.033, 1.053 and 1.019 per 10 µg m^{-3} of anthropogenic $PM_{2.5}$ derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

*Using COMEAP's recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 µg m^{-3} of NO_2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for $PM_{2.5}$ from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies, respectively

** Associated life years lost, age 30+ and calculated by gender and 1-year age groups, by LSOA then summed up to Wards/boroughs/Greater London level.

[34] These are the numbers of years across the population expected to be lived over time if the deaths to which particulate and NO_2 pollution contributed had not occurred.

[35] Some further cohort studies were omitted because of high correlations between pollutants (see COMEAP (2018a)

Boroughs

The upper attributable deaths results for no cut-off varied by boroughs by a factor of about 2.5 (from 77 to 204, excluding the City of London (4 attributable deaths) which has a very small and young resident population, the modelling does not account for exposure of the much larger daytime population of the City). The full list of results by borough is given in the Appendix in *Table 21* and *Table 22*. For context, the total number of deaths (irrespective of a contribution from air pollution) across boroughs (excluding the City of London) ranged from 801 – 2633. Table 4 below provides the 4 highest and 4 lowest results for the upper result for no cut-off for illustration (note the choice of 4 is arbitrary, with other boroughs only just below the top 4 and only just above the bottom 4). The purpose of this table is to illustrate some factors that drive the differences between boroughs that can then help with interpretation of the full list. The results are influenced by the size of the population, pollutant concentrations and variations in death rates by LSOA in each borough, which in turn are driven in part by the proportion of elderly in the population and the level of deprivation. For example, the City of London has the lowest burden but once its small population is taken into account, the air pollution attributable deaths per 10,000 population is in the middle of the list. It might be expected that it would be higher, given the pollution levels are the highest. The reason is that the baseline mortality rate is low, which, in turn, is due to the higher proportion of young people. Conversely, Havering and Bromley have the lowest pollution levels but are high on the mortality burden list, particularly on a per 10,000 population basis. This is because they have higher baseline mortality rates, in turn due to higher proportions of the population in older age groups and lower proportions in younger age groups. The columns in Table 4 give only a partial snapshot of this. It is best illustrated by examining the full population age pyramids[36].

It is outside the scope of this particular project to examine the influence of deprivation, but it should be noted that areas of deprivation may have a younger population[37]. This will probably counter to some extent the higher mortality in deprived areas for equivalent age groups. Understandably, age is a very strong driver of mortality rates so this can have more influence on the air pollution mortality burden than other factors.

The same factors are likely to influence the ranking of results for examples other than the maximum, no cut-off, multi-pollutant model estimate result. The influence of age will be slightly less for the life-year results because the numbers in each age group are multiplied by the expected remaining life-expectancy and this is lower in older age groups. For other examples, the influence of pollution levels will be slightly reduced, either because the relative risk is lower (lower option for no cut-off multi-pollutant estimates) or because the pollution difference is lower (cut-off options).

[36]https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/articles/ukpopulationpyramidinteractive/2020-01-08

[37] For example, in Tower Hamlets, 2.3% of the population are age 24; 2.3% age 35 and only 0.2% age 75.

Table 4 Comparisons between local authorities with largest and smallest results for attributable deaths (maximum Multi Pollutant approach, no cut-off, male and female combined, as an example)

Local Authority	Attributable deaths (AD) MP max	AD per 10,000 population (rank)	PWAC NO_2 (rank)	PWAC anthro-pogenic $PM_{2.5}$ (rank)	Baseline mortality rate per 10,000 population[a] (rank)	Age distribution (% pop all ages)[b]		
						25	35	75
Greater London	4,100	7.8	28.8	10.9	91.6			
Borough mean	124	7.8	29.1	11.0	90.8			
Bromley	204	9.5 (3)	23.6 (32)	10.1 (32)	122.7 (3)	1.1	1.4	0.8
Barnet	201	8.4 (7)	28.5 (18)	10.8 (18)	100.1 (10)	1.3	1.7	0.6
Croydon	196	8.3 (8)	25.5 (29)	10.4 (29)	104.8 (7)	1.2	1.5	0.6
Havering	178	11.0 (1)	23.0 (33)	10.0 (33)	147.2 (1)	1.3	1.4	0.7
Kingston upon Thames	87	8.2 (10)	26.7 (24)	10.5 (26)	100.5 (9)	1.4	1.7	0.6
Hammersmith and Fulham	82	7.5 (21)	31.9 (7)	11.4 (9)	81.9 (21)	2.0	1.9	0.4
Kensington and Chelsea	77	7.5 (22)	34.6 (3)	11.9 (4)	77.4 (23)	1.5	1.7	0.7
City of London	4	7.7 (16)	37.2 (1)	12.6 (1)	73.1 (28)	2.6	1.3	0.7

[a] Calculated from the same data used for the burden calculations i.e. summed from 3 year average deaths and population data per LSOA. It therefore may not match mortality rates from other sources which may be for a single year and a different geographical scale.

[b] Read off the ONS interactive population pyramids giving the percentage of the total population in each age group (here age 25, 35 and 75). For reference see footnote[36].

Wards

As expected, the pollution levels by Ward vary more than by local authority (2-fold and 1.5-fold for NO_2 and $PM_{2.5}$ respectively, compared with 1.7- and 0.7-fold for local authorities). Bringing in variations in the other inputs to the attributable deaths calculations exaggerated the variation in numbers of attributable deaths compared with local authorities (details in accompanying file). The maximum, no cut-off, multi-pollutant model estimate result varies from 1.4 to 16.4 attributable deaths (about 12-fold); the minimum, no cut-off from 1.1 to 12.3; the maximum, with cut-off from 1.0 to 9.8 and the minimum, with cut-off from 0.8 to 8.3. The ranges for life years lost are similarly greater than for local authorities (e.g. 8-fold variation for the maximum, no cut-off, multi-pollutant estimate result).

As with local authorities, wards in outer London tend to have larger results (*Figure 3* and *Figure 4*). It can also be seen that age distribution has an influence because the contrast between outer and inner London is less for life years lost (which assigns fewer life years lost (expected remaining life expectancy) per death with increasing age). However, it is worth noting that there can be substantial variation across wards within particular local authorities covering significant parts of the range across the wards as a whole.

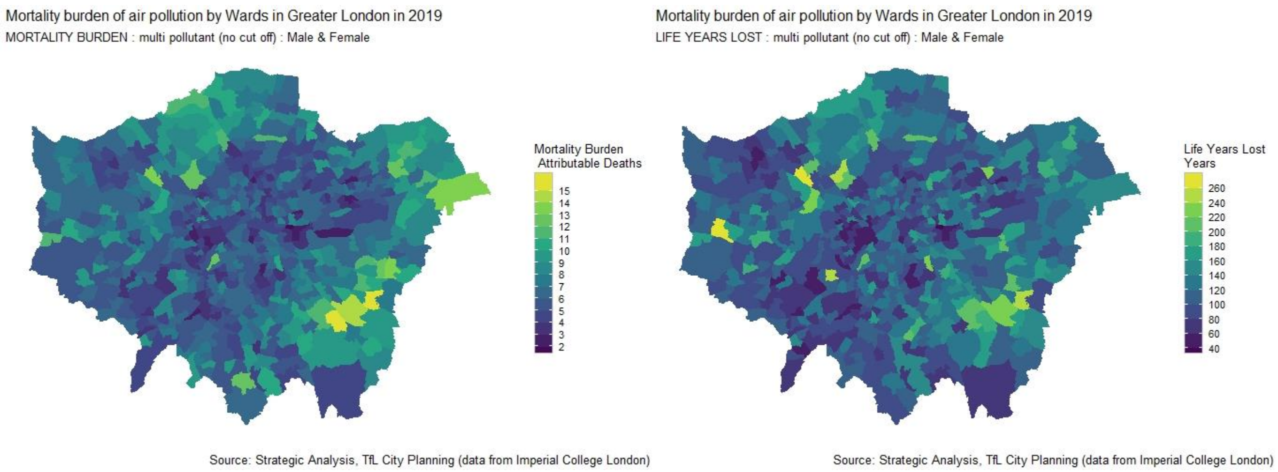

Figure 3 Mortality burden (map left) and life years lost (map right) of air pollution by wards (largest attributable deaths *and life years lost* of the multiple-pollutant model approach) *in Greater London in 2019 (no cut-off)*

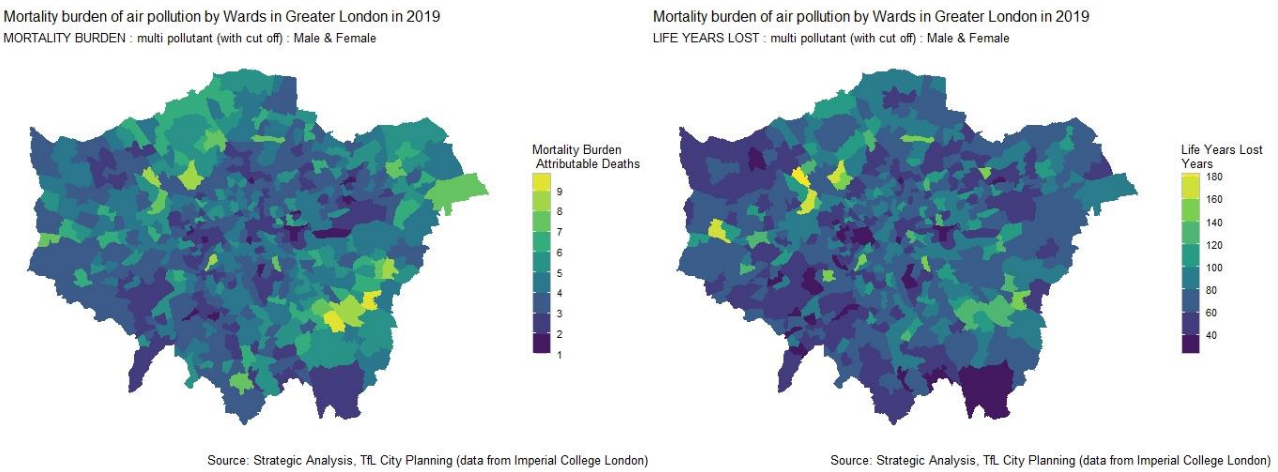

Figure 4 Mortality burden (map left) and life years lost (map right) of air pollution by wards (largest attributable deaths *and life years lost* of the multiple-pollutant model approach) *in Greater London in 2019 (with cut-off)*

5.3 Single pollutant model estimates

Greater London

The single-pollutant model for $PM_{2.5}$ estimates that Greater London's 2019 levels of anthropogenic $PM_{2.5}$ would lead to effects equivalent to 2,960 (range[38] 2,010 to 3,860) attributable deaths (or 50,600 range 34,400 to 66,100 life years lost) at typical ages. Implementing the cut-off gave results equivalent to 1,140 (range 770 to 1,500) deaths (or 19,600 range 13,200 to 25,800 life years lost). (see Table 5). This result represents effects of the regional pollution mixture and partially represents the contribution from traffic pollution.

The lower and upper estimates in Table 5 are based on the 95% confidence intervals (1.04 – 1.08) around the pooled summary estimate (1.06) for the increase in risk from Hoek et al (2013). COMEAP

[38] From the 95% confidence interval around the coefficient.

recently agreed to use this range (COMEAP, 2018b) rather than the wider ones of 1.01 – 1.12 in the original COMEAP (2010) report. Nonetheless, the wider ones remain reflective of the fact that the uncertainties are wider than just the statistical uncertainty represented by the confidence intervals. We have included results for this wider range of uncertainty in Table 19 of the Appendix but as a rough guide the range goes from around a sixth to around double the central estimate in Table 5.

Table 5 Estimated burden (from single-pollutant model summary estimate) of effects on annual mortality in 2019 of 2019 levels of anthropogenic $PM_{2.5}$ (representing regional pollution, and partially representing traffic pollution, without and with cut-off)

Zone **Greater London**	**Anthropogenic $PM_{2.5}$ (without cut-off)**			**$PM_{2.5}$ (with cut-off)**		
	Attributable deaths (Life year lost*)			**Attributable deaths (Life year lost*)**		
	Central estimate	**Lower estimate**	**Upper estimate**	**Central estimate**	**Lower estimate**	**Upper estimate**
Total (male and female)	2,955 (50,556)	2,010 (34,384)	3,864 (66,099)	1,136 (19,601)	768 (13,247)	1,495 (25,787)
Male	1,485 (26,732)	1,010 (18,181)	1,941 (34,950)	573 (10,388)	387 (7,021)	754 (13,666)
Female	1,471 (23,824)	1,000 (16,203)	1,923 (31,149)	563 (9,213)	381 (6,226)	741 (12,121)

Using COMEAP's recommended concentration-response coefficient of 1.06 per 10 $\mu g\ m^{-3}$ of anthropogenic $PM_{2.5}$ for the central estimate (lower estimate RR of 1.04 and upper estimate RR 1.08)

* Associated life years lost, age 30+ and calculated by gender and 1 year age groups, by LSOA then summed up to Wards/boroughs/Greater London level.

These results (see *Table 5* central estimate results) use recommendations from COMEAP, 2010 and, for the central estimate, is the same as used for $PM_{2.5}$ in Walton et al. (2015). In addition, Walton et al. (2015) used WHO (2013b) recommendations that included recommendations for nitrogen dioxide to provide estimates for London. The results were presented as a range from $PM_{2.5}$ alone to the sum of the $PM_{2.5}$ and NO_2 results, but the uncertainty of the latter was emphasized. Since then it has become clearer that the overlap is likely to be substantial (COMEAP, 2015). COMEAP (2018a) concluded that the combined adjusted coefficients were similar to, or slightly larger than, the single-pollutant association reported with either pollutant alone.

In addition to the combined multi-pollutant model derived estimates in the section above, the COMEAP (2018a) report suggests also calculating the burden using the single pollutant model result for NO_2 (this may represent the burden of traffic pollution more clearly than that of $PM_{2.5}$). They also suggested taking the largest of the two single-pollutant model estimates for comparison with the multi-pollutant model estimates. This is because they are in any case likely to be underestimates. The results give estimates that Greater London's 2019 levels of NO_2 lead to effects equivalent to 3,000 (range[39] 1,070 to 4,700) attributable deaths (or 51,600 range 18,500 to 80,900 life year lost) at typical ages, or results equivalent to 2,500 (range 890 to 3,910) deaths (or 42,900

[39] From the 95% confidence interval around the coefficient.

range 15,300 to 67,400 life year lost) when the cut-off was implemented (see Table 6). This is larger than the result for $PM_{2.5}$.

Table 6 Estimated burden (from single pollutant model summary estimate) of effects on annual mortality in 2019 of 2019 levels of NO_2 (as an indicator of traffic pollution, with and without cut-off)

Zone **Greater London**	**NO_2 (without cut-off)** **Attributable deaths (Life year lost*)**			**NO_2 (with cut-off)** **Attributable deaths (Life year lost*)**		
	Central estimate	**Lower estimate**	**Upper estimate**	**Central estimate**	**Lower estimate**	**Upper estimate**
Total (male and female)	2,999 (51,606)	1,073 (18,474)	4,700 (80,859)	2,484 (42,850)	886 (15,285)	3,906 (67,358)
Male	1,510 (27,337)	541 (9,787)	2,367 (42,830)	1,252 (22,714)	447 (8,103)	1,969 (35,703)
Female	1,489 (24,269)	533 (8,687)	2,333 (38,029)	1,232 (20,136)	439 (7,182)	1,937 (31,655)

Using COMEAP's recommended concentration-response coefficient of 1.023 per 10 µg m^{-3} of NO_2 for the central estimate (lower estimate RR of 1.008 and upper estimate RR 1.037)

* Associated life years lost, age 30+ and calculated by gender and 1-year age groups, by LSOA then summed up to Wards/boroughs/Greater London level.

Boroughs

For the single pollutant model options, the influence of pollution differences is likely to be lower than for the maximum, no cut-off, multi-pollutant estimates. For the $PM_{2.5}$ single-pollutant model estimates, this is because it is more spatially homogenous than combining $PM_{2.5}$ and NO_2; for the NO_2 single-pollutant model estimates, it is because the relative risk is much smaller relative to the combined approach.

Wards

The general message is similar for wards (see *Figure 5*). Note that the highest of the two single pollutant model estimates for no cut-off is often but not always NO_2. With a cut-off, it is always NO_2 (because the cut-off is further down the current range of concentrations than cut-off for $PM_{2.5}$ (which is derived from older studies).

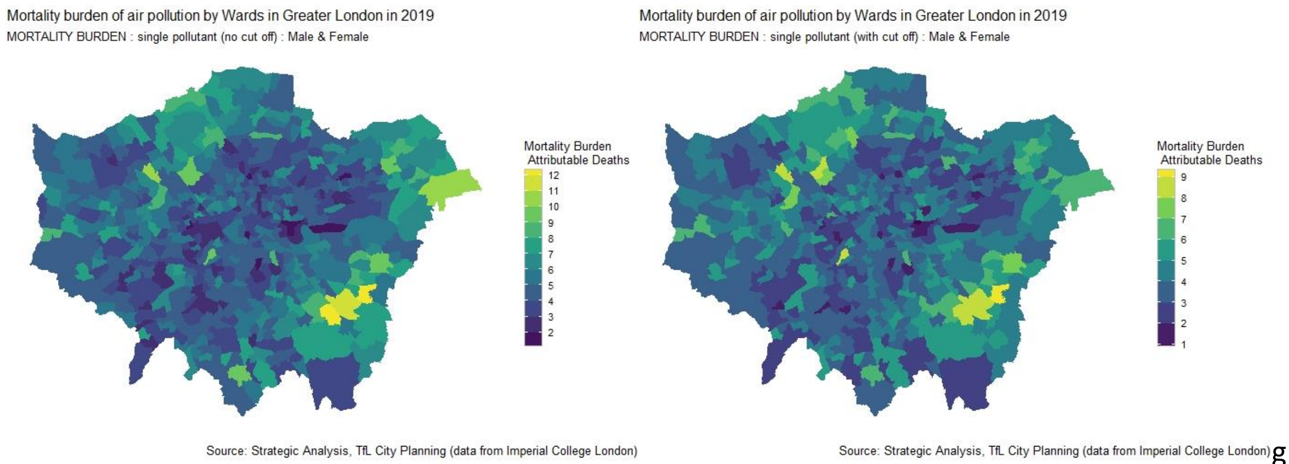

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Figure 5 Mortality burden of air pollution by wards (largest attributable deaths of the two single-pollutant models) *in Greater London in 2019; no cut-off (map left) and with cut-off (map right)*

6.0 Results: Health Estimates of the mortality impact of air pollution

6.1 Mortality impact background

Impacts in the next section are all expressed in terms of life years – the most appropriate metric for the health impact of air pollution concentration changes over time. This used a full life-table approach rather than the short-cut method used for burden and the data for these calculations had already been incorporated for previous work (Walton, 2015, Williams et al., 2018a and Dajnak et al., 2018/2019a/2019b/2020a).

