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London health burden of recent air pollution

For: Transport for London (TfL) and
Greater London Authority (GLA)

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Key findings[1]

- This report finds that air pollution in London in 2024 was still associated with a large number of deaths. An updated methodological framework which takes into consideration the latest evidence from air pollution epidemiological studies, as well as the estimation of the combined effects of $PM_{2.5}$ and NO_2, was applied. It was estimated that **3,800 to 5,100 premature deaths in 2024** (equivalent to **65,600 to 87,700 life years lost**) can be attributed to air pollution and the associated economic costs are **£3.8 to £5.1 billion**.

- **Air pollution in London has improved markedly between 2019 and 2024** but it still is responsible for a substantial impact on mortality and **remains a major public health challenge**. Over this five-year period, population-weighted average concentrations fell by 28% for $PM_{2.5}$ and 41% for NO_2 reflecting long-term progress and the impact of policies to reduce emissions, particularly from road transport.

- **New evidence from recent studies on the increased harm from long-term exposure to air pollution** has been utilised under a **revised methodological framework**. Using this updated framework, the mortality burden for 2024 exceeds our previous estimates for 2019 which were calculated using the most up-to-date methodology at that time.

- One way to judge **progress made between 2019 and 2024** is to apply a consistent hypothetical framework with up-to-date methods and inputs. Within this framework, **estimated mortality burden was reduced by 37% to 40%** from ~6,390–8,040 attributable deaths under 2019 air pollution levels to ~3,810–5,100 under 2024 levels, **although this comparison assumes all other inputs (population, baseline deaths, exposure-response associations) remain constant and only air pollution changes**.

- These reductions highlight significant air quality improvements across Greater London over this period, likely driven by various policies, most notably the Ultra Low Emission Zone (ULEZ). This study shows that **London has made real progress** but a crucial message for policy makers and the public is that **continued action is needed to reduce the health burden associated with air pollution even where legal standards are being met** and it should remain a public health priority. Current UK legal limits are not the same as safe levels, and current scientific evidence indicates that health effects continue even at low concentrations (with new evidence of $PM_{2.5}$ effects continue down to the lowest measurable levels) pointing to the need for ever lower air pollution standards.

- This work also shows that the **burden of air pollution** is **not evenly distributed** across London. Boroughs with larger populations tend to have the highest total numbers of attributable deaths (i.e. absolute burden), while per-capita burden (i.e. burden per 100,000) is also shaped by age profile and underlying death rates. This means areas with lower pollution can still experience relatively high health burdens as **both pollution level and local population characteristics influence where impacts are greatest**.

- This assessment therefore supports sustained efforts to **reduce air pollution exposure** further **across all parts of London**.

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[1] This assessment was commissioned by Transport for London and the Greater London Authority and undertaken by researchers at the Environmental Research Group, Imperial College London.

- This study uses the **most advanced and methodologically robust mortality burden assessment** undertaken for London to date. It updates earlier work with the most up-to-date pollution modelling, new Census 2021 data, and stronger epidemiological evidence.

- Importantly, this work introduces an approach for **estimating more accurately the combined health effects of $PM_{2.5}$ and NO_2 using multi-pollutant model results,** as recommended by the World Health Organization (WHO) in its 2025 Health Risks of Air Pollution In Europe (HRAPIE-2) guidance report.

- **Finally, future health impact assessments** should look to **incorporate morbidity outcomes**, such as asthma and cardiovascular disease, given that new evidence suggests they carry a health and economic burden comparable to that of mortality.

1.0 Summary for decision-makers and stakeholders

Background and purpose

This report provides an estimate of the mortality burden (MB) associated with air pollution in Greater London for the year 2024. This study was commissioned by Transport for London (TfL) and the Greater London Authority (GLA) and undertaken by researchers at the Environmental Research Group (ERG), Imperial College London (Imperial). This assessment builds on earlier London health burden assessments, by Walton et al. (2015) and Dajnak et al. (2021) and updates them in several important ways.

This work represents the most methodologically advanced mortality burden assessment undertaken for London, incorporating the latest epidemiological evidence on concentration-response functions (CRFs) recommended by WHO in the 2025 HRAPIE-2 guidance report, refreshed Census 2021 geographic boundaries, updated Census 2021 population and mortality data, and a new approach to estimating the combined health effects of multiple air pollutants. This study also developed and used a new high-resolution air quality modelling dataset representing a recent snapshot of London's air pollution for the year 2024.

London's air quality in 2024

The assessment focuses on two pollutants with well-established links to premature mortality: particles with an aerodynamic diameter < 2.5 µm ($PM_{2.5}$) and nitrogen dioxide (NO_2). Air pollution concentrations for $PM_{2.5}$ and NO_2 were modelled across Greater London at high spatial resolution (20 m × 20 m) using the well-established 'London Toolkit' model (Dajnak et al. 2023). These annual mean concentrations were then averaged to small output area (OA) and population-weighted average concentrations were calculated at Lower layer Super Output Area (LSOA) [2] level for use in the health burden calculations, allowing the researchers to estimate the mortality burden at LSOA level and then aggregate results to wards, boroughs, and Greater London as a whole.

The air quality modelling outputs from this study showed that the population-weighted average concentrations (PWAC) across Greater London declined markedly between 2019 and 2024:

- $PM_{2.5}$ fell from 10.9 $\mu g\ m^{-3}$ (2019) to 7.8 $\mu g\ m^{-3}$ (2024) – a reduction of 28%
- NO_2 fell from 28.8 $\mu g\ m^{-3}$ (2019) to 17.0 $\mu g\ m^{-3}$ (2024) – a reduction of 41%

London's substantial improvements in air quality over the period 2019 to 2024 reflect the cumulative impact achieved through a combination of long-term pollution trends and successive policies to reduce emissions, especially from road transport. The Ultra Low Emission Zone (ULEZ) has been central to this progress as detailed in the London-wide ULEZ One Year Report (GLA, 2025).

Mortality burden estimation

The premature mortality burden was estimated using CRFs from the WHO HRAPIE-2 report (WHO, 2025). More specifically, pooled single-pollutant model estimates from recent systematic reviews were used (Orellano et al., 2024; Kasdagli et al., 2024). These CRFs reflect stronger exposure-response associations, i.e. higher risks of death associated with an increase in long-term exposure to air pollution, than those used in the previous 2021 report:

- $PM_{2.5}$: Hazard Ratio (HR) = 1.095 (95% CI: 1.064–1.127) per 10 $\mu g\ m^{-3}$
- NO_2: HR = 1.05 (95% CI: 1.03–1.07) per 10 $\mu g\ m^{-3}$

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[2] OAs and LSOAs are standardised UK geographic areas used to collect and publish census and socio-economic data, ensuring consistent and population-balanced comparisons across different regions over time.

Addition of the results for $PM_{2.5}$ and NO_2 from these single pollutant functions is considered likely to overestimate impacts given correlation in concentrations of the two pollutants, arising because they share common sources (e.g. road traffic) to a significant degree. A key methodological advance in this report is the estimation of the combined health effects of $PM_{2.5}$ and NO_2 using adjustment factors derived from the work of Chen et al. (2024), as recommended by the WHO HRAPIE-2 report and supported by the Committee on the Medical Effects of Air Pollutants (COMEAP) subgroup on the quantification of air pollution risks (QUARK). This approach accounts for the correlation between the two pollutants by applying adjustment factors to the single-pollutant CRFs, yielding adjusted combined-effect estimates of

- $PM_{2.5}$: HR = 1.062 (95% CI: 1.042–1.083) per 10 µg m^{-3}
- NO_2: HR = 1.037 (95% CI: 1.023–1.052) per 10 µg m^{-3}

To calculate the total impact of both pollutants, the central burden estimates for $PM_{2.5}$ and NO_2, each based on adjusted CRFs, were added together to reflect their combined effect on health.