Calculations are first given for $PM_{2.5}$ and NO_2 separately. Because air pollutants are correlated with each other, the air pollutant concentrations in the health studies represent both the pollutants themselves but also other air pollutants closely correlated with them. Health impacts from changes in $PM_{2.5}$ and NO_2 represent the health impacts of changes in the air pollution mixture in slightly different ways that overlap i.e. they should not be added. This is discussed further in this section.

6.2 Mortality impact of the Mayoral Air Quality Policies (MAQP scenario)

Table 7 shows the results from the life table calculations for anthropogenic $PM_{2.5}$ and NO_2 assuming (i) that the concentration does not reduce from 2013 levels or (ii) that the predicted concentrations changed between 2013 and 2050 (concentrations were modelled at 2013, 2016, 2019, 2020, 2021, 2025, 2030 LES and 2050 but also interpolated for the intervening years; see *Table 2*).

The life years lost give a large number because the life years (one person living for one year) is summed over the whole population in London over 142 years (2013 to 2154). For context, the total life years lived with baseline mortality rates over this period is around 1.5 billion, so these losses of life years involve about 0.5% of total life years lived.

If 2013 concentrations of anthropogenic $PM_{2.5}$ remained unchanged for 142 years, around 6.4 – 11.2 million life years would be lost across London's population over that period. This improves to around 0.8 – 5.7 million life years lost with the predicted concentration changes between 2013 and 2050 for the Mayor's air quality policies scenario examined here.

Another way of representing the health impacts if air pollution concentrations remained unchanged (in 2013) compared with the projected future changes of air pollution up to 2050 (projected from 2013) is provided by the results for NO_2. If 2013 concentrations of NO_2 remained unchanged for 142 years, around 8.7 – 10.1 million life years would be lost across London's population over that period. This improves to around 2.6 – 4 million life years lost with the predicted concentration changes between 2013 and 2050 for the Mayor's air quality policies scenario examined here.

A wider range of uncertainty around the results can be found in *Table 7* (for both anthropogenic $PM_{2.5}$ and NO_2 and represented by lower and upper estimates based on the 95% confidence intervals for the concentration-response functions).

Summarising these results is not easy. The results should not be added as there is considerable overlap. On the other hand, either result is an underestimate to some extent as it is missing the impacts that are better picked up in the calculations using the other pollutant. COMEAP (2017, 2018a) suggested taking the larger of the two alternatives in the calculation of benefits. We have interpreted this as the larger of the two alternatives ($PM_{2.5}$ or NO_2) in the case of each calculation.

Note that this means that the indicator pollutant changes in different circumstances. In the case above, for no cut-off, this is the result for $PM_{2.5}$ (5.7 vs 4 million life years lost for NO_2). However, for the cut-off, this is the result for NO_2 (2.6 vs 0.7 million life years lost for $PM_{2.5}$). Other interpretations e.g. keeping the same indicator pollutant with and without a cut-off, are possible. All the relevant data are in the tables to enable creation of summaries in a different form.
So, the **overall summary** for the projected future changes in air pollution concentrations up to 2050 (projected from 2013) would be around **2.6 to 5.7 million life years lost** for the population of London over 142 years.

Table 7 Total life years lost across London population for anthropogenic $PM_{2.5}$ and NO_2 for the baseline and the MAQP scenario

Pollutant	**Scenario**	**Life years lost without cut-off (with cut-off)**		
		Central estimate	**Lower estimate**	**Upper estimate**
Anthropogenic $PM_{2.5}$ (representing the regional air pollution mixture and some of the local mixture)	Baseline: concentration does not reduce from 2013 levels	11,216,303 (6,429,953)	7,573,725 (4,335,705)	14,767,020 (8,477,579)
	MAQP scenario: predicted concentration 2013 - 2050	**5,678,505** (778,311)	3,828,738 (524,434)	7,487,415 (1,026,923)
NO_2 (representing the local mixture and the rural air pollution mixture)	Baseline: concentration does not reduce from 2013 levels	10,112,667 (8,727,251)	3,564,362 (3,073,664)	16,066,646 (13,876,322)
	MAQP scenario: predicted concentration 2013 - 2050	4,038,278 (**2,638,265**)	1,419,057 (926,644)	6,435,237 (4,206,176)

For anthropogenic $PM_{2.5}$ assuming no net migration, with projected new births, 2013-2154, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.06 per 10 $\mu g\ m^{-3}$ of anthropogenic $PM_{2.5}$ without cut-off and with 7 $\mu g\ m^{-3}$ cut-off[40], with lags from the USEPA.
For NO_2 assuming no net migration, with projected new births, 2013-2154, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.023 per 10 $\mu g\ m^{-3}$ of NO_2 without cut-off and with 5 $\mu g\ m^{-3}$ cut-off, with lags from the USEPA.
(Results with cut-offs do not extrapolate beyond the original data, results with no cut-off represent the possibility that there are effects below the cut-off value (it is unknown whether or not this is the case).)
The upper and lower estimates are based on the 95% confidence intervals for the concentration-response functions and not other uncertainties.

[40] It is possible that this cut-off will be defined at a value lower than 7 $\mu g\ m^{-3}$ in the future as this is based on a 2002 study by Pope et al (2002) which in turn used particulate concentrations from many years earlier. As concentrations reduce and newer studies are completed, it is often found that the health effects at lower concentrations become clearer as there are more data points available for analysis at these lower concentrations. The concentration-response function and its confidence intervals have been updated using a 2013 meta-analysis by Hoek et al (the central estimate happened to remain the same). The cut-off has not so far been updated to reflect the range of the data in the meta-analysis.

Figures in bold are the larger of the alternative estimates using $PM_{2.5}$ or NO_2, as summarized in the headline results. Note that the comparison for which is largest for the predicted concentration changes is across the results either without a cut-off (first row in each cell; 5,678,505 vs 4,038,278) or with a cut-off (second row in each cell; 2,638,265 vs 778,311) using Life year lost of predicted concentration between 2013 and 2050 results as an example.

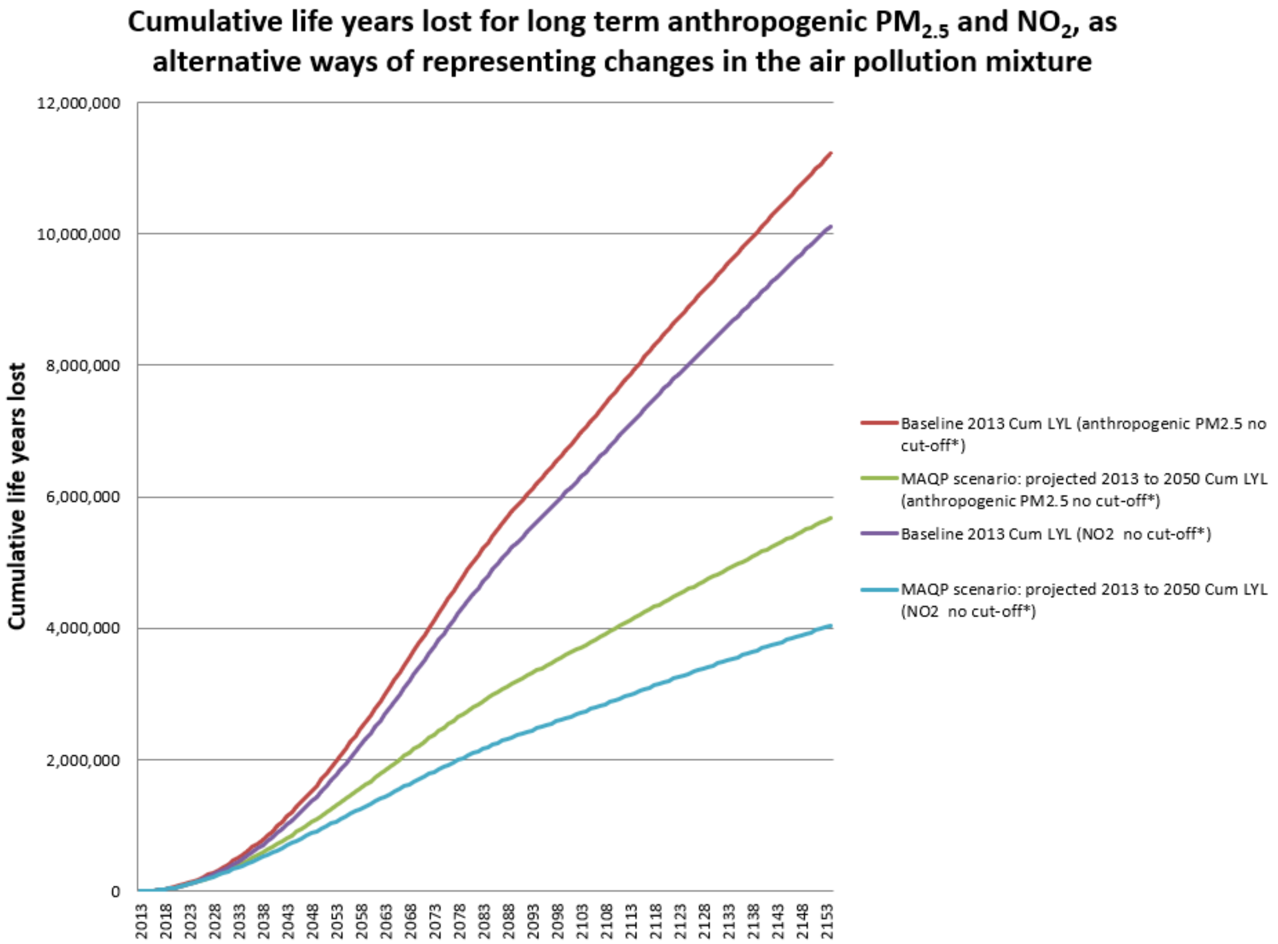


Figure 6 Cumulative life years lost for anthropogenic $PM_{2.5}$ and NO_2 if 2013 concentrations remained unchanged and the MAQP scenario (current and future policies 2013-2050) across London population (no migration), with projected new births, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) 2013-2154. RR 1.06 per 10 µg m^{-3} for anthropogenic $PM_{2.5}$ and RR 1.023 per 10 µg m^{-3} for NO_2, EPA lag. Counterfactual is zero concentrations for NO_2 and non-anthropogenic concentrations for $PM_{2.5}$.

* Cut-off results not shown

Figure 6 shows that the cumulative life years lost for the predicted concentration between 2013 and 2050 accumulates more slowly than the constant 2013 concentration results for both anthropogenic $PM_{2.5}$ and NO_2 as a result of the MAQP scenario reduced concentrations from 2013 to 2050. It is worth remembering that there is a delay before the full benefits of concentration reductions are achieved. This is not just due to a lag between exposure and effect, but also because the greatest gains occur when mortality rates are highest i.e. in the elderly.

Table 8 shows the differences in life years between the predicted concentrations between 2013 and 2050 and both particulate levels and NO_2 concentration constant at 2013 levels. Using $PM_{2.5}$ as an indicator of the regional pollution and some of the local pollution mixture gives an estimate of 5.5 to 5.7 million life years gained as a result of the predicted concentration changes between 2013 and 2050. Using NO_2 as an indicator of mostly the local pollution mixture and some of the rural pollution gives a slightly higher estimate of 6.1 million life years gained, although the $PM_{2.5}$ concentration response function (see *Table 15*) is much stronger than for NO_2 (RR 1.06 per 10 µg m^{-3} for anthropogenic $PM_{2.5}$ and RR 1.023 per 10 µg m^{-3} for NO_2). This makes sense because the concentrations projected (2013 to 2050) suggests more continuous declines in NO_2 concentrations (likely to be mostly due to the improvement in NO_X emissions of large parts of the road transport sector) than for $PM_{2.5}$. This also reflects the fact that PM reduction from traffic is not larger due to the increasing contribution from non-exhaust emissions[41] and also that the declines in regional $PM_{2.5}$ are relatively small.

The **overall summary** would be that taking into account predicted air pollution concentration changes between 2013 and 2050, the population in London would **gain around 6.1 million life years** over a lifetime.

Table 8 Life years saved across the London population of the predicted concentration between 2013 and 2050 compared with 2013 anthropogenic $PM_{2.5}$ concentrations and NO_2 remaining unchanged

Pollutant	**Scenario**	**Total life years saved compared with 2013 concentrations maintained without cut-off (with cut-off)**		
		Central estimate	**Lower estimate**	**Upper estimate**
Anthropogenic $PM_{2.5}$ (representing the regional air pollution mixture and some of the local mixture)	Predicted concentration between 2013 and 2050	5,537,798 (5,651,641)	3,744,987 (3,811,271)	7,279,606 (7,450,655)
NO_2 (representing the local mixture and the rural air pollution mixture)	Predicted concentration between 2013 and 2050	**6,074,389** (**6,088,986**)	2,145,305 (2,147,020)	9,631,408 (9,670,145)

Figures in bold are the larger of the alternative estimates using $PM_{2.5}$ or NO_2, as summarized in the headline results. Note that the comparison for which is largest for the predicted concentration changes is across the results either without a cut-off (first row in each cell; 6,074,389 vs 5,537,798) or with a cut-off (second row in each cell; 6,088,986 vs 5,651,641) using total life years saved compared with 2013 concentrations maintained as an example.

[41] Particle traps/DPF already reduced most PM exhaust emissions from Traffic

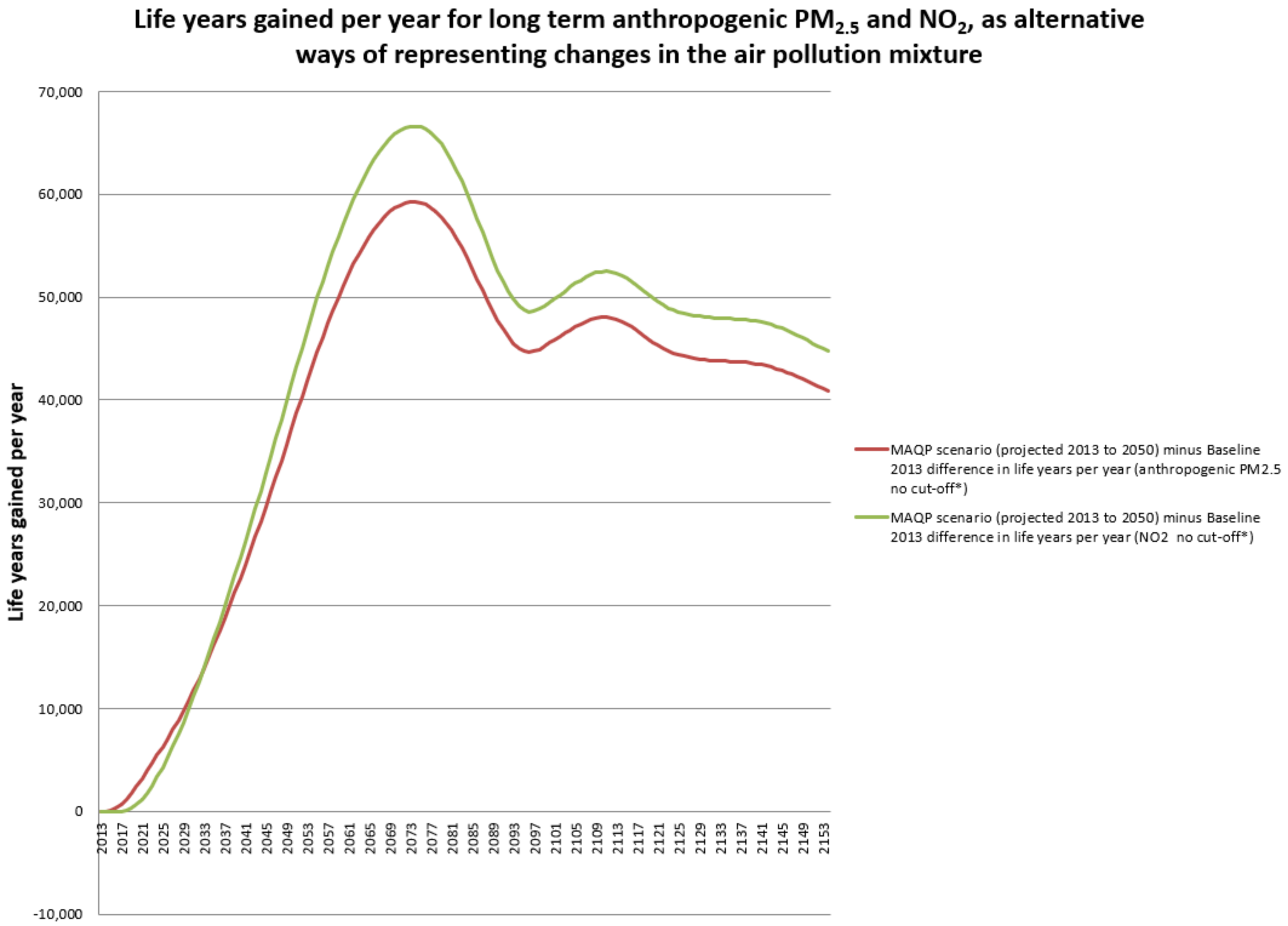


Figure 7 Life years gained per year from long-term exposure to the improvements in pollution from 2013 to 2050 (MAQP scenario) of anthropogenic $PM_{2.5}$ and NO_2 relative to 2013 concentrations remaining unchanged

* Cut-off results not shown

Figure 7 shows the effect of the decrease in $PM_{2.5}$ and NO_2 concentration from 2013 to 2050 (as seen in *Table 2*). Note the delay in LY gained at the start of the NO_2 curve due to the slight increase in NO_2 in 2016 (compared with the NO_2 concentration in 2013). In later years, though, the gains are greater for NO_2, despite the smaller concentration-response function for $NO_2$and mortality, due to the larger concentration reductions shown in Table 2.

Boroughs

Table 9 shows the range of the differences in life years across London boroughs between the predicted concentrations between 2013 and 2050 and both particulate levels and NO_2 concentrations constant at 2013 levels. For no cut-off, the life years gained in London boroughs varied from 87,088 – 242,764 using anthropogenic $PM_{2.5}$ as an indicator of the changes in the pollution mixture (excluding the City of London, which has a much lower population) and from 90,372 – 286,095 using NO_2 as an indicator of the changes in the pollution mixture (again excluding the City of London). The larger result in each borough was often that for NO_2 but it was $PM_{2.5}$ for several outer London boroughs. The range for the largest answer in each borough was 92,405 – 286,095 life years gained (the lower end of this range being the second lowest result for $PM_{2.5}$ as the lowest one was exceeded by the answer for NO_2). The ranking of the results for the boroughs did not entirely follow the ranking of the concentration changes for 2030 compared with 2013 (as an example), probably due to differences in population size. Further comparisons across boroughs are better discussed in relation to life expectancy (section 6.3) as this is independent of population size. The results with a cut-off were lower than the results for no cut-off (see *Table 27* in Appendix).

Table 9 Range of life years saved across London boroughs of the predicted concentrations between 2013 and 2050 compared with 2013 anthropogenic $PM_{2.5}$ concentrations and NO_2 remaining unchanged

Pollutant	**Scenario**	**Range of life years saved across boroughs compared with 2013 concentrations maintained without cut-off Central estimate**
Anthropogenic $PM_{2.5}$ (representing the regional air pollution mixture and some of the local mixture)	Predicted concentration between 2013 and 2050	87,088 – 242,764
NO_2 (representing the local mixture and the rural air pollution mixture)	Predicted concentration between 2013 and 2050	90,372 – 286,095

Wards

The factors influencing results for Wards are likely to be similar to those described for boroughs above and in the sections on gains in life expectancy for the MAQP scenario and gains in life years and life expectancy for the WHO scenario. These are not presented here but will be available on request. There may be more variation across Wards than across boroughs according to whether air pollution concentration change variations and baseline mortality rate variations line up with each other or not.

6.3 Life-expectancy from birth in 2013 - MAQP scenario

Total life years across the population is the most appropriate metric for cost-benefit analysis of policies as it captures effects in the entire population. However, it is a difficult type of metric to communicate as it is difficult to judge what is a 'small' answer or a 'large' answer. Life-expectancy from birth is a more familiar concept for the general public, although it only captures effects on those born on a particular date. Results for life expectancy from birth are shown in Table 10.

The average loss of life expectancy from birth in London would be about 26 – 46 weeks for males and 23 – 40 weeks for females if 2013 $PM_{2.5}$ concentrations were unchanged but improves to 1 – 21 weeks for males and 1 – 19 weeks for females for the predicted concentration changes between 2013 and 2050 (an improvement by about 22-25 weeks).

Using NO_2, the average loss of life expectancy from birth in London would be about 36 – 41 weeks for males and 31 – 36 weeks for females if NO_2 concentrations were unchanged from 2013 but improves by about 24-27 weeks to 9 – 14 weeks for males and 8 – 13 weeks for females with projected future changes between 2013 and 2050 included.

The **overall summary** would be that the projected future changes provide an **improvement** in average **life expectancy** from birth in 2013 **of around 5 – 6 months** (22 – 27 weeks) but an average **loss of life expectancy** from birth in 2013 **of around 2 to 5 months** (8 – 21 weeks) (compared with no human-made pollution) remains even with the reduced concentrations. Males are more affected than females – this is mainly due to the higher mortality rates in men compared with women rather than differences in air pollution exposure. The concentration-response function is implemented as a percentage change in baseline mortality rates. If the baseline mortality rates are higher, then the absolute impact is higher even though the percentage change is the same.

Table 10 Loss of life expectancy by gender across London from birth in 2013 (followed for 105 years) for anthropogenic $PM_{2.5}$ and NO_2

Pollutant	**Scenario**	**Loss of life expectancy from birth compared with baseline mortality rates, 2013 birth cohort (in weeks) without cut-off (with cut-off)**		**Percentage gain of life expectancy from birth compared with baseline mortality rates, 2013 birth cohort (in weeks) without cut-off (with cut-off)**	
		Male	**Female**	**Male**	**Female**
Anthropogenic $PM_{2.5}$	Concentration does not reduce from 2013 levels	45.8 (26.3)	40.1 (23.0)		
	Predicted concentration between 2013 and 2050	**21.3** (1.2)	**18.6** (1.0)	**53%** (95%)	**54%** (96%)
NO_2	Concentration does not reduce from 2013 levels	41.3 (35.6)	36.1 (31.1)		
	Predicted concentration between 2013 and 2050	14.3 (**8.6**)	12.6 (**7.5**)	65% **(76%)**	65% **(76%)**

Figures in bold are the larger of the alternative estimates using $PM_{2.5}$ or NO_2, as summarized in the headline results. Note that the comparison for which is largest for the predicted concentration changes is across the results either without a cut-off (first row in each cell; 21.3 vs 14.3) or with a cut-off (second row in each cell; 8.6 vs 1.2) using Male results as an example.

Additional data such as the loss of life expectancy lower and upper estimates and the full range of confidence intervals with and without the counterfactual for both $PM_{2.5}$ and NO_2 are available upon request to the authors.

Boroughs

The life expectancy gains across boroughs ranged from 117-249 days (17-36 weeks) using NO_2 (no cut-off) as an indicator of the air pollution changes and 138-179 days (20-26 weeks) using $PM_{2.5}$ (no cut-off) as an indicator of the air pollution changes. Results for the full list of boroughs is given in Table 28 in the Appendix. Table 11 and Table 12 below give the results for the top 4 and bottom 4 boroughs for both gains in life years and gains in life expectancy. (The choice of 4 is arbitrary, there are boroughs just below the top 4 and just above the bottom 4.) The purpose of the tables is to illustrate some factors that influence the results. It can be seen that the top 4 and bottom 4 are different for the gain in life expectancy compared with those for the gain in life years. Population size is probably one of the main factors behind this as life expectancy from birth is independent of population size (it divides the life years gained in those born in 2013 by the size of the birth cohort in 2013). For mortality burden the results could be divided by the total population as it was for just one year. For life years over an extended period this is complicated by the fact that different people of different ages have different durations of exposure. Within the scope of this project, we chose life-expectancy from birth to illustrate the effect of population size as everyone in the birth cohort has the potential to be exposed for the same period of time. Borough birth cohort size is related to borough total population, but not perfectly.

The ranking of gains in life expectancy across boroughs lines up more clearly (but not totally) with the size of the pollution change. We have chosen the difference between pollutant concentrations in 2030 compared with 2013 but the actual modelled pollution changes evolve with a different time profile in different places. Nonetheless, the 2030/2013 difference does represent the larger changes occurring in Inner London compared with Outer London. As an example, for NO_2, Tower Hamlets had the highest gain in life years but is ranked 7th in terms of the pollution change and comes down to 4th on the list for gain in life expectancy. The City of London is last on the gain in life years list due to its small population but has the largest pollution change for NO_2 and rises to 10th on the list for gains in life expectancy (not shown). For $PM_{2.5}$ (no cut-off), there is less variation in pollutant changes by location than there is for NO_2 so the ranking of gain in life expectancy lines up less closely with the ranking of the change in $PM_{2.5}$ concentration. This is despite the fact that the concentration-response function for $PM_{2.5}$ is larger. Nonetheless, generally the ranking for change in $PM_{2.5}$ concentration is higher for the top 4 than the bottom 4, except for the City of London. While the City of London has the largest change in $PM_{2.5}$, the actual difference with other changes in the top 10 boroughs is very small (less than 0.5 $\mu g/m^3$ difference).

Looking at the order within the top 4 and bottom 4, the NO_2 change for Westminster is sufficiently larger than for Islington to outweigh the lower baseline mortality rate. Conversely, the NO_2 change for Havering is low enough to outweigh its higher baseline mortality rate than Bromley. It should be noted, however, that the baseline mortality rate overall may have less influence for life expectancy from birth than for life years because the change is not applied until the birth cohort is age 30, which is after most air pollution changes have happened. The influence of baseline mortality rate is also harder to see for $PM_{2.5}$, where the changes are smaller after 2030 compared with before. It is also worth noting that more deprived areas may have higher mortality rates at younger ages. We have not considered age standardized mortality rates but it can be seen that some deprived areas with a younger age distribution have higher baseline mortality rates than might be expected

(Islington has a higher baseline mortality rate than might be expected from the age distribution, for example).

Similar principles will apply for the results with a cut-off. For $PM_{2.5}$, the concentration change may have a little more influence with cut-off than without as the changes are a little bigger.

In summary, the reasons for variation across boroughs are complex. We have not been able to investigate this fully here. Factors include:

- Population size
- Size of pollution change
- Timing of pollution change relative to when changes in risks are applied (lags, application age over 30, larger influence in older age groups due to higher mortality rates in those age groups)
- Baseline mortality rates
- Baseline mortality rates by age (influenced by deprivation)
- Age distribution – proportion of particular age groups relative to population size

Table 11 *Comparisons between local authorities with largest and smallest results for gain in life years and gain in life expectancy for the MAQP scenario (NO_2, no cut-off, male and female combined, as an example)*

Local Authority (top 4 and bottom 4 for gain in life years)	**Gain in life years NO_2**	**Local Authority (top 4 and bottom 4 for gain in life expectancy)**	**Gain in life expectancy NO_2**	**Change in PWAC NO_2 2030 vs 2013 (LAs in column 3) (rank)**	**Baseline mortality rate per 10,000 population (LAs in column 3)[a] (rank)**	**Age distribution (% pop all ages)[b]**		
						25	**35**	**75**
Greater London					91.6			
Borough mean	184,072		179	-18.33	90.8			
Tower Hamlets	286,095	**Westminster**	249	-27.00 (2)	69.8 (30)	2.0	2.1	0.5
Southwark	280,457	**Islington**	234	-22.80 (5)	80.9 (22)	2.7	2.0	0.4
Lambeth	274,477	**Kensington and Chelsea**	231	-25.85 (3)	77.4 (23)	1.5	1.7	0.7
Newham	264,647	**Tower Hamlets**	228	-21.80 (7)	63.5 (33)	2.3	2.3	0.2
Sutton	104,111	**Harrow**	136	-14.04 (29)	94.4 (12)	1.3	1.5	0.6
Richmond upon Thames	103,224	**Bexley**	134	-13.83 (30)	133.2 (2)	1.3	1.4	0.7
Kingston upon Thames	90,372	**Bromley**	134	-13.43 (32)	122.7 (3)	1.1	1.4	0.8
City of London	5,210	**Havering**	117	-11.90 (33)	147.2 (1)	1.3	1.4	0.7

[a] Calculated from the same data used for the burden calculations i.e. summed from 3 year average deaths and population data per LSOA. It therefore may not match mortality rates from other sources which may be for a single year and a different geographical scale.

[b] Read off the ONS interactive population pyramids giving the percentage of the total population in each age group (here age 25, 35 and 75). For reference see footnote[36].

Table 12 Comparisons between local authorities with largest and smallest results for gain in life years and gain in life expectancy for the MAQP scenario ($PM_{2.5}$, no cut-off, combined male and female, as an example)

Local Authority	Gain in life years $PM_{2.5}$	Local Authority (top 4 and bottom 4 for gain in life expectancy)	Gain in life expectancy $PM_{2.5}$ (days)	Change in PWAC anthro-pogenic $PM_{2.5}$ (rank)	Baseline mortality rate per 10,000 population[a] (LAs in column 3) (rank)	Age distribution (% pop all ages)[b]		
						25	35	75
Greater London					91.6			
Borough mean	167,812		160	-5.89	90.8			
Newham	242,764	**Tower Hamlets**	179	-6.17 (7)	63.5 (33)	2.3	2.3	0.2
Croydon	237,724	**Hackney**	178	-6.10 (11)	65.8 (32)	1.7	2.5	0.3
Tower Hamlets	224,912	**Islington**	177	-6.24 (5)	80.9 (22)	2.7	2.0	0.4
Southwark	219,761	**Southwark**	173	-6.13 (9)	73.2 (27)	2.0	2.0	0.3
Richmond upon Thames	104,134	**Harrow**	148	-5.59 (29)	94.4 (12)	1.3	1.5	0.6
Kingston upon Thames	92,405	**Kingston upon Thames**	147	-5.65 (24)	100.5 (9)	1.4	1.7	0.6
Kensington and Chelsea	87,088	**Richmond upon Thames**	145	-5.72 (22)	92.2 (17)	1.0	1.6	0.3
City of London	3,260	**City of London**	138	-6.57 (1)	73.1 (28)	2.6	1.3	0.7

[a] Calculated from the same data used for the burden calculations i.e. summed from 3 year average deaths and population data per LSOA. It therefore may not match mortality rates from other sources which may be for a single year and a different geographical scale.
[b] Read off the ONS interactive population pyramids giving the percentage of the total population in each age group (here age 25, 35 and 75). For reference see footnote[36].

6.4 Mortality impact of the London Environment Strategy (Plus) (WHO scenario)

The results from the life table calculations assuming that the concentrations do not reduce from 2013 levels and assuming the predicted concentrations between 2013 and 2050 for the WHO scenario (concentrations were modelled at 2013, 2016, 2019, 2030 LES Plus and 2050 but also interpolated for the intervening years; see *Table 2*) and MAQP scenario (see section above) can be found in *Table 13*, for anthropogenic $PM_{2.5}$.

The WHO scenario projected future changes in air pollution concentrations up to 2050 (projected from 2013) would be around 0.6 to 5.5 million life years lost compared with 0.8 to 5.7 million life years lost for the MAQP scenario for the population of London over 142 years (see *Table 13*).

Figure 8 shows that the cumulative life years lost of the WHO scenario for the predicted concentration between 2013 and 2050 accumulates more slowly than the MAQP scenario concentration results for anthropogenic $PM_{2.5}$ as a result of the reduced concentrations in 2030 due to the policies additional to the LES (namely LES Plus) designed to meet the WHO (2005) Guideline of 10 µg m^{-3} by 2030. Note that there is a delay before the full benefits of concentration reductions are achieved. This is not just due to a lag between exposure and effect, but also because the greatest gains occur when mortality rates are highest i.e. in the elderly.

Table 14 shows the differences between the predicted concentrations between 2013 and 2050 and particulate matter concentrations constant at 2013 levels for both the MAQP and WHO scenarios. With the WHO scenario, the population in London would gain around 5.7 to 5.8 million life years over a lifetime compared with a gain around 5.5 to 5.7 million life years for the MAQP scenario.

Figure 9 and *Figure 10* show the effect of the decrease in $PM_{2.5}$ concentration from 2013 to 2050 for both the MAQP and WHO scenario (as seen in *Table 2*). The WHO scenario starts showing additional gains (compared with the MAQP scenario) from 2020 onward carrying on for about half a century. The WHO scenario maximum life years gain happened in the period 2020 to 2049 (see *Figure 9* and *Figure 10*) in line with the additional air quality $PM_{2.5}$ concentration decrease within the same period as a result of meeting $PM_{2.5}$ WHO (2005) guidelines by 2030 as described in section 4 (*Table 2*).

In **summary** if $PM_{2.5}$ met WHO (2005) guidelines by 2030 on top of the predicted mayoral air quality policies, the population in London would **gain a 20% increase in life years** saved during this period (2020 to 2049). There are about 600,000 life years gained with the WHO scenario from 2020 to 2049 versus about 500,000 life years saved for the Mayor's air quality policies scenario.