The Chen et al. (2024) approach used in this report draws on evidence from 17 cohort studies. This represents a substantial advancement over our previous report which used multi-pollutant model methods based on only four cohort studies. Results are presented both with and without a cut-off concentration for NO_2 (5 µg m^{-3}), reflecting ongoing uncertainty about the shape of the concentration-response relationship at lower pollution levels. No cut-off was applied for $PM_{2.5}$, in line with current evidence suggesting health effects persist at low concentrations close to zero, following COMEAP recommendations. All burden calculations were performed at LSOA level using three-year averaged (2022–2024) population and mortality data from the Office for National Statistics (ONS), ensuring robustness and consistency with previous analyses.

The mortality-related economic costs are measured using the Value of a Life Year (VOLY) methodology, which monetises changes in longevity. VOLYs are a well-established method used in environmental economics to translate years of life lost into a standardised economic cost. This study follows the approach used by His Majesty's Treasury (HMT, 2026) and the Department for Environment Food & Rural Affairs (DEFRA, 2025a), estimating the VOLY for 2024 at £58,069 (95% CI: £36,637 to £72,354). VOLYs provide a consistent and standardised way to assign an economic cost to the loss of utility (quality of life) from reduced life expectancy from exposure to air pollutants. VOLYs method do not account for additional impacts on health care costs, productivity or utility leading up to death that may be linked to pollutants causing a higher incidence of disease – those costs would be factored into estimates of elevated morbidity linked to air pollution.

Mortality burden results based on the effects of $PM_{2.5}$ and NO_2 separately

Using single-pollutant model CRFs, the premature mortality burden attributable to each pollutant in Greater London in 2024 was estimated as follows:

- $PM_{2.5}$ (no cut-off): 3,340 attributable deaths (95% CI: 2,310–4,350), equivalent to 57,100 life years lost (95% CI: 39,500–74,500), at an estimated annual cost of £3,320 million (£1,870–£4,770 million).
- NO_2 (no cut-off): 3,810 attributable deaths (95% CI: 2,340–5,200), equivalent to 65,600 life years lost (95% CI: 40,400–89,600), at an estimated annual cost of £3,810 million (£1,950–£5,670 million).
- NO_2 (with cut-off of 5 µg m^{-3}): 2,680 attributable deaths (95% CI: 1,640–3,670), equivalent to 46,400 life years lost (95% CI: 28,400–63,600), at an estimated annual cost of £2,690 million (£1,370–£4,020 million).

Given the strong correlation between $PM_{2.5}$ and NO_2, directly summing the independent estimates would overestimate the true combined burden. In line with existing COMEAP recommendations, **the maximum of the two burden estimates can be used as a proxy for their combined effects**. Accordingly, the NO_2 no cut-off estimate of **3,810 (2,340–5,200) attributable deaths** could be taken as a representative of the mortality burden from air pollution as a mixture.

Mortality burden results based on the combined effects of $PM_{2.5}$ and NO_2

Applying the multi-pollutant model adjustment approach recommended by the WHO HRAPIE-2 report, the **combined mortality burden attributable to $PM_{2.5}$ and NO_2** in Greater London in 2024 was estimated at:

- Without cut-off: 5,100 attributable deaths (95% CI: 3,820–6,380), equivalent to 87,700 life years lost (95% CI: 65,700–110,000), at an estimated annual cost of £5,090 million (£3,380–£6,800 million).
- With cut-off for NO_2: 4,250 attributable deaths (95% CI: 3,210–5,280), equivalent to 73,100 life years lost (95% CI: 55,300–91,000), at an estimated annual cost of £4,250 million (£2,850–£5,650 million).

These combined estimates are substantially larger than the maximum of the separate single-pollutant estimates, demonstrating that the previously recommended approach of using the larger of the two independent estimates as a proxy for the combined burden is likely to underestimate the true impact of air pollution as a mixture.

Summary of results in 2024

Condensing these findings into a single central estimate is not straightforward, given the range of methodological assumptions involved. The most appropriate range, depending on the preferred assumptions, can be summarised as follows:

- Using the latest scientific evidence, the report estimates that the burden for long-term exposure to $PM_{2.5}$ and NO_2 in 2024 was equivalent to around **3,810 to 5,100 attributable deaths or 65,600 to 87,700 life years lost. The associated mortality-related economic costs have been valued at £3.8 billion to £5.1 billion**, reflecting the monetised impact of changes in longevity as quantified by the Value of a Life Year (VOLY) methodology.
- Presenting a combination of the largest single-pollutant and multiple-pollutants results is a strength of this report as it provides a transparent range rather than implying a false precision.

Spatial variation across London

Spatially, the **highest concentrations of both $PM_{2.5}$ and NO_2 were recorded in central and inner London boroughs**, reflecting dense road networks and other concentrated urban emission sources. Boroughs such as the City of London, Westminster, Camden, Kensington and Chelsea, Islington, and Tower Hamlets had some of the highest population-weighted concentrations, while the **lowest concentrations were found in outer London boroughs** such as Havering and Bromley. Notable exceptions included Hillingdon and Hounslow, which ranked considerably higher for NO_2 than for $PM_{2.5}$, reflecting the significant influence of Heathrow Airport on local concentrations.

The analysis was conducted at LSOA level, enabling detailed examination of spatial variation in mortality burden across London's wards and boroughs. Key findings included:

- In absolute terms, boroughs with the largest populations had the highest number of attributable deaths – notably Croydon, Barnet, Bromley, Ealing and Brent.

- When normalised by population (attributable deaths per 100,000 residents), a markedly different pattern emerges. Despite having relatively lower pollution concentrations, Bexley, Havering and Sutton had the highest per-capita burdens, driven primarily by their older demographic profiles and higher baseline death rates among the 30+ population.
- Kensington & Chelsea and Camden also ranked highly on a per-capita basis, and the burden is primarily driven by their elevated pollution concentrations.
- Several inner London boroughs such as Tower Hamlets, Newham and Wandsworth had the lowest per-capita burdens, largely attributable to their younger population profiles and lower baseline death rates, despite comparatively higher pollution concentrations.
- The City of London presented a distinct case: despite recording the highest $PM_{2.5}$ and NO_2 concentrations of any borough, its very small residential population and low baseline death rate resulted in the lowest absolute mortality burden across Greater London. It should be noted that the modelling does not account for the City's substantially larger daytime working population.