Table 13 Total life years lost across London population for anthropogenic $PM_{2.5}$ and NO_2 (central estimate) for the baseline, the MAQP and WHO scenarios

Pollutant	**Scenario**	**Life years lost without cut-off (with cut-off)**	
		Over the period 2013 to 2154	**Over the period 2020 to 2049***
		Central estimate**	**Central estimate****
Anthropogenic $PM_{2.5}$ (representing the regional air pollution mixture and some of the local mixture)	Baseline: concentration does not reduce from 2013 levels	11,216,303 (6,429,953)	1,565,924 (897,139)
	MAQP scenario: predicted concentration 2013 - 2050	5,678,505 (778,311)	1,058,485 (376,331)
	WHO scenario: predicted concentration 2013 - 2050	5,489,600 (587,516)	948,690 (265,136)
NO_2 (representing the local mixture and the rural air pollution mixture)	Baseline: concentration does not reduce from 2013 levels	10,112,667 (8,727,251)	1,400,677 (1,207,225)
	MAQP scenario: predicted concentration 2013 - 2050	4,038,278 (2,638,265)	875,992 (680,582)

For anthropogenic $PM_{2.5}$ assuming no net migration, with projected new births, 2013-2154, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.06 per 10 µg m^{-3} of anthropogenic $PM_{2.5}$ without cut-off and with 7 µg m^{-3} cut-off[42], with lags from the USEPA.
For NO_2 assuming no net migration, with projected new births, 2013-2154, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.023 per 10 µg m^{-3} of NO_2 without cut-off and with 5 µg m^{-3} cut-off, with lags from the USEPA.
(Results with cut-offs do not extrapolate beyond the original data, results with no cut-off represent the possibility that there are effects below the cut-off value (it is unknown whether or not this is the case).)
*Cumulative life years lost compiled over a shorter period (2020 to 2049) instead of the general method (2013 to 2154) to represent the effect of the WHO scenario change of air quality versus the MAQP scenario (i.e. a decrease in $PM_{2.5}$ concentration from 2020 to 2049 as described in section 4)
**Lower and upper estimate data available on request

[42]It is possible that this cut-off will be defined at a value lower than 7 µg m^{-3} in the future as this is based on a 2002 study by Pope et al (2002) which in turn used particulate concentrations from many years earlier. As concentrations reduce and newer studies are completed, it is often found that the health effects at lower concentrations become clearer as there are more data points available for analysis at these lower concentrations. The concentration-response function and its confidence intervals have been updated using a 2013 meta-analysis (the central estimate happened to remain the same). The cut-off has not so far been updated to reflect the range of the data in the meta-analysis.

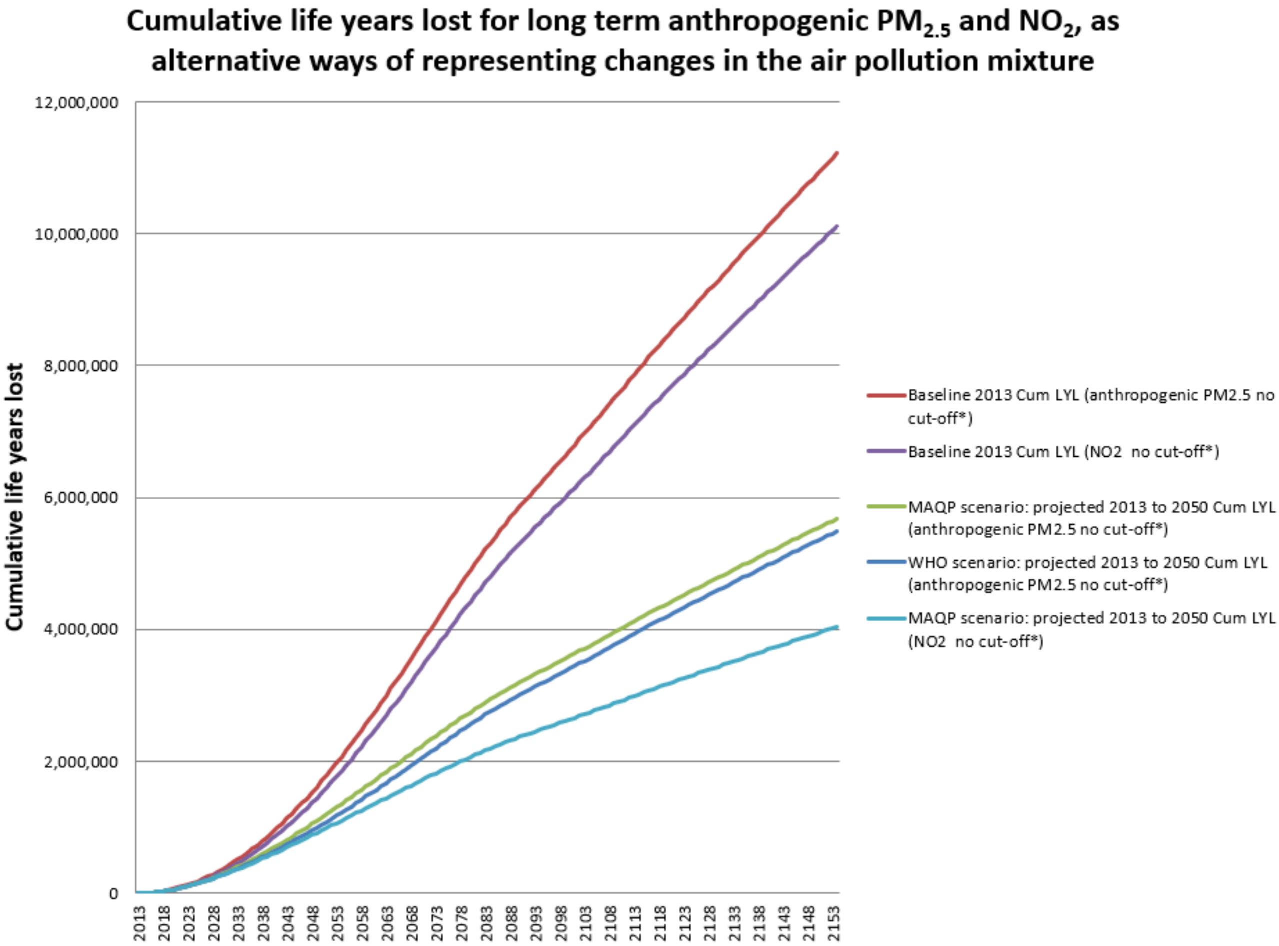


Figure 8 Cumulative life years lost for anthropogenic $PM_{2.5}$ and NO_2 if 2013 concentrations remained unchanged and both the MAQP and WHO scenario (current and future policies 2013-2050) across London population (no migration), with projected new births, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) 2013-2154. RR 1.06 per 10 $\mu g\ m^{-3}$ for anthropogenic $PM_{2.5}$ and RR 1.023 per 10 $\mu g\ m^{-3}$ for NO_2, EPA lag. Counterfactual is zero concentrations for NO_2 and non-anthropogenic concentrations for $PM_{2.5}$

* Cut-off results not shown

Table 14 Life years saved across London population of the predicted concentration between 2013 and 2050 compared with 2013 anthropogenic $PM_{2.5}$ concentrations and NO_2 remaining unchanged

Pollutant	**Scenario**	**Total life years saved compared with 2013 concentrations maintained without cut-off (with cut-off)**	
		Over the period 2013 to 2154	**Over the period 2020 to 2049***
		Central estimate**	**Central estimate****
Anthropogenic $PM_{2.5}$ (representing the regional air pollution mixture and some of the local mixture)	MAQP scenario: predicted concentration between 2013 and 2050	5,537,798 (5,651,641)	507,439 (520,808)
	WHO scenario: predicted concentration between 2013 and 2050	5,726,703 (5,842,437)	617,234 (632,003)
NO_2 (representing the local mixture and the rural air pollution mixture)	MAQP scenario: Predicted concentration between 2013 and 2050	6,074,389 (6,088,986)	524,685 (526,643)

*Total life years lost compiled over a shorter period (2020 to 2049) instead of the general method (2013 to 2154) to represent the effect of the WHO scenario change of AQ versus the MAQP scenario (i.e. a decrease in $PM_{2.5}$ concentration from 2020 to 2049 as described in section 4)

**Lower and upper estimate data available on request

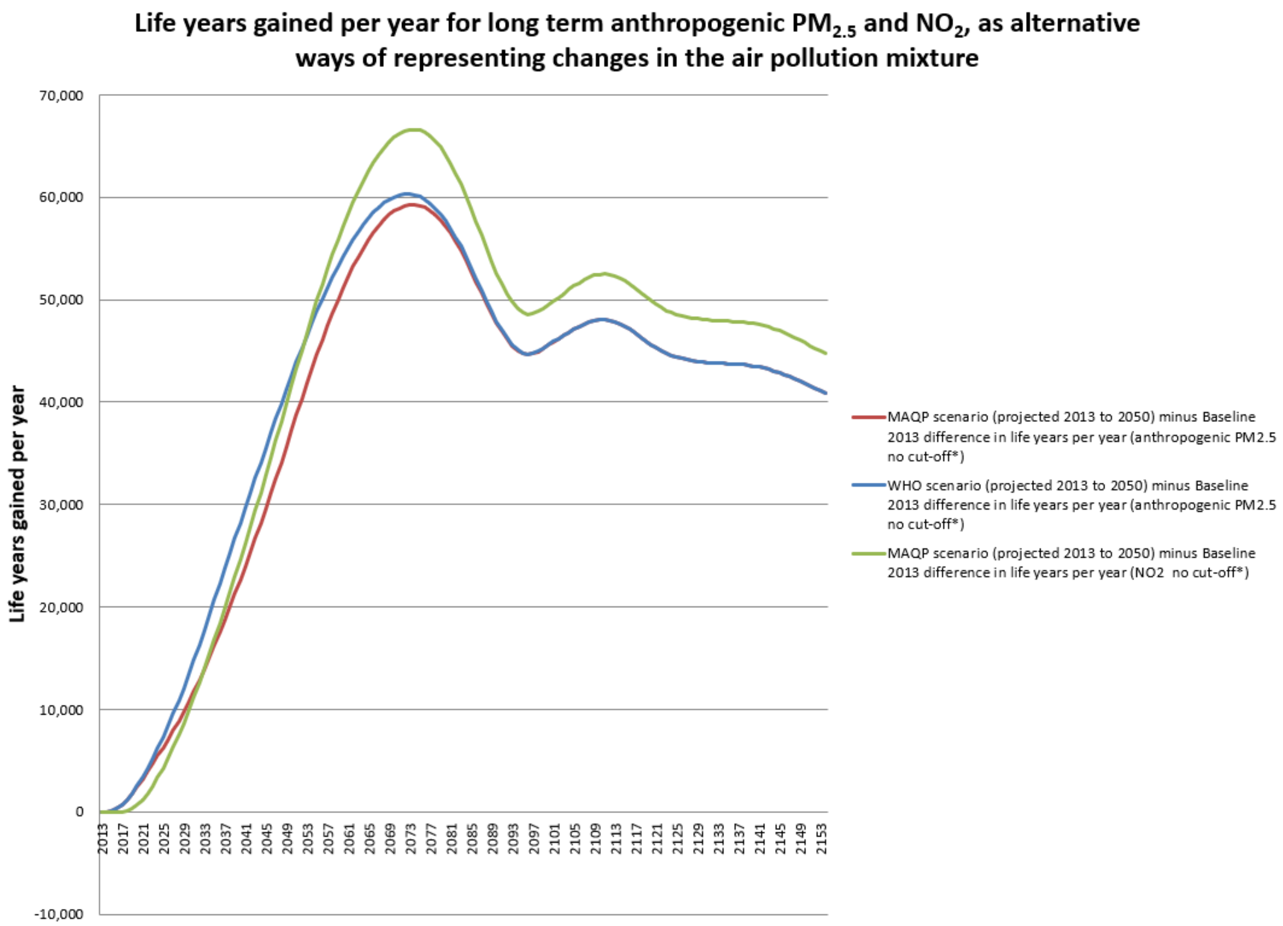


Figure 9 Life years gained per year from long-term exposure to the improvements in pollution from 2013 to 2050 (MAQP and WHO scenario) of anthropogenic $PM_{2.5}$ and NO_2 relative to 2013 concentrations remaining unchanged

* Cut-off results not shown

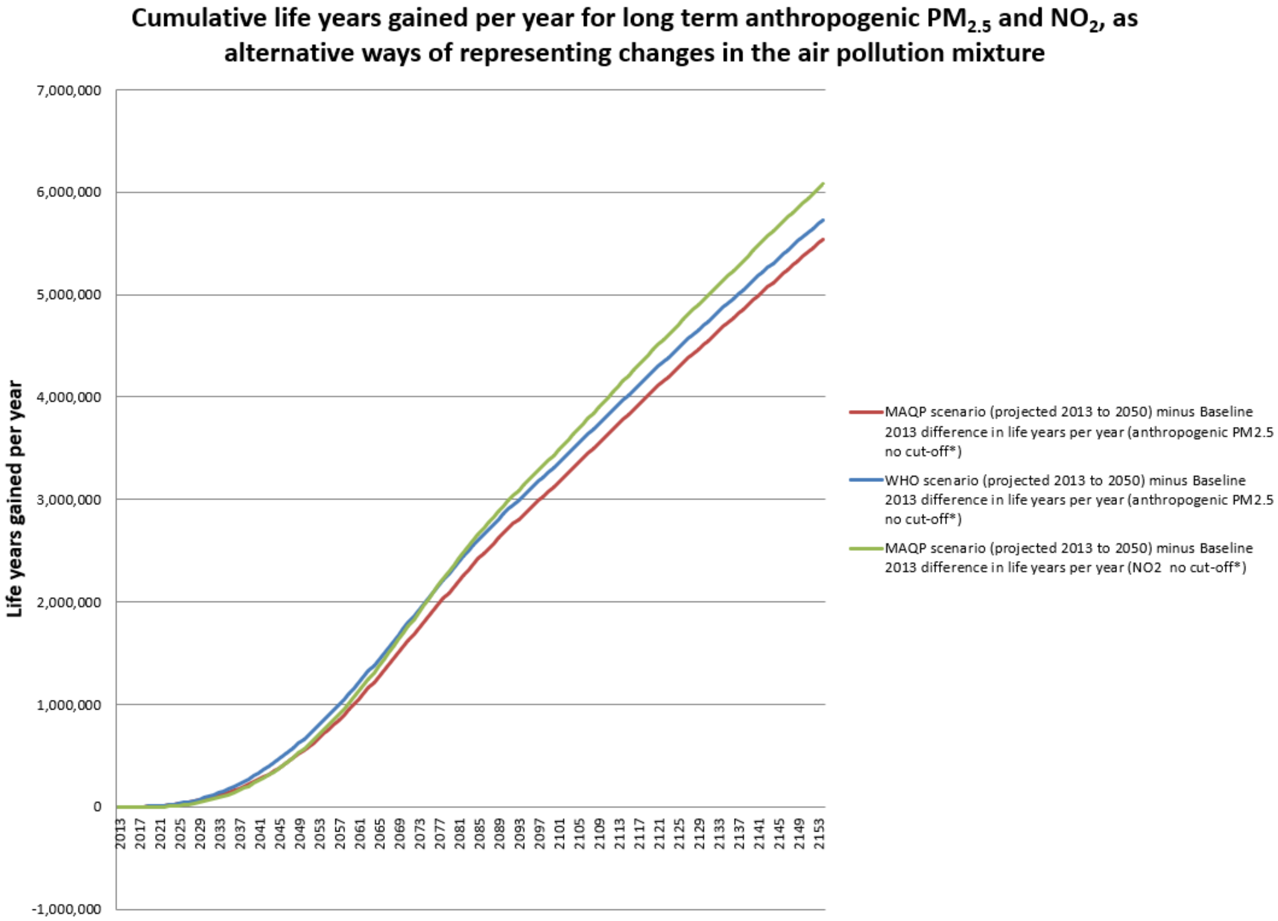


Figure 10 Cumulative life years gained per year from long-term exposure to the improvements in pollution from 2013 to 2050 (MAQP and WHO scenario) of anthropogenic $PM_{2.5}$ and NO_2 relative to 2013 concentrations remaining unchanged

* Cut-off results not shown

Boroughs

This paragraph gives the range of the differences in life years across London boroughs between particulate concentrations remaining constant at 2013 levels and the predicted concentrations between 2013 and 2050, including changes aiming to achieve the WHO (2005) Guideline by 2030. For no cut-off, the life years gained in London boroughs varied from 90,853 to 249,776 (excluding the City of London, which has a much lower population). As expected, this is larger than for $PM_{2.5}$ for the MAQP scenario (87,088 – 242,764). Full results including those for no cut-off are given in *Table 27*. The ranking of the results across boroughs is very similar to that for the MAQP scenariho and many of the same factors will be driving the differences.

Life expectancy

The results for life-expectancy are very similar to those for the MAQP scenario (to within fractions of a day) so are not described separately here. The probable reason for this is that the differences between the MAQP scenario and the WHO scenario mainly occur between 2020 and 2030 and then, with interpolation, end up at the same point by 2050. For a birth cohort born in 2013 (as opposed to life years which cover all age groups), the change in risk is not applied until age 30 (in 2033) and then there is still a lag before the effect is fully implemented (most is applied within 5 years). At age

35, baseline mortality rates are still low and do not increase much until the late 40s. On the exposure side, the difference between the MAQP and the WHO scenario is getting smaller and smaller as the years approach 2050. In further work, it might be possible to consider a birth cohort born earlier than 2013 but it would rely on having modelling of the appropriate pollution changes over that earlier time period. Alternatively, a cohort age 30 in 2013 could be followed. These small differences relative to the MAQP scenarios are not, of course, to say that the WHO scenario does not have benefits, it has all the benefits of the MAQP scenario on life expectancy and more when considering the effects on life years which include other age groups (see above).

7.0 Discussion

7.1 Summary of burden results

Results without the cut-off give a range of 3,600 to 4,100 attributable deaths (or 61,800 to 70,200 life years lost) using the approach derived from multi-pollutant model results. This compares with around 3,000 attributable deaths (or 51,600 life years lost) using the single-pollutant model estimate for NO_2 (a good indicator of traffic pollution and the largest single pollutant model result) and around 2,960 attributable deaths (or 50,600 life years lost) using the single-pollutant model estimate for $PM_{2.5}$ (the previous COMEAP method; COMEAP, 2010). As expected, the estimate combining effects of NO_2 and $PM_{2.5}$ is slightly larger than for either pollutant alone but not by much, reflecting the substantial overlap between the single pollutant model estimates for $PM_{2.5}$ and NO_2. Nonetheless, there are substantial ranges of uncertainty around these estimates, so it is not clear cut that there is an additional effect over and above estimates using the previous method.