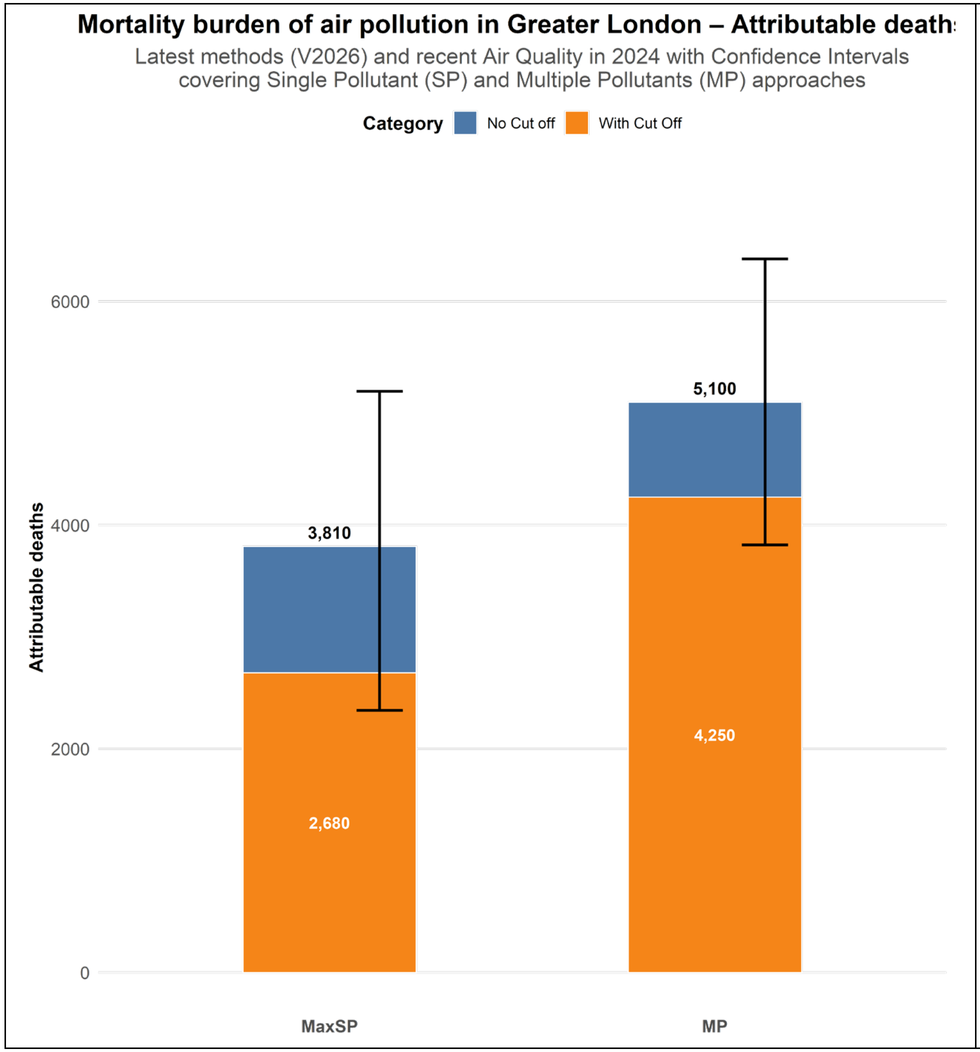
These findings underscore that both absolute and per-capita burden metrics are essential for a comprehensive understanding of the health impacts of air pollution across London's diverse boroughs.

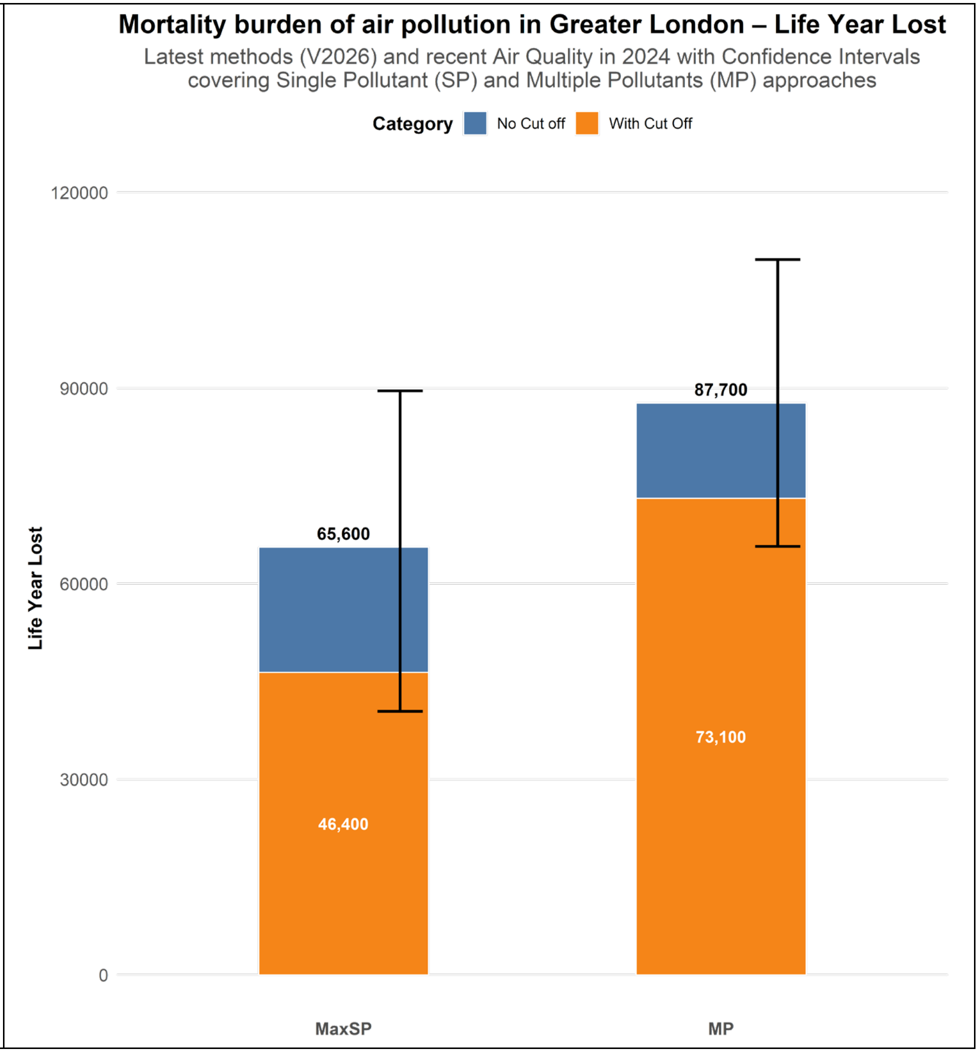
Discussion

The estimates in this report represent a snapshot of the mortality burden within a specific year associated with long-term exposure to air pollution, under the assumption that the pollutant concentrations have remained constant at 2024 levels over the preceding years. The updated framework incorporated a broader and more comprehensive epidemiological evidence base, making it scientifically more robust than previous estimates (Dajnak et al., 2021). The present analysis applied substantially higher CRFs across all pollutants considered (i.e. $PM_{2.5}$ and NO_2) with and without adjustment for the combined effects using multi-pollutant model results. Importantly, higher CRFs meant that for a given level of pollution exposure, population size, and mortality rates, the estimated mortality burden was larger. Even with cleaner air in 2024, the absolute burden figures are now higher compared with older estimates reported for 2019 (Dajnak et al., 2021). The upward revision in CRFs has outweighed the downward effect of cleaner air when comparing across methodological generations. This is not a contradiction; it reflects better scientific understanding of the impacts of air pollution on health.

For this reason, policymakers should use the same analytical framework as the most meaningful indicator of progress, rather than comparing burden estimates across different methodological versions.

Comparing the 2024 mortality burden with that estimated for 2019, using a hypothetical scenario based on a consistent methodological framework to ensure direct comparability, revealed a reduction from around 6,390 to 8,040 attributable deaths using 2019 air pollution levels to approximately 3,810 to 5,100 deaths based on 2024 air pollution levels. This is a difference in premature mortality of 37% to 40% between 2019 and 2024, but it is based on a hypothetical scenario in which all the inputs remain stable (i.e. population, deaths and CRFs) and only the air pollution levels vary.


Mortality burden of air pollution in Greater London – Attributable death
Latest methods (V2026) and recent Air Quality in 2024 with Confidence Intervals
covering Single Pollutant (SP) and Multiple Pollutants (MP) approaches
Category
No Cut off
With Cut Off
Attributable deaths
6000
4000
2000
0
3,810
2,680
5,100
4,250
MaxSP
MP


Mortality burden of air pollution in Greater London – Life Year Lost
Latest methods (V2026) and recent Air Quality in 2024 with Confidence Intervals
covering Single Pollutant (SP) and Multiple Pollutants (MP) approaches
Category
No Cut off
With Cut Off
Life Year Lost
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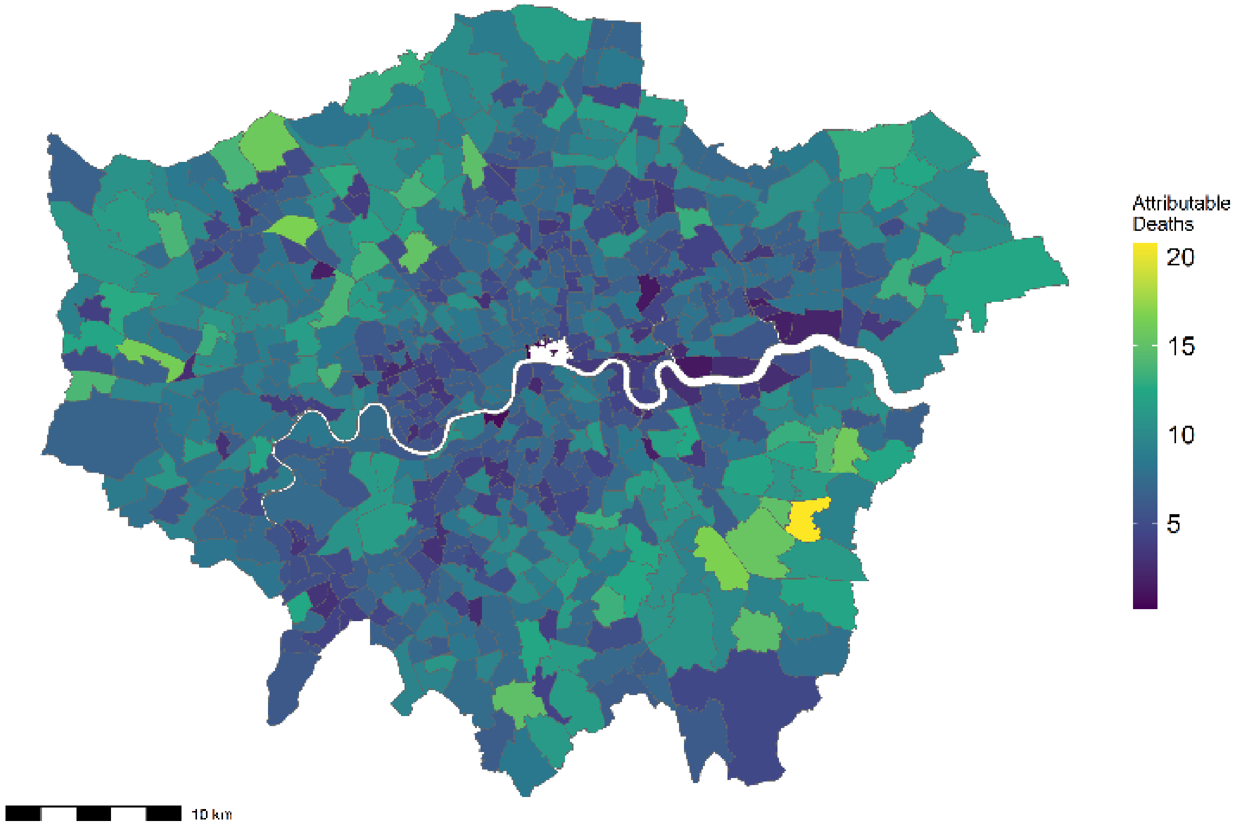
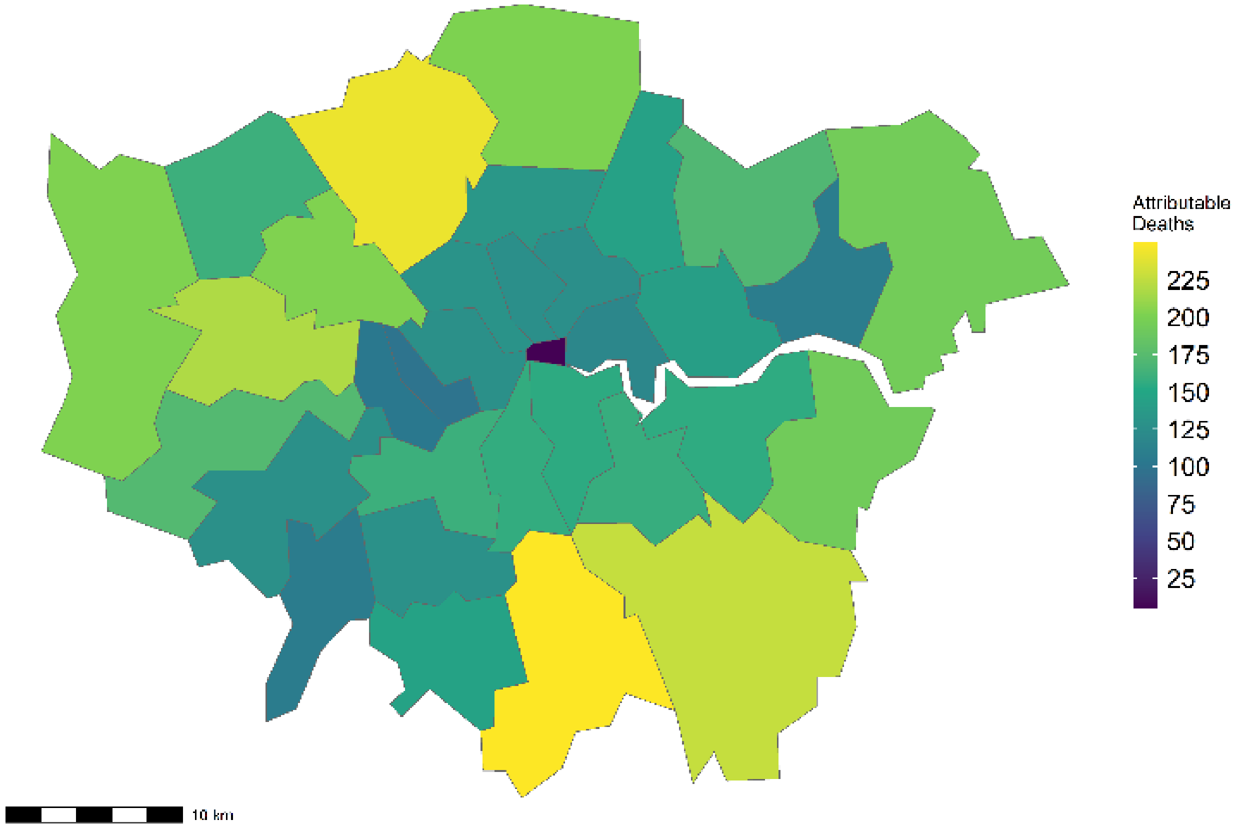
90000
60000
30000
0
65,600
46,400
87,700
73,100
MaxSP
MP



Mortality Burden by Ward of air pollution in Greater London in 2024
based on the 2026 MP method (no cut off)



Mortality Burden by borough of air pollution in Greater London in 2024
based on the 2026 MP method (no cut off)

Conclusions

This report provides the most comprehensive and methodologically robust assessment of the mortality burden of air pollution in London to date, leading to the following conclusions:

1. London's air quality has improved markedly since 2019, with estimated reductions of 28% in $PM_{2.5}$ and 41% in NO_2 population weighted annual mean concentrations, translating into a reduction in the health burden of air pollution.
2. London’s air pollution in 2024 still imposed a substantial mortality burden on its population, with the combined effects of long-term exposure to $PM_{2.5}$ and NO_2 estimated to be responsible for between approximately 3,800 and 5,100 attributable deaths in 2024, depending on the assumptions applied.
3. The new multi-pollutant approach for estimating the combined health effects of $PM_{2.5}$ and NO_2, based on Chen et al. (2024), recommended by the WHO HRAPIE-2 report and supported by COMEAP's QUARK subgroup, represents a scientifically more robust methodology than previous approaches and yields greater combined burden estimates, suggesting that earlier methods likely underestimated the impact of air pollution as a mixture.
4. Spatial variation across London is substantial, with the mortality burden shaped by a complex interplay of pollution concentrations, population size, age structure, and baseline death rates – making the case for targeted action across all boroughs.
5. Continued action remains necessary even after legal compliance has been achieved. Legal limits are important and set expectations as to level that should be achievable, but they are not health-based thresholds below which no harm occurs. Whilst these reductions represent a significant step forward, further reductions in air pollution remain both essential and beneficial, as epidemiological evidence indicates that health effects persist at concentrations below both current UK legal limits and WHO guideline levels, and that there is no identifiable threshold below which $PM_{2.5}$ exposure can be considered safe. This growing body of evidence also points to the need for ever tighter air pollution standards set at lower concentrations.
6. Given the substantial and comparable burden of air pollution on morbidity outcomes, including asthma, chronic obstructive pulmonary disease, stroke, hypertension, and lung cancer, incorporating morbidity analysis into future health impact assessments would provide a more comprehensive picture of the true health and economic costs of air pollution.

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 (Imperial) to produce an up-to-date assessment of the mortality burden (MB) associated with air pollution levels in London for the year 2024 (represented by a snapshot view of 2024 based on provisional emission sources data in London).

To undertake this assessment, the team first compiled 2024 air pollution data for every Output Area (OA) in London using methodologies established for the London Atmospheric Emissions Inventory that is compiled by TfL and GLA. Population-Weighted Average Concentrations (PWAC) were then combined with established concentration–response relationships to estimate the mortality burden associated with the air pollution levels modelled for each Lower layer Super Output Area (LSOA), ward and borough across London.

The researchers from ERG produced the mortality burden methodology and calculations in two previous reports, the 2015 report (Walton et al, 2015) 'Understanding the Health Impacts of Air Pollution in London' and the 2021 report (Dajnak et al, 2021) 'London Health Burden of Current Air Pollution and Future Health Benefits of Mayoral Air Quality Policies'. The ERG researchers updated this work using the following methodology (see next sections for further details):

- Use the recent World Health Organization (WHO) HRAPIE-2 updated guidance on concentration-response functions for health risk assessment of air pollution (WHO, 2025) recommended methodology for calculating the health impacts of particulate matter with diameter <2.5 µm ($PM_{2.5}$) and nitrogen dioxide (NO_2).
- Use updated geographic boundaries (OA, LSOA, ward, borough) from the latest 2021 Census for all the calculations.
- Use updated data inputs (population and deaths at OA and LSOA levels, respectively) based on the new census 2021 to give the current mortality burden in the London population in 2024 at a fine spatial scale (at LSOA, ward and borough levels).
- Use updated air pollution data based on a snapshot view of 2024 to give the mortality burden in the London population for the levels of air pollution in 2024.

2.1 London air quality: background summary

Over more than two decades, successive London mayors have implemented comprehensive packages of policies to reduce emissions, particularly from road transport. These measures have ensured sustained improvements in London's air quality. More recently, the Ultra Low Emission Zone (ULEZ), introduced 2019-2023, has been the core component of the recent mayor's strategy to tackle air pollution. Evidence from the London-wide ULEZ One Year report (GLA, 2025) shows that by 2024, nitrogen oxides (NOx) emissions across London were estimated to be 36% lower than they would have been without ULEZ, while roadside NO_2 concentrations were around 27% lower than a 'no ULEZ' scenario, with particularly large reductions (54%) in central London. Furthermore, compliance with ULEZ standards is now very high, with more than 97% of vehicles seen driving in London meeting ULEZ emissions requirements[3].

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[3] source: https://content.tfl.gov.uk/ulez-online-factsheet-jul-sep2025.pdf

Whilst this represents a step in the right direction, it is important to acknowledge that epidemiological evidence indicates that adverse health effects continue to occur at pollution concentrations below both the current legal limit values and WHO guideline levels. This underlines the critical importance of not only reducing emissions at source to achieve compliance with UK limit values and WHO guidelines, but also of pursuing reductions in pollution levels as far as possible below these levels.

2.2 Mortality burden background

Air pollution is one of the most substantial contributors to global mortality and disease burden, with approximately one in eight deaths worldwide being associated with ambient air pollution exposure in 2023 (GBD 2021 Risk Factors Collaborators, 2024 and HEI, 2025). More importantly, the total disease burden attributable to air pollution exposure has been previously underestimated, as recent evidence syntheses have established stronger relationships between air pollution exposure and mortality, as well as other outcomes such as dementia, type 2 diabetes, and childhood asthma incidences (Hegelund et al., 2024 and HEI, 2025).

In the UK, the mortality burden of air pollution is well-documented. It is estimated that around 30,000 premature deaths can be attributable to air pollution in 2025, costing the economy upwards of £27 billion annually in healthcare costs, productivity losses, and reduced quality of life (RCP, 2025). Furthermore, substantial health co-benefits from mortality alone, expressed in 3.8 million life years gained, corresponding to £77.9 billion of monetised benefits over the period 2019 to 2154, can be realised by the UK's Net-Zero policies (Walton, 2025). These estimates are based on the previous methodological framework for the combined effects of $PM_{2.5}$ and NO_2 and may represent an underestimation of the true impacts. However, the strengthened burden estimates and the assessment of health benefits from policies are underpinned by methodological advances. The WHO HRAPIE-2 report, complemented by the WHO Estimating the Morbidity from Air Pollution and its Economic Costs (EMAPEC) project[4], drew on new evidence from the last decade and produced guidance with concentration-response functions covering a substantially larger number of health outcomes, enabling more comprehensive health impact assessments (WHO, 2025 and Forastiere et al., 2024).

Health impact assessments have traditionally relied on epidemiological analyses that assessed the impact of different air pollutants independently using Single-Pollutant (SP) regression models. However, as some pollutants share common sources to a certain degree and thus tend to vary in concentration together, the results from SP models may represent the effect of more than one pollutant and summing the results from different pollutants directly might overestimate the findings. Hence, the importance of using Multi-Pollutant (MP) model results, which shows the combined effect across two pollutants, is increasingly being recognised (COMEAP, 2018a).

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[4] https://www.who.int/activities/estimating-the-morbidity-from-air-pollution-and-its-economic-costs

3.0 Methods

3.1 Air quality modelling

TfL commissioned ERG to provide an estimate air quality across Greater London for the year 2024[5]. The dispersion modelling exercise represented a snapshot for 2024 based on provisional emission sources data in London, providing an initial view of air quality in London and reflecting the operational status of numerous Mayoral policies – including the ULEZ – already in operation at that time.