The message from the results with a cut-off is similar with a range of 2,220 to 2,630 deaths (or 38,300 to 45,300 life years lost) using the approach derived from multi-pollutant model results compared with the largest single pollutant model result of 2,500 deaths (or 42,900 life years lost) (NO_2 single-pollutant model). In this case, the result for NO_2 is much larger than that for the $PM_{2.5}$ single-pollutant model (1,140 deaths (or 19,600 life years lost) - probably a reflection of the different cut-offs for NO_2 and $PM_{2.5}$.

Figure 11 (below) summarises the results as a whole. These are difficult to summarise as a single central figure or even as a single range. If a range is quoted it needs to be clear whether it is a numerical range from within one method/set of assumptions or a range across different methods. COMEAP preferred the former (which is why ranges with and without a cut-off are given separately in their report (COMEAP, 2018a)). Loosely, it can certainly be said that the result is in the mid thousands not in the hundreds or in the tens of thousands. The choice for a more detailed range depends on which assumptions are preferred.

There are three key assumptions to consider:

- The assumption that using multi-pollutant estimates is an improvement over previous methods, despite the uncertainties discussed in COMEAP (2018a) (the majority of COMEAP, but not everyone, accepted this assumption),
- The assumption that the relationship between the air pollutants and mortality continues down to zero concentrations, even though data points are sparse at these lower concentrations (COMEAP chose to give results both with and without this assumption),
- The assumption that nitrogen dioxide (and traffic pollutants closely correlated with it) have effects that are independent of the effects represented by $PM_{2.5}$. (There is certainly debate over the independent effects of nitrogen dioxide itself but it should be noted that the association between nitrogen dioxide and mortality may represent the effects of primary traffic PM better than the association between $PM_{2.5}$ and mortality, given the closer correlation between NO_2 and traffic PM).

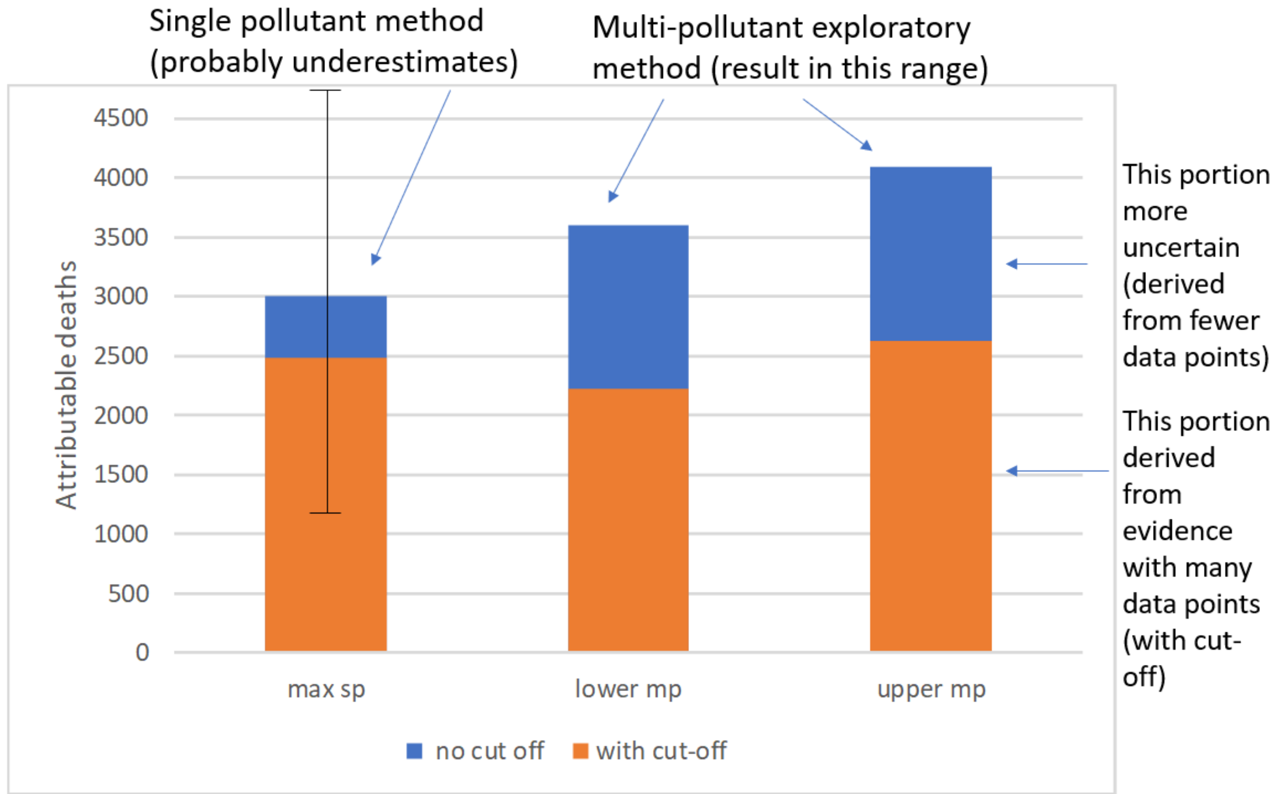
The first option, as used in this report, is to use the new method (COMEAP, 2018)) and accepting extrapolation to lower concentrations with sparse data-points would give 3,600 to 4,100 attributable deaths (61,800 – 70,200 life years lost) (combined NO_2 and $PM_{2.5}$; no cut-off). Results using multi-pollutant model estimates with the cut-off (2,220 to 2,630 attributable deaths or 38,300 to 45,300 life years lost) are also part of this option and similar to the second option below.

Another (second) option is to use the largest of the single pollutant model estimates, in this case that for nitrogen dioxide, i.e. not using the new methods but accepting that the single pollutant model estimate for NO_2 can act as a reasonable marker for the air pollution mixture. This would give a range from 2,500 – 3,000 attributable deaths (42,900 - 51,600 life years lost). This may still be an underestimate.

A final option is to take an 'at least' approach, using the most conservative assumptions. This would give a result of 1,140 attributable deaths (or 19,600 life years lost) i.e. assuming a preference for using associations with $PM_{2.5}$, a preference for using only data above the cut-off and a preference for staying with older methods based on single pollutant model estimates. The current authors (and many on COMEAP) consider this to be an underestimate (it is not included in Figure 11). (Note that the cut-off of 7 $\mu g\ m^{-3}$ is derived from the American Cancer Society study (Pope *et al* 2002) and newer studies have more data points at concentrations below this). On the precautionary principle, if this option were to be taken, it would be important to mention the possibility of the larger results from the other options.

If wanting to define a range across methods, with and without a cut-off, including the largest single pollutant model estimate answer as being likely to provide less of an underestimate, the range with rounding would be 2,000 to 4,000 attributable deaths (38,000 to 70,000 life years lost).

(a) Attributable deaths



(b) Life years lost

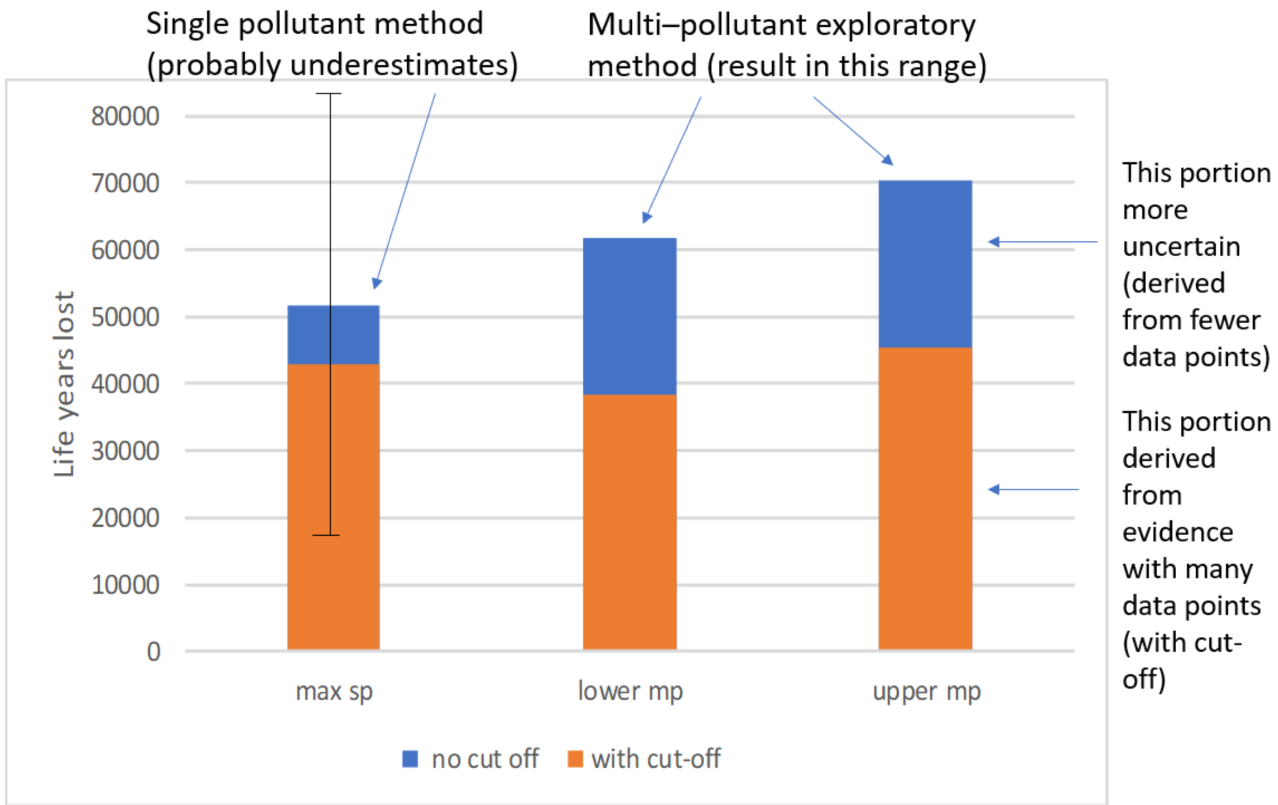


Figure 11 Mortality burden of air pollution in Greater London in 2019 – Attributable deaths (a) and Life years lost (b)

Note that results are for NO_2 and $PM_{2.5}$ combined (lower and upper multi-pollutant (mp) estimates) or for the maximum result between single pollutant (sp) model results for $PM_{2.5}$ or NO_2 as an indicator of the pollution mixture (in this case it was NO_2; $PM_{2.5}$ single pollutant model results are given in *Table 5*). The cut-off below which the shape of the relationship between either $PM_{2.5}$ or NO_2 and mortality is more uncertain was 7 µg m^{-3} and 5 µg m^{-3} respectively. The error bars are for calculations using the upper and lower confidence intervals of the single pollutant model concentration-response relationship. For technical reasons (see COMEAP 2018a) this is not possible for the combined multi-pollutant model estimates.

7.2 Summary of impact results

Summary of impact results for the Mayor's Air Quality Policies and for Policies to reach the (2005) WHO $PM_{2.5}$ guideline by 2030

The population in London would **gain** around **6.1 million life years** over a lifetime to 2154[43] if air pollution concentrations improved as projected by the Mayor's air quality policies scenario from 2013 to 2050, compared with remaining at 2013 concentrations. The average **life expectancy** of **a child born in London in 2013** would **improve** by around **5 to 6 months** for the same comparison.

Taking into account the mayoral air quality policies projected future changes in air pollution concentrations up to 2050 (projected from 2013), the population would still be **losing** between **2.6 to 5.7 million life years** in London (a life year is one person living for one year) compared with no pollution. Put another way, **children born in 2013** are still estimated to **die 2-5 months early[44]** on average**, if exposed over their lifetimes to the projected future air pollution concentrations in London**.

Results varied by borough and were more variable using NO_2 concentrations than using $PM_{2.5}$ concentrations. The largest changes were in Inner London for NO_2, but the $PM_{2.5}$ changes could be more important in Outer London. Several more deprived boroughs attained larger benefits than some other boroughs when expressed as gain in life expectancy (which is less influenced by population size).

For the policies to attain the WHO $PM_{2.5}$ air quality (2005) guideline, the population in London would gain around 5.7 to 5.8 million life years over a lifetime compared with a gain around 5.5 to 5.7 million life years for the Mayor's air quality policies scenario.

While the results do not appear to make a large proportional difference when considered over the full period from 2013-2154, this is expected because large portions of that time period the two scenarios are the same. In the period 2020 to 2049, however, the population in London would **gain** a **20% increase in life years** saved (600,000 life years saved versus about 500,000 life years gained during the same period for the MAQP scenario) as a result of **meeting $PM_{2.5}$ WHO (2005) guidelines by 2030**.

7.3 Factors driving variation across London

One thing that the comparisons across local authority results has highlighted is that the susceptibility of the local population can be important. Thus, the mortality burden can be just as high, or higher, in Outer London due to the greater proportion of older people in the population, even if the pollution levels are not as high. It should be noted, however, that even if some Inner

[43] It is not possible to calculate the full result for gains in life expectancy until everyone in the initial population has died (105 years from 2050), necessitating follow-up for a life-time even if the pollution changes are only for the next decade or so.
[44] The range is according to whether the indicator pollutant is taken as $PM_{2.5}$ or NO_2, whether or not there is a cut-off concentration below which no effects are assumed and gender.

London boroughs have lower mortality results, this does not mean the same will apply for other outcomes such as asthma admissions in children, where boroughs with younger populations will be more affected. This discussion argues for air pollution reductions in all areas of London.

For impact, the largest gains in life years or life expectancy were often in Inner London because the greatest reductions are targeted at the areas with the largest initial concentrations. This was less clear for $PM_{2.5}$ for which reductions occurred more evenly across London. Factors driving differences in results between boroughs included:

- Population size
- Size of pollution change
- Timing of pollution change relative to when changes in risks are applied (lags, application age over 30, larger influence in older age groups due to higher mortality rates in those age groups)
- Baseline mortality rates
- Baseline mortality rates by age (influenced by deprivation)
- Age distribution – proportion of particular age groups relative to population size

7.4 Method

The results in this report are not directly comparable with the results in Walton *et al* (2015), using 2010 pollution data. The methodology has changed substantially according to the publication of the COMEAP (2018a) report. While there are many uncertainties, the new method aims to take account of the overlap in the epidemiological study results between $PM_{2.5}$ and NO_2. In addition, the new meta-analysis of studies of long-term exposure to NO_2 and mortality (Atkinson et al 2018; COMEAP 2018a) used as the starting point for the new method, finds smaller results (central single pollutant model hazard ratio (relative risk) 1.023 compared with 1.055 in the previous WHO (2013b) recommendation or (1.055) further reduced to 1.037 to partially account for overlap with $PM_{2.5}$). The single pollutant model central estimate for $PM_{2.5}$ is unchanged, except for the fact that the 2015 report population-weighted from OA to local authority (this is likely to make only a small difference).

7.5 Ozone

The study from Williams et al. (2018a and 2018b) shows that ozone concentrations in 2035 and 2050 are projected to increase in winter because the removal of ozone by reaction with NO occurs to a lesser extent due to reductions in NOx emissions. So-called summer smog ozone concentrations are projected to decrease because of the reductions in emissions of ozone precursors. The Williams (2018a and 2018b) study found that the long-term ozone exposure metric recommended by WHO (2013b) is projected to decrease over time compared with 2011. This outcome is a relatively small change compared with that for the other pollutants, due to the WHO threshold of 35 parts per billion and the effect being on respiratory mortality, not all cause mortality. Williams et al. (2018a and 2018b) also warned that the increased proportion of ozone in the mixture of oxidant gases, including NO_2, is potentially of some concern because ozone has a higher redox potential than does NO_2, and so could possibly increase the hazard from oxidative stress, although it is too early to be confident about this theory.

7.6 Further effects linked with air pollution

This study addressed the effect of air pollution on attributable deaths and changes in life years lost. This included all causes of death grouped together so covers, for example, respiratory, lung cancer and cardiovascular deaths for which there is good evidence for an effect of air pollution. It does not, however, cover the effect of air pollution on health where this does not result in death. So well established effects (such as respiratory and cardiovascular hospital admissions, effects on asthma, etc.) and other outcomes more recently potentially linked with air pollution (such as dementia, low birth weight and type 2 diabetes) are not included. This was addressed to some extent in a previous study commissioned by the GLA, although the uncertainties and need for further work were acknowledged for some of these outcomes.[45]

In summary, we have presented the burden of air pollution on mortality in 2019 but also shown that air pollution concentrations are projected to reduce over time, bringing health benefits across London.

[45] Modelling the long-term health impacts of air pollution in London, Health Lumen, 2020

8.0 Appendix

8.1 Additional tables- Method

Additional data such as the loss of life expectancy lower and upper estimates and the full range of results using confidence intervals with and without cut-off for both $PM_{2.5}$ and NO_2 are available upon request to the authors.