The 'London toolkit' model

The well-established 'London Toolkit' has been central to every major air pollution policy development in London for over two decades, underpinning the evidence base for every major air pollution initiative developed by both TfL and the GLA. This continued achievement has been driven by a longstanding and productive collaboration with TfL, which has played a key role in the ongoing development and refinement of the London Toolkit – ensuring the model remains at the forefront of air quality assessment and continues to deliver meaningful improvements for London's air pollution policies. Its long-standing use reflects its reputation as a reliable and well-tested tool for accurately estimating pollution levels across the complex and diverse urban landscape of London. Its use spans from the introduction of the Congestion Charging Scheme in 2003 through to the current ULEZ, ensuring methodological consistency across successive policy evaluations. This continuity is reflected in a broad body of published work, including Dajnak et al. (2021, 2026), GLA (2019), LAEI2019 (2021), LAEI2022 (2025) and Mudway et al. (2019). Furthermore, a comprehensive description of the 'London Toolkit' model is available in the wider scientific literature in Beevers et al. (2013) and more recently in Dajnak et al. (2023). In simple terms, the model estimates how pollution spreads from each individual source, such as roads, railways, and other sources, using pre-calculated dispersion patterns called kernels. These kernels are based on established air pollution models, ADMS-Roads and ADMS 5 (CERC, 2018), and on hourly weather data from the Weather Research and Forecasting (WRF) model. This makes it possible to build up a detailed map of pollution levels by combining contributions from each individual source onto a fine-scale 20 m x 20 m grid across the whole of London. This high-resolution approach allows for a detailed representation of air pollution concentrations across London, capturing the variation in pollution levels from street to street and neighbourhood to neighbourhood.

Road transport emission source

The 'London Toolkit' model incorporates a highly detailed assessment of road traffic emissions across London, enabling precise estimation of air pollution concentrations attributable to local road sources. To achieve this, the UK road network was split into individual sources spaced 10 m apart, with each segment assigned both an emission estimate and a set of road characteristics. The kernel modelling approach was applied to characterise the initial dispersion from every road source segment. The contributions from each source were subsequently aggregated onto a fixed 20 m × 20 m high resolution grid in the vicinity of roads. Road types were classified into the following categories, each of which plays an important role in determining the local-scale dispersion behaviour:

- Open roads – such as motorways, with minimal surrounding obstructions
- Typical roads – characterised by low-rise buildings in the surrounding environment

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[5] As part of the delivery of the modelling outputs to TfL, the model evaluation has been documented in a technical note, which can be made available upon request from TfL

- Street canyons – of varying dimensions and orientations, defined by their height-to-width ratios

Other non-road transport emission sources
Other non-road transport emissions source types were represented using distinct approaches, including:

- Railway sources were treated in a manner consistent with road sources, with the key distinction that emissions were assigned a greater release height of 5 m above ground level, reflecting the elevated nature of railway infrastructure and associated emissions.
- Individual industrial point sources, incorporating relevant stack parameters (i.e. diameter, height, temperature, flow rate).
- Jet sources, representing aircraft emissions.
- Domestic and commercial combustion were represented in detail, taking into account the height of emission release, the geographic distribution of gas sources, and changes in emission levels across different times of the year.
- Three-dimensional volume sources, encompassing sources such as domestic wood burning, cooking, and other airport-related sources.

3.2 Air quality data format for the mortality burden assessment

Annual mean concentrations of $PM_{2.5}$ and NO_2 were predicted across Greater London at a spatial resolution of 20 m × 20 m for the year 2024 using the 'London Toolkit' model.

From 20 m grid data to OA concentration
Annual mean concentration data for $PM_{2.5}$ and NO_2 were extracted at 20 m grid resolution and spatially intersected with the most recent Output Area (OA) boundaries, derived from the 2021 census and obtained from the Office for National Statistics (ONS, 2023) for the Greater London area, encompassing a total of 26,369 OAs. Concentration values from all grid points falling within each OA were subsequently averaged at the OA level, providing a single representative concentration estimate for 2024 for each spatial unit.

From OA to population-weighted LSOA and ward concentration
Population-weighted average concentrations (PWAC) were calculated at LSOA level. For each OA, the averaged pollutant concentration was multiplied by the population aged 30 and over (i.e. the population for whom the epidemiological evidence is robust enough to be included in burden estimates – see section 3.3), disaggregated by gender. The resulting population-concentration products were then summed across all OAs within each LSOA and divided by the total LSOA population, yielding a single PWAC for each LSOA. These LSOA-level PWACs were subsequently used directly as inputs to the health impact calculations and finally applied consistently across all LSOAs within the Greater London area.

3.3 Mortality burden assessment

The associations between long-term exposure to ambient air pollution and the risk of mortality, as well as a variety of cardiorespiratory health outcomes are well-established (Forastiere et al., 2024; Kasdagli et al., 2024; Orellano et al., 2024). Toxicological evidence has shown that potential mechanisms of damage include oxidative stress, inflammation, endocrine disruption, and epigenetic alterations (Chen et al., 2022; Fussell et al., 2024). This body of evidence has led major policymakers and governing bodies – including the US Environmental Protection Agency (US EPA), the WHO, and the Committee on the Medical Effects of Air Pollutants (COMEAP) – to conclude that the evidence is sufficiently robust to support a causal relationship between ambient air pollution and certain adverse health outcomes (USEPA, 2019; WHO, 2025; COMEAP, 2023). This conclusion is reached through a process of triangulation, whereby convergent findings across multiple and varied study methodologies reduce the likelihood that any single source of bias could be responsible for the observed associations (Pearce et al., 2019).

3.3.1 Concentration-response functions (CRFs)

The concentration-response functions (CRFs) used in this analysis were sourced from the recent WHO HRAPIE-2 comprehensive report (WHO, 2025) which provided epidemiological effect estimates for $PM_{2.5}$ and NO_2 exposure and the risk of all-cause mortality for those aged 30 or above (*Table 1*). These CRFs are based on pooled single-pollutant model estimates from recent systematic reviews (Orellano et al., 2024; Kasdagli et al., 2024). Based on evidence from studies on areas with low levels of pollution, it is suggested that the health effects at lower concentrations become clearer, especially for $PM_{2.5}$ (WHO, 2025). Previously, the epidemiological evidence was less clear to support the existence of an effect at low levels, and “cut-off” or “counterfactual” concentrations were used in health impact assessments. This did not mean there was no effect below the cut-off, just that the number of data points were too small to identify an effect. In this analysis, no cut-off was assumed for $PM_{2.5}$, and cut-offs of zero and 5 μg m^{-3} were used for NO_2. The no cut-off assumption for $PM_{2.5}$ was based on COMEAP recommendations (COMEAP, 2018), while WHO proposed a range for health risk assessment of 5 to 70 μg/m^3. The corresponding range for NO_2 proposed by WHO is 10 to 130 μg/m^3.