Table 15 Concentration-response functions (CRFs) for long-term exposures and mortality (for impact calculations of general changes in pollutant concentrations (rather than policies targeting one pollutant alone)

Pollutant	Averaging time	Hazard ratio per 10 µg m^{-3}	Confidence interval	Counterfactual	Comment/Source
$PM_{2.5}$	Annual average	1.06	1.04-1.08 1.01-1.12*	Zero Or 7 µg m^{-3}	Age 30+, Anthropogenic $PM_{2.5}$ (Hazard ratio COMEAP (2010) and COMEAP (2018a)) Age 30+, total $PM_{2.5}$ (cut-off reference COMEAP (2010))
NO_2	Annual average	1.023	1.008 – 1.037	Zero or 5 µg m^{-3}	Age 30+ (Hazard ratio COMEAP (2017), (cut-off reference COMEAP (2018a))

*This wider uncertainty is only used as an addition for the single-pollutant model aspect of burden calculations

Table 16 Concentration-response functions (CRFs) for the mortality burden from the four multi-pollutant model cohort studies including multi-pollutant model estimates

Pollutant	**Averaging time**	**Hazard ratio per 10 µg m^{-3}**	**Counterfactual**	**Comment/Source**
$PM_{2.5}$	Annual average	1.029 (Jerrett) 1.033 (Fischer) 1.053 (Beelen) 1.019 (Crouse)	Zero Or 7 µg m^{-3}	Age 30+, Anthropogenic $PM_{2.5}$ (Hazard ratio COMEAP (2010) and COMEAP (2018a)) Age 30+, total $PM_{2.5}$ (cut-off reference COMEAP (2010))
NO_2	Annual average	1.019 (Jerrett) 1.016 (Fischer) 1.011 (Beelen) 1.020 (Crouse)	Zero or 5 µg m^{-3}	Age 30+ (Hazard ratio COMEAP (2017), cutoff COMEAP (2018a)

*Derived from applying the % reduction on adjustment for the other pollutants in each individual study to the pooled single pollutant summary estimate as in COMEAP (2018a)

Table 17 Geographic scales for mortality burden calculations

Concentrations	Concentration output for health impacts	Population by gender and age group	Mortality burden data	Mortality burden calculations
20m	OA	OA	LSOA	Sum of LSOA results

Table 18 Geographic scales for mortality impact calculations

Concentrations	Concentration output for health impacts	Population by gender and age group	Population-weighting	Mortality data	Impact calculations
20 m	OA	OA	Ward	LSOA to Ward	Sum of Ward results

8.2 Additional tables - Burden

Table 19 Estimated burden (from single-pollutant model summary estimate with wider estimates of uncertainty) of effects on annual mortality in 2019 of 2019 levels of anthropogenic $PM_{2.5}$ (with and without cut-off)

Zone	Anthropogenic $PM_{2.5}$ (without cut-off)			Anthropogenic $PM_{2.5}$ (with cut-off)		
	Attributable deaths (Life year lost*)			Attributable deaths (Life year lost*)		
	Central estimate	Lower estimate	Upper estimate	Central estimate	Lower estimate	Upper estimate
Greater London	2,955 (50,556)	518 (8,864)	5,580 (95,440)	1,136 (19,601)	196 (3,382)	2,185 (37,681)

Using COMEAP's recommended concentration-response coefficient of 1.06 per 10 µg m^{-3} of anthropogenic $PM_{2.5}$ for the central estimate (lower estimate RR of 1.01 and upper estimate RR 1.12)

* Associated life years lost, age 30+ and calculated by gender and 1-year age groups, by LSOA then summed up to Wards/boroughs/Greater London level.

Table 20 2019 Anthropogenic $PM_{2.5}$ and NO_2 concentration (in µg m^{-3}) (PWAC annual) by borough

Local Authority	Anthropogenic $PM_{2.5}$ 2019 (without cut-off)	NO_2 2019 (without cut-off)	$PM_{2.5}$ 2019 (with cut-off)	NO_2 2019 (with cut-off)
Barking and Dagenham	10.5	26.5	3.9	21.5
Barnet	10.8	28.5	4.0	23.5
Bexley	10.3	24.7	3.6	19.7
Brent	11.1	30.1	4.3	25.1
Bromley	10.1	23.6	3.3	18.6
Camden	12.0	34.0	5.2	29.0
City of London	12.6	37.2	5.9	32.2
Croydon	10.4	25.5	3.7	20.5
Ealing	10.8	29.1	4.1	24.1
Enfield	10.6	26.7	3.9	21.8
Greenwich	10.7	27.8	4.1	22.9
Hackney	11.5	31.4	4.8	26.5
Hammersmith and Fulham	11.5	31.9	4.7	26.9
Haringey	11.1	29.5	4.3	24.6
Harrow	10.4	25.8	3.7	20.9
Havering	10.0	23.0	3.2	18.0
Hillingdon	10.3	26.3	3.5	21.3
Hounslow	10.6	28.8	3.9	23.8
Islington	11.7	32.8	5.0	27.8
Kensington and Chelsea	11.9	34.6	5.1	29.6
Kingston upon Thames	10.5	26.7	3.7	21.7
Lambeth	11.3	30.7	4.6	25.7
Lewisham	10.9	28.2	4.2	23.3
Merton	10.7	27.6	4.1	22.6
Newham	11.0	29.3	4.4	24.4
Redbridge	10.7	27.7	3.9	22.7
Richmond upon Thames	10.6	27.1	3.8	22.1
Southwark	11.5	32.1	4.8	27.1
Sutton	10.5	25.3	3.7	20.3
Tower Hamlets	11.6	33.4	4.9	28.4
Waltham Forest	11.0	28.6	4.2	23.6
Wandsworth	11.1	29.8	4.4	24.8
Westminster	12.2	35.5	5.5	30.5

Table 21 Estimated burden by borough (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies and from single-pollutant model summary estimate) of effects on annual mortality in 2019 of 2019 levels of anthropogenic $PM_{2.5}$ and NO_2 (No cut-off)

Local Authority	Attributable deaths (Life year lost*) - No cut off			
	Multi-pollutant model estimates		Single-pollutant model estimates	
	Lowest estimate[a]	Highest estimate[a]	$PM_{2.5}$ Central estimate (Lower and Upper limit)[b]	NO_2 Central estimate (Lower and Upper limit)[b]
Barking and Dagenham	84 (1440)	97 (1660)	71 (49, 93) 1220 (830, 1600)	69 (25, 108) 1180 (420, 1860)
Barnet	177 (2850)	201 (3230)	144 (98, 189) 2330 (1580, 3040)	148 (53, 231) 2380 (850, 3730)
Bexley	139 (2010)	162 (2350)	119 (81, 156) 1740 (1180, 2270)	113 (40, 178) 1650 (590, 2590)
Brent	133 (2540)	149 (2840)	106 (72, 138) 2010 (1370, 2630)	112 (40, 176) 2140 (770, 3350)
Bromley	172 (2560)	204 (3020)	152 (104, 199) 2250 (1530, 2950)	140 (50, 220) 2080 (740, 3260)
Camden	99 (1780)	109 (1960)	76 (51, 99) 1370 (930, 1790)	84 (30, 131) 1520 (550, 2370)
City of London	4 (60)	4 (70)	3 (2, 4) 50 (30, 60)	3 (1, 5) 50 (20, 80)
Croydon	168 (2780)	196 (3240)	145 (98, 189) 2390 (1620, 3120)	137 (49, 216) 2280 (810, 3580)
Ealing	147 (2490)	165 (2800)	118 (80, 154) 2000 (1360, 2620)	123 (44, 193) 2090 (750, 3280)
Enfield	142 (2330)	164 (2680)	120 (81, 156) 1960 (1330, 2560)	117 (42, 184) 1930 (690, 3020)
Greenwich	113 (1930)	129 (2210)	93 (64, 122) 1600 (1090, 2090)	94 (34, 147) 1610 (570, 2520)
Hackney	86 (1780)	96 (1980)	68 (46, 89) 1400 (950, 1830)	73 (26, 114) 1510 (540, 2360)
Hammersmith and Fulham	74 (1330)	83 (1470)	58 (40, 76) 1040 (710, 1350)	63 (23, 99) 1120 (400, 1760)
Haringey	90 (1710)	101 (1930)	72 (49, 94) 1380 (940, 1800)	75 (27, 118) 1440 (510, 2250)
Harrow	102 (1560)	118 (1810)	86 (58, 113) 1320 (900, 1730)	84 (30, 132) 1290 (460, 2030)
Havering	149 (2090)	178 (2490)	134 (91, 175) 1870 (1270, 2450)	120 (43, 189) 1690 (600, 2660)
Hillingdon	135 (2200)	155 (2510)	112 (76, 147) 1820 (1240, 2390)	112 (40, 176) 1830 (650, 2870)
Hounslow	114 (1920)	128 (2150)	91 (62, 119) 1530 (1040, 2000)	96 (34, 150) 1620 (580, 2530)
Islington	90 (1640)	100 (1820)	70 (48, 92) 1270 (870, 1660)	77 (28, 120) 1400 (500, 2180)
Kensington and Chelsea	70 (1240)	77 (1360)	54 (36, 70) 940 (640, 1230)	60 (22, 94) 1060 (380, 1650)

Kingston upon Thames	76 (1210)	87 (1390)	63 (43, 83) 1010 (680, 1320)	63 (22, 99) 1000 (360, 1570)
Lambeth	112 (2110)	126 (2370)	89 (61, 117) 1680 (1140, 2200)	94 (34, 148) 1780 (640, 2780)
Lewisham	111 (2140)	127 (2440)	92 (62, 120) 1760 (1200, 2300)	93 (33, 145) 1790 (640, 2800)
Merton	87 (1510)	100 (1730)	73 (50, 95) 1250 (850, 1640)	72 (26, 114) 1250 (450, 1960)
Newham	98 (2050)	111 (2310)	79 (54, 104) 1650 (1130, 2160)	82 (29, 128) 1720 (610, 2690)
Redbridge	124 (2170)	142 (2480)	103 (70, 134) 1800 (1220, 2350)	103 (37, 161) 1810 (650, 2830)
Richmond upon Thames	86 (1410)	98 (1610)	71 (48, 93) 1160 (790, 1520)	71 (25, 112) 1170 (420, 1830)
Southwark	109 (2110)	121 (2340)	85 (58, 111) 1650 (1120, 2150)	93 (33, 145) 1790 (640, 2800)
Sutton	101 (1530)	118 (1780)	87 (59, 114) 1320 (900, 1720)	83 (30, 130) 1250 (450, 1970)
Tower Hamlets	88 (1750)	97 (1930)	68 (46, 89) 1350 (920, 1760)	75 (27, 118) 1490 (540, 2330)
Waltham Forest	102 (1820)	116 (2070)	84 (57, 110) 1490 (1010, 1950)	85 (30, 133) 1520 (540, 2380)
Wandsworth	115 (2120)	129 (2390)	92 (63, 121) 1710 (1160, 2230)	96 (35, 151) 1780 (640, 2790)
Westminster	100 (1640)	110 (1790)	76 (52, 99) 1230 (840, 1610)	86 (31, 134) 1400 (500, 2190)

[a] The higher and lower estimate from the calculations using the 4 different cohort studies. Confidence intervals were not available for the multi-pollutant approach (see COMEAP 2018a for explanation).

[b] Based on the 95% confidence intervals for the single-pollutant model concentration-response functions. Top row within each cell is attributable deaths and bottom row within each cell is life years lost.

Table 22 2019 Estimated burden by borough (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies and from single-pollutant model summary estimate) of effects on annual mortality in 2019 of 2019 levels of $PM_{2.5}$ and NO_2 (with cut-off)

	Attributable deaths (Life year lost*) - With cut off			
	Multi-pollutant model estimates		**Single-pollutant model estimates**	
Local Authorities	**Lowest estimate[a]**	**Highest estimate[a]**	**$PM_{2.5}$ Central estimate (Lower and Upper limit)[b]**	**NO_2 Central estimate (Lower and Upper limit)[b]**
Barking and Dagenham	51 (870)	60 (1020)	26 (18, 35) 450 (310, 600)	56 (20, 89) 960 (340, 1520)
Barnet	108 (1750)	129 (2080)	55 (37, 72) 880 (600, 1160)	122 (44, 192) 1970 (700, 3100)
Bexley	82 (1200)	97 (1410)	43 (29, 56) 620 (420, 810)	92 (33, 144) 1330 (470, 2100)
Brent	83 (1590)	99 (1890)	42 (28, 55) 800 (540, 1050)	94 (34, 148) 1800 (640, 2830)
Bromley	101 (1500)	118 (1760)	52 (35, 69) 780 (530, 1020)	111 (40, 176) 1660 (590, 2610)
Camden	65 (1180)	77 (1390)	34 (23, 44) 610 (410, 800)	72 (26, 113) 1310 (470, 2050)
City of London	3 h(40)	3 (50)	1 (1, 2) 20 (20, 30)	3 (1, 4) 50 (20, 70)
Croydon	100 (1670)	118 (1960)	52 (35, 68) 860 (580, 1140)	111 (40, 175) 1850 (660, 2910)
Ealing	90 (1530)	108 (1830)	45 (31, 60) 770 (520, 1010)	103 (37, 162) 1750 (620, 2740)
Enfield	86 (1410)	102 (1670)	44 (30, 58) 720 (490, 950)	96 (34, 151) 1580 (560, 2480)
Greenwich	70 (1190)	82 (1410)	36 (24, 47) 610 (420, 810)	78 (28, 122) 1330 (470, 2090)
Hackney	56 (1160)	66 (1360)	29 (20, 38) 600 (400, 790)	62 (22, 97) 1280 (460, 2010)
Hammersmith and Fulham	48 (860)	57 (1010)	24 (17, 32) 440 (300, 570)	54 (19, 84) 960 (340, 1500)
Haringey	56 (1070)	67 (1270)	29 (19, 38) 550 (370, 720)	63 (22, 99) 1200 (430, 1890)
Harrow	61 (930)	72 (1110)	31 (21, 41) 470 (320, 620)	68 (24, 108) 1050 (370, 1650)
Havering	85 (1190)	100 (1410)	44 (30, 58) 620 (420, 810)	95 (34, 149) 1330 (470, 2100)
Hillingdon	79 (1290)	95 (1550)	39 (26, 51) 630 (430, 840)	91 (32, 143) 1490 (530, 2350)
Hounslow	69 (1160)	83 (1400)	34 (23, 45) 570 (380, 750)	80 (29, 126) 1350 (480, 2110)
Islington	59 (1080)	70 (1270)	31 (21, 40) 560 (380, 730)	66 (24, 103) 1200 (430, 1870)
Kensington and Chelsea	46 (810)	55 (960)	24 (16, 31) 410 (280, 540)	52 (19, 81) 910 (330, 1430)

Kingston upon Thames	46 (730)	54 (860)	23 (16, 30)370 (250, 480)	51 (18, 81) 820 (290, 1290)
Lambeth	72 (1360)	85 (1600)	37 (25, 49)700 (470, 920)	80 (29, 125) 1500 (540, 2360)
Lewisham	69 (1330)	82 (1570)	36 (24, 47) 690 (460, 900)	77 (27, 121) 1480 (530, 2330)
Merton	54 (930)	63 (1090)	28 (19, 37) 480 (320, 630)	60 (21, 94) 1030 (370, 1620)
Newham	62 (1300)	73 (1530)	32 (22, 42) 670 (450, 880)	69 (25, 108) 1440 (510, 2260)
Redbridge	76 (1330)	89 (1570)	39 (26, 51) 680 (460, 890)	85 (30, 133) 1490 (530, 2340)
Richmond upon Thames	52 (850)	61 (1010)	26 (18, 34) 430 (290, 560)	58 (21, 92) 960 (340, 1510)
Southwark	71 (1370)	83 (1620)	36 (24, 47) 700 (470, 920)	79 (28, 124) 1530 (550, 2390)
Sutton	60 (910)	71 (1070)	31 (21, 41) 470 (320, 620)	67 (24, 106) 1010 (360, 1590)
Tower Hamlets	58 (1150)	68 (1350)	30 (20, 39) 590 (400, 770)	64 (23, 101) 1280 (460, 2010)
Waltham Forest	63 (1130)	75 (1340)	33 (22, 43) 580 (390, 770)	71 (25, 111) 1260 (450, 1980)
Wandsworth	73 (1340)	86 (1580)	37 (25, 49) 690 (470, 910)	81 (29, 127) 1490 (530, 2350)
Westminster	68 (1100)	79 (1300)	35 (24, 46) 570 (390, 750)	75 (27, 117) 1220 (440, 1900)

[a] The higher and lower estimate from the calculations using the 4 different cohort studies. Confidence intervals were not available for the multi-pollutant approach (see COMEAP 2018a for explanation).

[b] Based on the 95% confidence intervals for the single-pollutant model concentration-response functions. Top row within each cell is attributable deaths and bottom row within each cell is life years lost.