Table 1 Concentration-response functions (CRFs) for the mortality burden from the single-pollutant model estimates

Pollutant	**Averaging time**	**Hazard ratio per 10 μg m^{-3}**	**Confidence interval**	**Counterfactual (cut-off)**	**Population at risk/Source**
$PM_{2.5}$	Annual average	1.095	1.064-1.120	Zero	Age 30+, from Orellano et al., 2024
NO_2	Annual average	1.050	1.030-1.070	Zero or 5 μg m^{-3}	Age 30+, from Kasdagli et al., 2024

3.3.2 Estimation of combined effects of $PM_{2.5}$ and NO_2

Adjusted CRFs based on two-pollutant model estimates were used for the estimation of the combined impacts of long-term exposure to $PM_{2.5}$ and NO_2. These were derived using the single-pollutant model CRFs above (Table 1), with information from the work by Chen et al. (2024) that identified 17 cohort studies that reported both single- and two-pollutant model relative risks (RRs) for $PM_{2.5}$ and NO_2 and their association with all-cause mortality (Table 2). They estimated pooled CRFs, and for each pollutant they estimated percentage coefficient differences between single- and two-pollutant models. For $PM_{2.5}$, the CRF was reduced by 33.4%, while for NO_2 the reduction was 24.7%. We applied these reduction factors in the CRFs chosen for this analysis, as well as the lower and upper limit of the 95% confidence interval, in order to estimate the combined burden for the two pollutants, as follows:

$RR_{\text{two-pollutant model}}(PM_{2.5}) = \text{Exp}((\ln(RR_{\text{single-pollutant model}})) \times (1–0.334)) = \text{Exp}((\ln(1.095)) \times (1–0.334)) = 1.062$

$RR_{\text{two-pollutant model}}(NO_2) = \text{Exp}((\ln(RR_{\text{single-pollutant model}})) \times (1–0.247)) = \text{Exp}((\ln(1.05)) \times (1–0.334)) = 1.037$

Similar to single-pollutant CRFs, no cut-off was assumed for $PM_{2.5}$ and zero or 5 µg m^{-3} was applied for NO_2.

Table 2 Concentration-response functions (CRFs) from Chen et al. (2024) for the mortality burden after adjustment using results from multi-pollutant models

Pollutant	**Averaging time**	**Hazard ratio per 10 µg m^{-3}**	**Confidence interval**	**Counterfactual**	**Comment/Source**
$PM_{2.5}$	Annual average	1.062	1.042-1.083	Zero	Age 30+, total $PM_{2.5}$
NO_2	Annual average	1.037	1.023-1.052	Zero or 5 µg m^{-3}	Age 30+, total NO_2

3.3.3 Population and mortality data

Population estimates by single year of age and gender from 2022 to 2024 at OA level were obtained from ONS via the NOMIS Query tool. The population estimates were then summed by gender and 1-year age groups for aged 30 or above for each LSOA, ward, borough, and for Greater London overall.

Mortality estimates by 5-year age group and gender at LSOA level were obtained from ONS for the years 2022 to 2024 (NOMIS Query tool). Mortality estimates by 1-year age group and gender at regional level (i.e. London) were also obtained for 2022 to 2024 to scale the 5-year age group data at LSOA level to 1-year age groups using the London-wide distribution (ONS, 2026).

Table 3 provides a breakdown of population size, number of deaths, and death rates disaggregated by gender across the Greater London area, covering both the 2019 data used in the previous report (Dajnak et al, 2021) and the most recent 2024 figures used in this study.

Table 3 Population, number of deaths and death rate by gender used for health impact assessment of air pollution for 2019 and 2024 in Greater London

Greater London area	**2019** **Total** **(male/female)**	**2024** **Total [% change compared with 2019]** **(male/female)**
Population	8,834,247* (4,405,660/4,428,587)	8,986,936** [+2%] (4,353,812/4,633,124)
Number of Deaths	49,472* (25,006/24,466)	51,783** [+5%] (26,573/25,210)
Death rate (per 10k)	56.0 (56.8/55.2)	57.6 [+3%] (61.0/54.4)

* Average of 3 years (2016-2018)
** Average of 3 years (2022-2024)

3.3.4 Burden calculations

The calculations used in this report are similar to those of Dajnak et al. (2021). In particular, for the effects of $PM_{2.5}$ and NO_2 using single-pollutant model estimates, we followed the earlier methodologies from COMEAP (2018a) and Gowers et al. (2014), which scaled the RR reported in recent systematic reviews per 10 µg m^{-3} for the relevant $PM_{2.5}$ and NO_2 concentration. We then estimated the attributable fraction (AF) for premature mortality related to the corresponding change in the $PM_{2.5}$ and NO_2 concentration using the following formula:
AF = (RR-1) / RR, which was then multiplied by 100 to give a percentage.

Attributable deaths were estimated as the product of the attributable fraction and the number of deaths in the relevant gender and 1-year age group (aged 30 or above). These calculations were performed at LSOA level. The total attributable deaths across wards, boroughs or London-wide were estimated as the sum of attributable deaths by LSOA across the 1-year age group aged 30 or above for both males and females. This estimation 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 to provide an estimate of the uncertainty around the burden estimates equivalent to a 95% confidence interval. Burden calculations were also performed using a cut-off of 5 µg/m^3 for NO_2.

For the combined effects of the two pollutants, the same methodology was applied as above but the CRFs that incorporated the evidence from multi-pollutant models, i.e. adjusted by correction factors (see Table 2), were used. The central burden estimates for $PM_{2.5}$ and NO_2 using the adjusted CRFs were added up to provide the combined effect of the two pollutants. To estimate the uncertainty around the central estimate, we estimated the standard error of the sum of the two CRFs using the following formula:
Standard error (SE) of sum = $\sqrt{(\mathrm{SE}^2_{\mathrm{PM2.5}} + \mathrm{SE}^2_{\mathrm{NO2}})}$, where $\mathrm{SE}^2_{\mathrm{PM2.5}}$ and $\mathrm{SE}^2_{\mathrm{NO2}}$ are the standard errors of the CRFs for $PM_{2.5}$ and NO_2, respectively. The lower and upper estimates based on 95% confidence intervals were then obtained by adding or subtracting the SE multiplied by 1.96 from the central estimate.

As part of our sensitivity analysis, we used the methodology suggested by COMEAP (2018a and 2018b) based on which the larger effect of the two single-pollutant model results was used as a proxy of the combined effects of the two pollutants. This approach can be regarded as a conservative estimate of the combined impact of $PM_{2.5}$ and NO_2, as it assumed that the maximum effect of the two fully captures the impact of both pollutants.

Expected remaining life expectancy for specified 1-year age groups was calculated for every LSOA using the deaths and population data described using the method from the Southeast Public Health Observatory (SEPHO) Life Expectancy Calculator (SEPHO, 2005). The tool uses baseline life expectancy which represents 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 values for expected remaining life expectancy in an age group were then multiplied by the number of pollution-attributable deaths to find the total life years lost. These are the numbers of years across the population expected to be lived over time if the deaths to which $PM_{2.5}$ and NO_2 pollution contributed had not occurred. 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. This approach was applied to estimate both the separate $PM_{2.5}$ and NO_2 effects, as well as their combined mortality impacts.

Overall, the inputs for the mortality burden calculations applied in this report can be summarised in Table 4, while Table 5 shows the geographic scale of the different inputs used for the calculations. All outputs are reported as exact values in the result tables but rounded to three significant digits in the text and figures, to better reflect the true level of uncertainty in the estimates, as well as to improve readability and interpretation.

Table 4 Summary table of inputs used in the calculations

Inputs	**Description**
Modelled concentrations	$PM_{2.5}$ and NO_2 PWAC at LSOA level.
Population estimates	Population estimates by single year of age and gender from 2022 to 2024 at OA level was obtained from ONS via the NOMIS Query tool. The population estimates were then summed by gender and 1-year age groups for aged 30 or above for each LSOA, ward, borough, and for Greater London overall.
Mortality estimates	Mortality estimates by 5-year age group and gender at LSOA level were obtained from ONS from 2022 to 2024 (NOMIS Query tool). Mortality estimates by 1-year age group and gender at regional level (i.e. London) were also obtained for 2022 to 2024 to scale the 5-year age group data at LSOA level to 1-year age groups using the London-wide distribution (ONS, 2026).
CRFs	Effect sizes per 10 µg/m^3 • $PM_{2.5}$: RR = 1.095 (1.064-1.127), from Orellano et al. (2024)[6] • NO_2: RR = 1.05 (1.03-1.07), from Kasdagli et al. (2024)

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[6] WHO used a rounded version of the Orellano et al. (2024) meta-analytic estimates in the HRAPIE-2 report, i.e. 1.10 (1.06, 1.13) per 10 µg/m^3.