8.3 Additional tables - Impact

Table 23 Anthropogenic $PM_{2.5}$ concentration without cut-off (in µg m^{-3}) (PWAC annual mean) by borough

Local Authority	Anthropogenic $PM_{2.5}$ 2013 (without cut-off)	Anthropogenic $PM_{2.5}$ 2030 (MAQP scenario) (without cut-off)	Anthropogenic $PM_{2.5}$ 2030 (WHO scenario) (without cut-off)	Anthropogenic $PM_{2.5}$ 2050 (without cut-off)
Barking and Dagenham	15.2	9.6	7.6	7.0
Barnet	15.4	9.6	7.7	7.0
Bexley	15.0	9.4	7.6	6.9
Brent	15.7	9.8	7.9	7.2
Bromley	15.0	9.4	7.4	6.9
Camden	16.7	10.4	8.2	7.7
City of London	17.9	11.3	8.6	8.6
Croydon	15.2	9.5	7.6	7.0
Ealing	15.6	9.7	7.8	7.1
Enfield	15.1	9.5	7.6	6.9
Greenwich	15.6	9.8	7.9	7.2
Hackney	16.3	10.2	8.1	7.5
Hammersmith and Fulham	16.4	10.2	8.1	7.5
Haringey	15.7	9.8	7.8	7.2
Harrow	15.0	9.4	7.5	6.8
Havering	14.6	9.2	7.3	6.7
Hillingdon	14.9	9.3	7.5	6.8
Hounslow	15.4	9.7	7.7	7.1
Islington	16.6	10.4	8.1	7.7
Kensington and Chelsea	16.9	10.4	8.2	7.7
Kingston upon Thames	15.2	9.6	7.6	7.0
Lambeth	16.3	10.1	8.1	7.5
Lewisham	15.8	9.9	7.8	7.3
Merton	15.5	9.7	7.8	7.1
Newham	15.8	10.0	8.0	7.4
Redbridge	15.3	9.6	7.7	7.1
Richmond upon Thames	15.3	9.6	7.7	7.0
Southwark	16.4	10.3	8.1	7.7
Sutton	15.1	9.5	7.6	6.9
Tower Hamlets	16.6	10.4	8.3	7.8
Waltham Forest	15.5	9.7	7.8	7.1
Wandsworth	16.0	10.0	8.0	7.4
Westminster	17.2	10.6	8.3	7.9

Table 24 NO_2 concentration without cut-off (in µg m^{-3}) (PWAC annual mean) by borough

Local Authority	NO_2 2019 (without cut-off)	NO_2 2030 (MAQP scenario) (without cut-off)	NO_2 2050 (without cut-off)
Barking and Dagenham	31.8	17.0	12.3
Barnet	34.0	17.1	11.5
Bexley	30.2	16.4	12.1
Brent	36.8	18.6	11.8
Bromley	29.3	15.9	11.6
Camden	44.4	20.6	12.6
City of London	52.3	23.6	14.4
Croydon	31.5	16.7	11.8
Ealing	36.1	18.2	12.2
Enfield	32.1	16.7	11.9
Greenwich	35.0	18.3	13.1
Hackney	40.9	19.3	12.3
Hammersmith and Fulham	42.3	20.1	12.8
Haringey	37.1	18.0	11.9
Harrow	30.6	16.5	11.6
Havering	26.8	14.9	11.4
Hillingdon	30.3	16.8	12.6
Hounslow	35.7	18.9	13.7
Islington	42.9	20.1	12.6
Kensington and Chelsea	46.9	21.0	12.7
Kingston upon Thames	32.9	17.5	12.2
Lambeth	41.1	19.7	12.7
Lewisham	36.4	18.4	12.6
Merton	34.5	17.7	12.1
Newham	36.7	19.3	13.3
Redbridge	32.7	16.9	11.7
Richmond upon Thames	33.9	18.1	12.8
Southwark	42.2	20.6	13.4
Sutton	31.0	16.8	12.0
Tower Hamlets	42.6	20.8	13.6
Waltham Forest	34.9	17.5	11.9
Wandsworth	38.9	19.0	12.3
Westminster	48.6	21.6	13.0

Table 25 $PM_{2.5}$ concentration with cut-off (in µg m^{-3}) (PWAC annual mean) by borough

Local Authority	$PM_{2.5}$ 2019 (with cut-off)	$PM_{2.5}$ 2030 (MAQP scenario) (with cut-off)	$PM_{2.5}$ 2030 (WHO scenario) (with cut-off)	$PM_{2.5}$ 2050 (with cut-off)
Barking and Dagenham	8.5	2.8	0.8	0.2
Barnet	8.6	2.8	0.9	0.2
Bexley	8.3	2.6	0.7	0.1
Brent	8.9	3.0	1.1	0.3
Bromley	8.2	2.6	0.6	0.1
Camden	10.0	3.6	1.4	0.9
City of London	11.2	4.5	1.8	1.8
Croydon	8.4	2.7	0.8	0.2
Ealing	8.9	2.9	1.0	0.2
Enfield	8.4	2.7	0.8	0.1
Greenwich	8.8	3.0	1.0	0.3
Hackney	9.6	3.4	1.2	0.7
Hammersmith and Fulham	9.7	3.4	1.3	0.7
Haringey	8.9	3.0	1.0	0.3
Harrow	8.3	2.6	0.7	0.0
Havering	7.9	2.4	0.5	0.0
Hillingdon	8.2	2.5	0.7	0.0
Hounslow	8.7	2.8	0.9	0.2
Islington	9.9	3.6	1.3	0.9
Kensington and Chelsea	10.1	3.6	1.4	0.9
Kingston upon Thames	8.5	2.7	0.8	0.1
Lambeth	9.5	3.3	1.3	0.6
Lewisham	9.0	3.1	1.0	0.4
Merton	8.8	2.9	0.9	0.2
Newham	9.1	3.2	1.1	0.5
Redbridge	8.6	2.8	0.9	0.2
Richmond upon Thames	8.6	2.8	0.8	0.2
Southwark	9.7	3.5	1.3	0.8
Sutton	8.4	2.7	0.8	0.1
Tower Hamlets	9.9	3.6	1.4	0.9
Waltham Forest	8.8	2.9	0.9	0.3
Wandsworth	9.3	3.2	1.2	0.5
Westminster	10.4	3.8	1.5	1.1

Table 26 NO_2 concentration with cut-off (in µg m^{-3}) (PWAC annual mean) by borough

Local Authority	NO_2 2019 (with cut-off)	NO_2 2030 (MAQP scenario) (with cut-off)	NO_2 2050 (with cut-off)
Barking and Dagenham	26.8	12.0	7.3
Barnet	29.0	12.1	6.5
Bexley	25.2	11.4	7.1
Brent	31.8	13.6	6.8
Bromley	24.3	10.9	6.6
Camden	39.4	15.6	7.6
City of London	47.3	18.6	9.4
Croydon	26.5	11.7	6.8
Ealing	31.1	13.2	7.2
Enfield	27.1	11.7	6.9
Greenwich	30.0	13.3	8.1
Hackney	35.9	14.3	7.3
Hammersmith and Fulham	37.3	15.1	7.8
Haringey	32.1	13.0	6.9
Harrow	25.6	11.5	6.6
Havering	21.8	9.9	6.4
Hillingdon	25.3	11.8	7.6
Hounslow	30.7	13.9	8.7
Islington	37.9	15.1	7.6
Kensington and Chelsea	41.9	16.0	7.7
Kingston upon Thames	27.9	12.5	7.2
Lambeth	36.1	14.7	7.7
Lewisham	31.4	13.4	7.6
Merton	29.5	12.7	7.1
Newham	31.7	14.3	8.3
Redbridge	27.7	11.9	6.7
Richmond upon Thames	28.9	13.1	7.8
Southwark	37.2	15.6	8.4
Sutton	26.0	11.8	7.0
Tower Hamlets	37.6	15.8	8.6
Waltham Forest	29.9	12.5	6.9
Wandsworth	33.9	14.0	7.3
Westminster	43.6	16.6	8.0

Table 27 Life years saved across the London boroughs of the predicted concentration between 2013 and 2050 compared with 2013 anthropogenic $PM_{2.5}$ concentrations and NO_2 remaining unchanged for the MAQP and WHO scenarios

Local Authorities	**Gain in life years - Without cut off (With cut off)**		
	MAQP		**WHO**
	NO_2	**$PM_{2.5}$**	**$PM_{2.5}$**
Barking and Dagenham	141125 (141498)	150728 (154297)	155110 (158720)
Barnet	228903 (229401)	217175 (221169)	224171 (228223)
Bexley	120543 (120772)	138555 (141159)	143777 (146412)
Brent	241943 (242599)	209106 (213984)	215740 (220690)
Bromley	157466 (157768)	181149 (183532)	188583 (191009)
Camden	202871 (203520)	147258 (150862)	152851 (156524)
City of London	5210 (5243)	3260 (3377)	3481 (3601)
Croydon	226869 (227313)	237724 (241639)	246333 (250320)
Ealing	236342 (236892)	216645 (221468)	224044 (228939)
Enfield	186264 (186628)	192792 (195826)	199141 (202230)
Greenwich	198777 (199184)	194486 (198598)	200279 (204441)
Hackney	261147 (261915)	206715 (211754)	213120 (218242)
Hammersmith and Fulham	153603 (153929)	118575 (121049)	122873 (125396)
Haringey	204008 (204567)	175376 (179582)	181285 (185560)
Harrow	126793 (127132)	139422 (142022)	144544 (147188)
Havering	108695 (108901)	142395 (142786)	147987 (148409)
Hillingdon	157402 (157747)	180718 (183408)	186777 (189519)
Hounslow	166521 (166869)	164629 (168103)	170132 (173661)
Islington	205434 (205913)	154730 (158125)	160302 (163762)
Kensington and Chelsea	127219 (127580)	87088 (89063)	90853 (92868)
Kingston upon Thames	90372 (90545)	92405 (94336)	95837 (97798)

Lambeth	274477 (275172)	219575 (224543)	227238 (232306)
Lewisham	227697 (228204)	206650 (211146)	213439 (218005)
Merton	131820 (132066)	126440 (129170)	130732 (133501)
Newham	264647 (265281)	242764 (248226)	249776 (255327)
Redbridge	177440 (177819)	179456 (183116)	185383 (189096)
Richmond upon Thames	103224 (103485)	104134 (106476)	108337 (110717)
Southwark	280457 (281203)	219761 (224810)	227322 (232462)
Sutton	104111 (104299)	114949 (117302)	119396 (121780)
Tower Hamlets	286095 (286880)	224912 (230129)	231241 (236541)
Waltham Forest	205922 (206461)	190127 (194501)	196066 (200504)
Wandsworth	257693 (258268)	215407 (220077)	222186 (226940)
Westminster	213300 (213928)	142692 (146004)	148368 (151747)

Table 28 Gain in life expectancy across London boroughs from birth in 2013 (followed for 105 years) for anthropogenic $PM_{2.5}$ and NO_2

Local Authorities	**Gain in life expectancy (in days) - Without cut off (With cut off)**	
	MAQP[a]	
	NO_2	**$PM_{2.5}$**
Barking and Dagenham	158 (158)	168 (172)
Barnet	160 (161)	151 (154)
Bexley	134 (134)	153 (157)
Brent	187 (188)	160 (164)
Bromley	134 (134)	152 (154)
Camden	228 (228)	167 (171)
City of London	210 (221)	138 (138)
Croydon	155 (156)	160 (163)
Ealing	179 (179)	163 (167)
Enfield	148	153

	(149)	(155)
Greenwich	169 (169)	166 (169)
Hackney	223 (224)	178 (182)
Hammersmith and Fulham	218 (219)	169 (172)
Haringey	194 (195)	166 (171)
Harrow	136 (137)	148 (151)
Havering	117 (117)	150 (151)
Hillingdon	138 (138)	156 (158)
Hounslow	156 (157)	155 (158)
Islington	234 (235)	177 (181)
Kensington and Chelsea	231 (232)	159 (163)
Kingston upon Thames	145 (145)	147 (151)
Lambeth	214 (215)	173 (177)
Lewisham	184 (185)	167 (171)
Merton	163 (164)	155 (159)
Newham	179 (180)	164 (168)
Redbridge	152 (152)	152 (155)
Richmond upon Thames	145 (146)	145 (149)
Southwark	220 (220)	173 (177)
Sutton	141 (141)	155 (158)
Tower Hamlets	228 (229)	179 (183)
Waltham Forest	181 (181)	165 (169)
Wandsworth	193 (194)	162 (165)
Westminster	249 (250)	169 (174)

[a] Data not shown for WHO scenario as it was very similar to that for the MAQP scenario. See section 6.4 for further discussion.

8.4 Technical note on background $PM_{2.5}$ concentrations

Method

Air pollution concentrations are highly sensitive to the prevailing meteorology within a year and the associated long-range transport of pollutants from outside London during this year. To address these issues, a typical current $PM_{2.5}$ background concentration (representing primary and secondary $PM_{2.5}$ background concentration and rural domestic wood burning $PM_{2.5}$ concentration) was developed using the most recent (measurement data) years available and projected forward (beyond 2019) using the most appropriate (CMAQ-urban) modelling available.

Typical current total background concentration based on latest measurement data

- a typical current $PM_{2.5}$ background concentration of 9.38 $\mu g\ m^{-3}$.was derived using the latest primary and secondary $PM_{2.5}$ measurement background data available between 2015 and 2019[46]
- a typical current $PM_{2.5}$ rural domestic wood burning (DWB) concentration of 0.36 $\mu g\ m^{-3}$ was calculated using an average of all the DWB measurement years available between 2010 and 2019[47].
- a typical current total $PM_{2.5}$ background concentration of 9.75 $\mu g\ m^{-3}$ (made of the sum of typical current primary/secondary background and rural DWB $PM_{2.5}$ as above) was then used to estimate a set of representative total $PM_{2.5}$ background concentration for all future years (2020 to 2050).

CMAQ-urban model and future projection trend

The typical current total $PM_{2.5}$ background concentration (9.75 $\mu g\ m^{-3}$) was projected forward to

- 2020/2021/2025/2030 using CMAQ-urban modelling (Defra, 2019b) based upon a 2012 year and projected to a 2030 Base case; modelled as part of a recently published DEFRA study assessing progress towards WHO (2005) guideline levels of $PM_{2.5}$ in the UK (Defra, 2019a).
- 2050 using CMAQ-urban modelling results extracted from ERG's climate change policy scenarios modelling study (Williams et al., 2018a).

Note that CMAQ-urban future projections used in this study were based on past NIHR and DEFRA modelling scenarios predictions using the best knowledge at the time; views on biomass increases, renewable energy, nuclear energy use, vehicle fleet electrification (and many other sectors assumptions) might have changed since these studies were completed.

Results

$PM_{2.5}$ background concentrations for all the years 2013 to 2050 (see section 4 for further details) have been compiled in *Table 29*. Using the year 2020 as an example, the 2020 $PM_{2.5}$ background concentration was previously projected to be 11.60 $\mu g\ m^{-3}$ using the best available data and method at the time (i.e. year 2013 from LAEI 2013). For this study, 2020 $PM_{2.5}$ background concentrations have been re-projected using a typical current year and estimated to be 9.29 $\mu g\ m^{-3}$. An associated top slicing factor of 2.31 $\mu g\ m^{-3}$ has been calculated. The 2020 (LEZ for Heavier vehicles scenario) air quality $PM_{2.5}$ concentrations have been corrected accordingly (i.e. top sliced by 2.31 $\mu g\ m^{-3}$) to represent the newly estimated $PM_{2.5}$ background concentration (lower) value of 9.29 $\mu g\ m^{-3}$ (instead of the previous value of 11.60 $\mu g\ m^{-3}$).

[46] Note that 2018 data was not available (source LAEI 2016 https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory--laei--2016 and LAEI 2019 snapshot studies in Dajnak et al., 2020b).

[47] Note that only 2010, 2013, 2016 and 2019 data was available (source LAEI2016 and 2019 snapshot studies).

Table 29 Total $PM_{2.5}$ background (i.e. sum of $PM_{2.5}$ primary and secondary background and rural domestic wood burning – DWB source) for all the years of interest 2013-2050

Scenarios	**$PM_{2.5}$ Background**	**$PM_{2.5}$ rural DWB source**	**Total Background**	**Top slicing factor**
2013 (LAEI2013)	12.32	0.40*	**12.72**	
2016 (LAEI2016)	9.78	0.39	**10.17**	
2017 (typical current year)	*9.38*	*0.36*	*9.75*	
2019 (LAEI2019) Snapshot	8.28	0.27	**8.55**	
2020 LEZ for Heavier vehicles New projection using typical current year: *Past projection using 2013 (LAEI2013):*	8.94 *11.20*	0.35 *0.40*	**9.29** *11.60*	*-2.31*
2021 ULEZ expansion to inner area New projection using typical current year: *Past projection using 2013 (LAEI2013):*	8.80 *11.14*	0.34 *0.40*	**9.14** *11.54*	*-2.40*
2025 LES New projection using typical current year: *Past projection using 2013 (LAEI2013):*	8.21 *10.85*	0.32 *0.40*	**8.53** *11.25*	*-2.72*
2030 LES New projection using typical current year: *Past projection using 2013 (LAEI2013):*	7.48 *10.18*	0.29 *0.35*	**7.77** *10.53*	*-2.76*
2030 LES (Plus) - meet WHO (2005) guidelines Projection using 2016 (LAEI2016)	6.49	0.10	**6.59**	
2050 LES New projection using typical current year: *Past projection using 2013 (LAEI2013):*	5.24 *8.06*	0.20 *0.35*	**5.44** *8.41*	*-2.97*

*Note that in LAEI2013 (year 2013 and future projections), the domestic wood burning was not disaggregated by urban and rural fraction but given as a total and represented as part of the background concentration (estimated to be 1.07 $\mu g\ m^{-3}$ and kept constant in all future years up to 2025 then reduced to 0.94 $\mu g\ m^{-3}$ as part of LES scenarios in 2030 and 2050); the rural fraction of domestic wood burning was estimated to be 37% in 2013 using the LAEI2016 wood burning methodology

8.5 Additional Health assessment methods

Anthropogenic $PM_{2.5}$: Non-anthropogenic $PM_{2.5}$ was derived by Ward using CMAQ data for a range of available years and subsequently by subtracting the modelled contribution from natural aerosols sources such as sea-salt - from the total $PM_{2.5}$ modelled to generate anthropogenic $PM_{2.5}$ concentrations; consistent with EU guidance (European Commission, 2011).

- CMAQ 2011 and 2012 data (Williams et al., 2018a) averaged at Ward level to represent 2013
- New CMAQ 2015 to 2017 data averaged at Ward level to represent 2016
- New CMAQ 2017 and 2018 data averaged at Ward level to represent 2019
- CMAQ 2030 data (Defra, 2019b) averaged at Ward level to represent 2030
- Interpolated between 2019 and 2030 to represent intermediate years 2020, 2021 and 2025
- CMAQ 2050 data (Williams et al., 2018a) averaged at Ward level to represent 2050

Population data in London used for the mortality burden calculations: The population data has been obtained from ONS by gender and by single year of age at OA level[48] and averaged for 2016/2017/2018 to represent 2019. The population has been summed by gender and 1-year age groups for aged 30 and above for each OA, each LSOA, each ward, each borough and for London overall.

Population data in London used for the mortality impacts calculations: The population data has been obtained from ONS by gender and by single year of age at OA level[49] and averaged for 2012/2013/2014 to represent 2013. OA data by gender and 1-year age groups was then aggregated up to Wards level.

Deaths data in London used for the mortality burden calculations: The deaths data has been obtained from ONS by gender and by single year of age at LSOA level and averaged for 2016/2017/2018 to represent 2019. LSOA level deaths data were available for the year 2016[50] and requested directly from ONS for the years 2017-2018.

Deaths data in London used for the mortality impacts calculations: The deaths data has been obtained from ONS by gender and by single year of age at LSOA level and averaged for 2012/2013/2014 to represent 2013. LSOA level deaths data were only available for the year 2016[51] and requested directly from ONS for the years 2012-2014. LSOA data by gender and 1-year age groups was then aggregated up to Wards level. Note that deaths data for subsequent years were projected within the life-tables. This means that it does not take into account the increased mortality from COVID-19 in 2020. We considered that any analysis to take this into account was best done after the pandemic when a full update could be completed.

Mortality Burden

The calculations followed COMEAP (2018a) and earlier methodology from COMEAP (2010) and Gowers et al (2014).

Using the COMEAP (2010)/Gowers *et* al (2014) methodology as the first example, the relative risk (RR) per 10 $\mu g\ m^{-3}$ was scaled to a new relative risk for the relevant anthropogenic $PM_{2.5}$ concentration. The equation used was:

RR(x) = 1.06x/10 where x is the average concentration of interest.

The new RR(x) was then converted to the attributable fraction (AF) using the following formula:

AF = (RR-1)/RR multiplied by 100 to give a percentage.

48 https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/censusoutputareaestimatesinthelondonregionofengland. (Accessed 21 July 2020).

49 https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/censusoutputareaestimatesinthelondonregionofengland (Accessed 24 September 2020).

50 https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/007713deathsbylowersuperoutputareasexandsingleyearofageenglandandwales2016. (Accessed 21 July 2020).

51 https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/007713deathsbylowersuperoutputareasexandsingleyearofageenglandandwales2016 (Accessed 24 September 2020).

The attributable fraction was then multiplied by the number of deaths in the relevant gender and 1-year age group aged 30+ to give the number of attributable deaths.
The attributable deaths were then summed across the 1-year age groups above aged 30, for both males and females, to give a total for each LSOA.
The calculations above were done at LSOA level and the results for deaths summed to give a total for each Ward and borough and for Greater London. This allows different death rates in different LSOAs to influence the results.
The process was repeated for the lower and upper confidence intervals around the relative risks, and for a cut-off of 7 µg m^{-3} $PM_{2.5}$.

The COMEAP (2018a) methodology uses the above method for $PM_{2.5}$ but also calculates a result using a single-pollutant model relative risk for NO_2 and a result combining multi-pollutant model estimates for NO_2 and $PM_{2.5}$.

The method for the single-pollutant model calculation for NO_2 is exactly analogous to that above for $PM_{2.5}$ except that the relative risk used is 1.023 (1.008 – 1.037) and the cut-off where used is 5 µg m^{-3} NO_2.

The method using multi-pollutant model results is also based on the same method for scaling the relevant relative risks (see Table 16) according to the relevant pollution concentration. In this case though, there are more calculations (16) because calculations are done separately for each pollutant for relative risks derived from each of 4 studies, both with and without the relevant cut-off for each pollutant. There is also an additional step in that the NO_2 and $PM_{2.5}$ results within each study are summed and then the final result expressed as the range for the sums across the 4 studies. This can be illustrated by examining Table 30 (without cut-offs). It can be seen for Greater London (Table 30) that the sum of column 2 (1,670 attributable deaths) and column 3 (2,114 attributable deaths) leads to the result in column 4 (3,784 attributable deaths). In this example, the results in columns 2 and 3 should be regarded only as intermediate steps in the calculation as it may be that one is over-estimated and the other under-estimated. This is thought to cancel out for the summed result, which is therefore more robust.

Table 30 Estimated burden (from one of the four multi pollutant studies) of effects on annual mortality in 2019 of 2019 levels of anthropogenic $PM_{2.5}$ and NO_2 (without cut-off)

Zone	**Anthropogenic $PM_{2.5}$ (without cut-off) (not to be used separately)**	**NO_2 (without cut-off) (not to be used separately)**	**Anthropogenic $PM_{2.5}$ and NO_2 (without cut-off) (combined estimate has less uncertainty)**
	Attributable deaths* (Life year lost*)**	**Attributable deaths** (Life year lost***)**	**Attributable deaths (Life year lost***)**
	Fischer	**Fischer**	**Fischer**
Greater London	1,670 (28,569)	2,114 (36,383)	3,784 (64,951)

* Using COMEAP's recommended concentration-response coefficient of 1.033 per 10 µg m^{-3} of anthropogenic $PM_{2.5}$ derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Fischer *et al* (2015) study

** Using COMEAP's recommended concentration-response coefficient of 1.016 per 10 µg m^{-3} of NO_2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for $PM_{2.5}$ from the Fischer *et al* (2015) study as an example.

*** Associated life years lost, age 30+ and calculated by gender and 1-year age groups, by LSOA then summed up to Wards/boroughs/Greater London level.

The expected remaining life expectancy was calculated in every LSOA in London using the deaths and population data in each LSOA based on the method from the South East Public Health Observatory (SEPHO) Life Expectancy Calculator[52] (for 5-year age groups). This adapted calculation provided the expected remaining life expectancy for specified 1-year age groups. This was calculated separately for males and females. Note that this is the baseline life expectancy, representing how much an average person of that age group would have been expected to live if it had not been for the pollution attributable deaths. The relevant values for expected remaining life expectancy in an age group were then multiplied by the number of pollution attributable deaths to estimate the total life years lost.

Wards/Boroughs/Greater London output: The final mortality burden output was summarised at Wards/Boroughs/Greater London level using the 2018 Wards layer[53] (with City of London Wards merged).

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52 https://webarchive.nationalarchives.gov.uk/20130329125326/http://www.lho.org.uk/viewResource.aspx?id=8943&sUri=http%3a%2f%2fwww.sepho.org.uk%2f

53 https://data.london.gov.uk/dataset/statistical-gis-boundary-files-london. (Accessed 21 July 2020)

Mortality Impact

Projections for the baseline life tables before applying concentration changes
Natural change – current population size, age distributions and mortality rates will generate future changes in population and age structure in any case. We did not add this separately as it is already taken into account in our life table modelling.

Changes in births over time –

- actual data on numbers of births at OA level[49] was used from 2013 to 2018 then aggregated up to Wards level
- birth projections by local authority (2018 based edition[54]) were obtained from 2019 to 2043 and combined with the ratio of birth by Wards (within each local authority) in 2018 to scale the 2019 to 2043 birth data to Wards level
- the ratio of birth projections to 2043 births for England obtained from national populations projections (2018 based edition[55]) was used to scale 2043 births in Wards to Wards births for 2044 to 2118
- No projections were available after 2118 so births were left constant for 2119 to 2154

Mortality rate improvements were applied to the 2013 all-cause hazard rates according to the projected % improvements per year provided by ONS. Percentage improvements by gender and ages are provided in Office for National Statistics (2014[56] and 2018[57] based edition); note that the rate of mortality improvement has been set at 1.2% for 2043 to 2154.

Migration – predicting migration at the current time post the European referendum is particularly uncertain with both increases and decreases forecast. We did not therefore include this in our first analyses as presented in this report. Over the country, as a whole, this contribution to overall health impacts is likely to be small. This can be explored further in future work.

Lags: The approach allowed for a delay between exposure and effect using the recommended distribution of lags from COMEAP (COMEAP, 2010) i.e. 30% of the effect in the first year, 12.5% in each of years 2-5 and 20% spread over years 5-20. An analogous approach was used for the effects of long-term exposure to NO_2. HRAPIE (WHO, 2013b) recommended that, in the absence of information on likely lags between long-term exposure to NO_2 and mortality, calculations should follow whatever lags are chosen for $PM_{2.5}$.

Calculations

The relative risk (RR) per 10 µg m^{-3} was scaled to a new relative risk for the appropriate population-weighted mean for each gender in each ward for each scenario and year. The equation used (for the example coefficient of 1.06) was: RR(x) = 1.06x/10 where x is the concentration of interest (with a negative sign for a reduction). Concentrations were assumed to reduce linearly between the years in which modelled concentrations were available (2013, 2016, 2019, 2020, 2021, 2025, 2030 and 2050). The scaled RR was then used to adjust the all-cause hazard rates in the life table calculations.
For the 5 µg m^{-3} cut-off for NO_2, ward concentrations were interpolated between the years in which modelled concentrations were available (2013, 2016, 2019, 2020, 2021, 2025, 2030 and 2050) and 5 µg m^{-3} was then subtracted from the ward concentrations in each year. Any resulting negative concentrations were then set to zero before all the ward concentrations were population-weighted to local authority level as normal.

[54] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/localauthoritiesinenglandz1 (Accessed 24 September 2020).
[55] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections (Accessed 24 September 2020).
[56] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/compendium/nationalpopulationprojections/2015-10-29/mortalityassumptions (Accessed 24 September 2020).
[57] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/adhocs/11827calendaryearmortalityimprovementsfor2018basedprojectionsukexcludingscotlandandscotlandseparately (Accessed 24 September 2020).

Life table calculations were programmed in SQL based on the methods used in the standard IOMLIFET spreadsheets with the following amendments:

- Extension to 2154 (105 years after 2050)
- Adjustment of the baseline hazard rates over time according to projected mortality rate improvements
- Inclusion of changes in numbers of births over time
- IOMLIFET excludes neonatal deaths. We included neonatal deaths and followed the South East Public Health Observatory life-expectancy calculator[58] and Gowers et al. (2014) in taking into account the uneven distribution of deaths over the course of the first year when calculating the survival probability. (The survival probability (the ratio of the number alive at the end of the year to the number alive at the beginning) is derived by the equivalent of adding half the deaths back onto the mid-year population to give the starting population and subtracting half the deaths from the mid-year population to give the end population, assuming deaths are distributed evenly across the year. This is not the case in the first year where a weighting factor based on 90% of the deaths occurring in the first half of the year and 10% in the second half is used instead. After rearrangement the actual formula is (1- 0.1 x hazard rate)/(1+ 0.9 x hazard rate) rather than the (1- 0.5 x hazard rate)/(1+ 0.5 x hazard rate) used in other years.)

Wards/Boroughs/Greater London output: The changes in life years in the life tables were then summed across the total population and the full time period in each ward. Results for total and annual life years lost by wards were then summed to local authorities and Greater London level. We also used the life tables to calculate changes in life expectancy.

[58] https://webarchive.nationalarchives.gov.uk/20130329125326/http://www.lho.org.uk/viewResource.aspx?id=8943&sUri=http%3a%2f%2fwww.sepho.org.uk%2f

8.6 Additional policies for meeting $PM_{2.5}$ WHO (2005) guidelines by 2030

Extracted from "$PM_{2.5}$ in London: Roadmap to meeting WHO guidelines by 2030"[59] report (page 9 and 10) published by TfL and GLA.

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The Mayor of London has many of the powers required to tackle road transport emissions. The London Environment Strategy and Mayor's Transport Strategy include policies such as:

• Introducing the world's first Ultra Low Emission Zone (ULEZ) in April 2019

• Expanding the Ultra Low Emission Zone in 2021 to the North and South Circulars for all vehicles and London wide for lorries, coaches and buses from 2020;

• Transforming the whole of London's bus fleet by phasing out of pure diesel buses and purchasing only hybrid or zero-emission double decker buses from 2018, with the entire fleet becoming 'zero emission' by 2037 at the latest;

• No longer licensing new diesel taxis from 2018 and supporting the trade to upgrade to much cleaner 'zero emission capable' vehicles;

• Reducing traffic volumes by encouraging mode shift from travelling by car to walking, cycling and using public transport so that 80 per cent of all trips in London to be made on foot, by cycle or using public transport by 2041.

These policies will greatly reduce $PM_{2.5}$ emissions from road transport.

However, as a result of this powerful action, the emissions from non-transport sources will increase as a proportion of London's total emissions. The Mayor has much weaker – and often no – powers to tackle these sources. The London Environment Strategy laid out the additional powers required by the Mayor to tackle non-transport sources to achieve WHO recommended guidelines, including:

• Introduce a powerful new twenty-first century Clean Air Act to entrench citizens' right to breathe clean air and tackle pollution in London once and for all;

• Revitalise smoke control zones by making it easier to declare them, strengthening and bringing up to date local authority enforcement powers and conferring the ability to create zero emission zones where no combustion is allowed on certain, time limited occasions. This should include new powers to require appropriate abatement of significant combustion related sources of $PM_{2.5}$ in London;

• Address wood burner emissions through a new fit-for-purpose testing regime and information on appropriate technology/ fuels for smoke control zones at point of sale as well as new powers for the Mayor to set tighter minimum emission standards for new wood burning stoves sold in London (for example, eco-design standard), or other standards based on contemporary understanding of pollutants such as $PM_{2.5}$, rather than "dark smoke" or "grit and dust";

• Provide new powers for regional and local authorities to control emissions from Non-Road Mobile Machinery (NRMM). This includes stronger enforcement powers to secure improved regulation of NRMM, including for auxiliary power and refrigeration units on vehicles and trailers, construction, road works, events and industrial sites; and

• Provide new powers and improved coordination for river and maritime vessels, including having a single regulatory authority for the Thames and London tributaries and introduce minimum emissions standards.

In addition, the Government should take a lead on working with industry and other partners to seek solutions to reduce emissions from tyre and brake wear alongside the other measures in the Clean Air Strategy.

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[59] https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/pm25-london-roadmap-meeting-who-guidelines-2030 (Accessed 22 September 2020).

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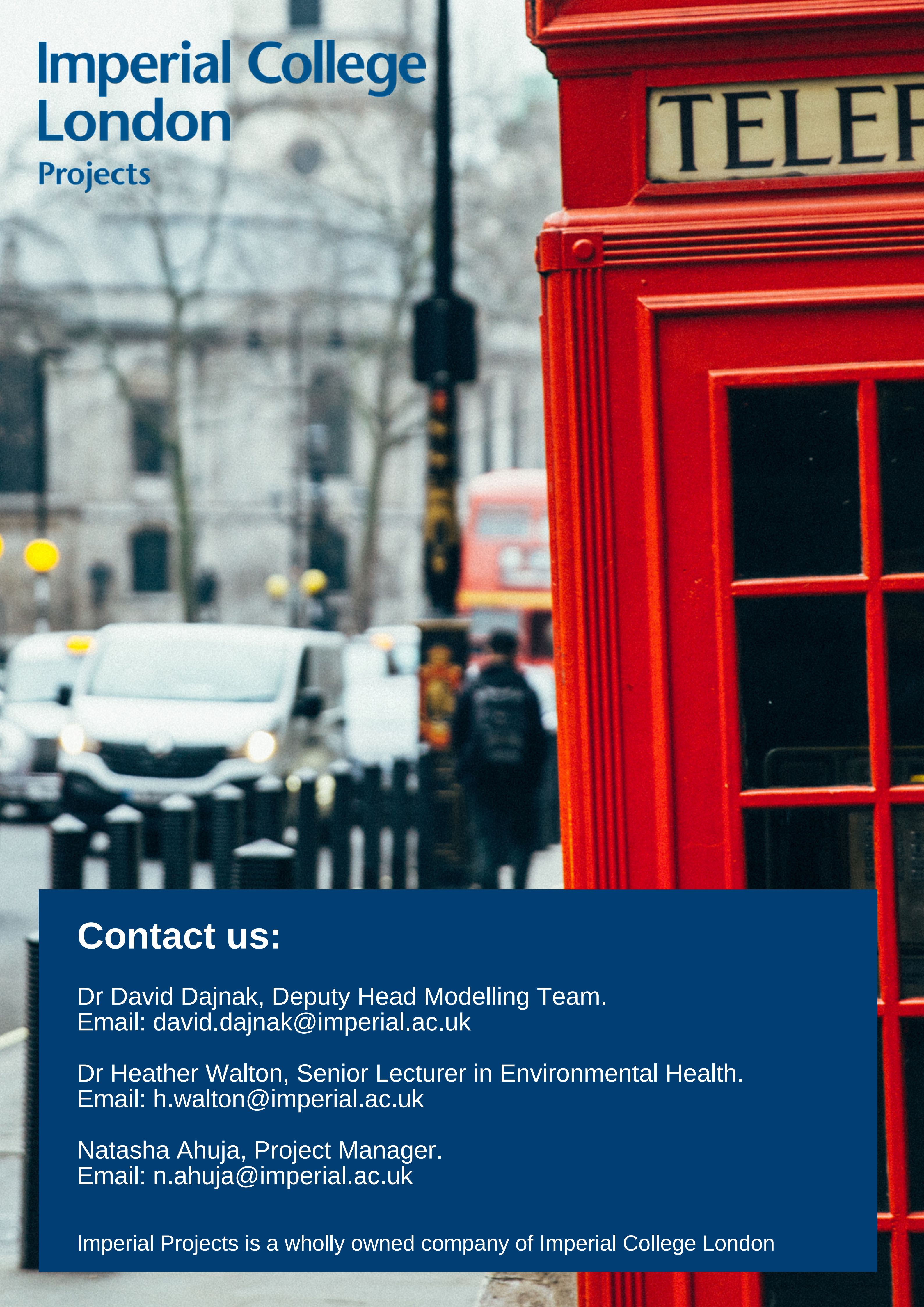

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