Table 5 Geographic scales for different input variables used in the 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

Finally, the methods adopted in this report have been updated in comparison to those used in the 2021 report (Dajnak et al., 2021). Previously, the single-pollutant model CRFs used for the effects of $PM_{2.5}$ and NO_2 were based on the advice from COMEAP in 2018 (COMEAP, 2018a) and are shown in Table 13 of Appendix Section 7.1. For the combined effects, we used findings from four epidemiological studies available at that time which included estimates from two-pollutant models. More details can be found in the previous report and in Table 14 of Appendix Section 7.1 of this current report. Further mortality burden, impacts and air quality methodology details from the previous 2021 report as well as health inputs such as population and death data, expected remaining life-expectancy and population at risk can be found in the Appendix section 7.2. We also assessed a hypothetical scenario under a methodological framework in which all the parameters of the mortality calculations remained fixed (i.e. population, baseline deaths, geographic boundaries and exposure-response associations), except for air pollution which varied from 2019 to 2024 levels. This scenario-based analysis allowed us to compare the progress made in London's air quality and how this might have affected mortality burden estimates.

3.4 Economic assessment

Mortality valuation related to air pollution can be carried out using either of 2 metrics, the Value of a Life Year (VOLY) which addressed change in longevity, or the Value of a Prevented Fatality (VPF, also often referred to as the Value of a Statistical Life or VSL) which is combined with some estimate of the number of deaths. Discussions in the UK have concluded that quantification of change in longevity is a more accurate interpretation of the burden on mortality indicated by the epidemiology (COMEAP, 2010) and hence preference is given here to use of the VOLY.

VOLYs are a well-established method used in environmental economics to translate years of life lost into a standardised economic cost. This study follows the approach used by His Majesty's Treasury (HMT, 2026) and Defra (DEFRA, 2025a). VOLYs provide a consistent and standardised way to assign an economic cost to the loss of utility (quality of life) from reduced life expectancy from exposure to air pollutants. They do not account for additional impacts on health care costs, productivity or utility leading up to death that may be linked to pollutants causing a higher incidence of disease – those costs would be factored into estimates of elevated morbidity linked to air pollution.

The VOLY representative of the year 2024 is estimated here to be £58,069 (range £36,637 to £72,354 based on 95% confidence intervals), drawing on guidance from His Majesty's Treasury (HMT) in the Green Book (HMT, 2026) and work on damage costs linked to air pollution by Ricardo (DEFRA, 2025a) carried out for DEFRA (DEFRA, 2025b).

Alternative and generally higher estimates are available in the literature, for example used in work for the European Commission (EC) for which a value equivalent to £92,058 (converted from Euro and inflated to 2024 prices) was used for the VOLY (EC, 2025a; EC, 2025b). This estimate may increase following new work from the Organisation for Economic Co-operation and Development (OECD, 2025), though other work from OECD indicates that UK valuation surveys tend to give lower results than those carried out in other countries. It is stressed that the estimate adopted here from the DEFRA damage costs work is consistent with UK government practice.

When the overall cost of the impact was calculated by multiplying estimates of Life Years Lost (LYL) by the VOLY, i.e., when different elements with uncertainty were multiplied together, the following function was applied to derive the combined Standard Error (SE):
Standard error (SE) of product = SQRT $[((\mathrm{SE\_LYL})^2 \text{ x } (\mathrm{SE\_Value})^2) + ((\mathrm{SE\_LYL})^2 \text{x } (\mathrm{VOLY}_{\mathrm{CE}})^2) + ((\mathrm{SE\_Value})^2 \text{ x } (\mathrm{LYL}_{\mathrm{CE}})^2)]$
The lower and upper estimates based on 95% confidence intervals were then obtained by adding or subtracting the SE multiplied by 1.96 from the central estimate.

4.0 Results: Air quality modelling

4.1 Recent air quality in the year 2024

Table 6 shows the PWACs of $PM_{2.5}$ (no cut-off) and NO_2 (no cut-off and with cut-off) based on their annual mean concentrations in 2019 and 2024, and the percentage change in 2024 relative to 2019, in Greater London. The PWACs of both $PM_{2.5}$ and NO_2 across Greater London declined substantially between 2019 and 2024. $PM_{2.5}$ concentrations decreased from 10.9 µg m^{-3} in 2019 to 7.8 µg m^{-3} in 2024, representing a reduction of 28%. NO_2 concentrations saw an even more pronounced decline, falling from 28.8 µg m^{-3} in 2019 to 17 µg m^{-3} in 2024, a reduction of 41%. When applying a concentration cut-off of 5 µg m^{-3}, NO_2 concentrations were further reduced, by approximately half, from 23.9 µg m^{-3} in 2019 to 12 µg m^{-3} in 2024. These reductions reflect meaningful improvements in air quality across Greater London over this period, likely attributable to the implementation of a range of air quality policies, most notably the ULEZ.

Table 6 2019 and 2024 $PM_{2.5}$ and NO_2 concentration (in µg m^{-3}) (PWAC based on annual mean)

Zone	**$PM_{2.5}$ [% change compared with 2019] no cut-off**		**NO_2 [% change compared with 2019] no cut-off (with cut-off)**	
	2019	**2024**	2019	**2024**
Greater London	10.9	**7.8 [-28%]**	28.8 (23.9)	**17 [-41%]** **(12)**

4.2 2024 air quality outputs for the mortality burden calculations

4.2.1 2024 air quality outputs by LSOA

The mortality burden (MB) calculations were performed at LSOA level using $PM_{2.5}$ and NO_2 PWAC aggregated to the LSOA level (as described previously in section 3.2). The resulting spatial distributions are illustrated in Figure 1 below. Note that the river Thames, shown as a white winding line, runs through the centre of the map, serving as a key geographic reference.

$PM_{2.5}$ PWAC by LSOA (Figure 1, top panel)

The $PM_{2.5}$ map displays concentrations ranging from approximately 6.3 to 9.8 µg m^{-3}. The most prominent feature is the elevated concentration hotspot in central London, shown in yellow-green, where $PM_{2.5}$ levels are highest. This is consistent with the convergence of multiple significant emission sources in this area, including dense road transport networks, commercial cooking emissions, some domestic wood burning (DWB), and construction dust from active development sites. Concentrations gradually decrease moving outward from the centre, transitioning through green and teal shades into the deeper blue and purple tones characteristic of the outer London boroughs, where emission source density is considerably lower.

NO_2 PWAC by LSOA (Figure 1, bottom panel)

The NO_2 (no cut-off) map displays concentrations ranging from approximately 10 to 32 µg m^{-3}. The spatial pattern is notably more heterogeneous than that of $PM_{2.5}$, reflecting the more localised nature of NO_2 emission sources. Key features include:

- A pronounced central London hotspot (shown in yellow), driven by the convergence of dense road transport networks, commercial combustion activity, and domestic combustion alongside major roads.
- A distinct elevated concentration to the west, corresponding to the area around Heathrow Airport, with an additional localised area east of Heathrow attributable to a large Sewage Treatment Works (STW) and several smaller, scattered concentration areas across the map reflecting emissions from other STW facilities.
- Localised elevated concentrations in the vicinity of Regent's Park, linked to Non-Road Mobile Machinery (NRMM) emissions associated with construction activity in the Camden borough.
- Concentrations decline progressively towards the outer boroughs, with the lowest values observed at the periphery of Greater London, where emission source density is considerably less.

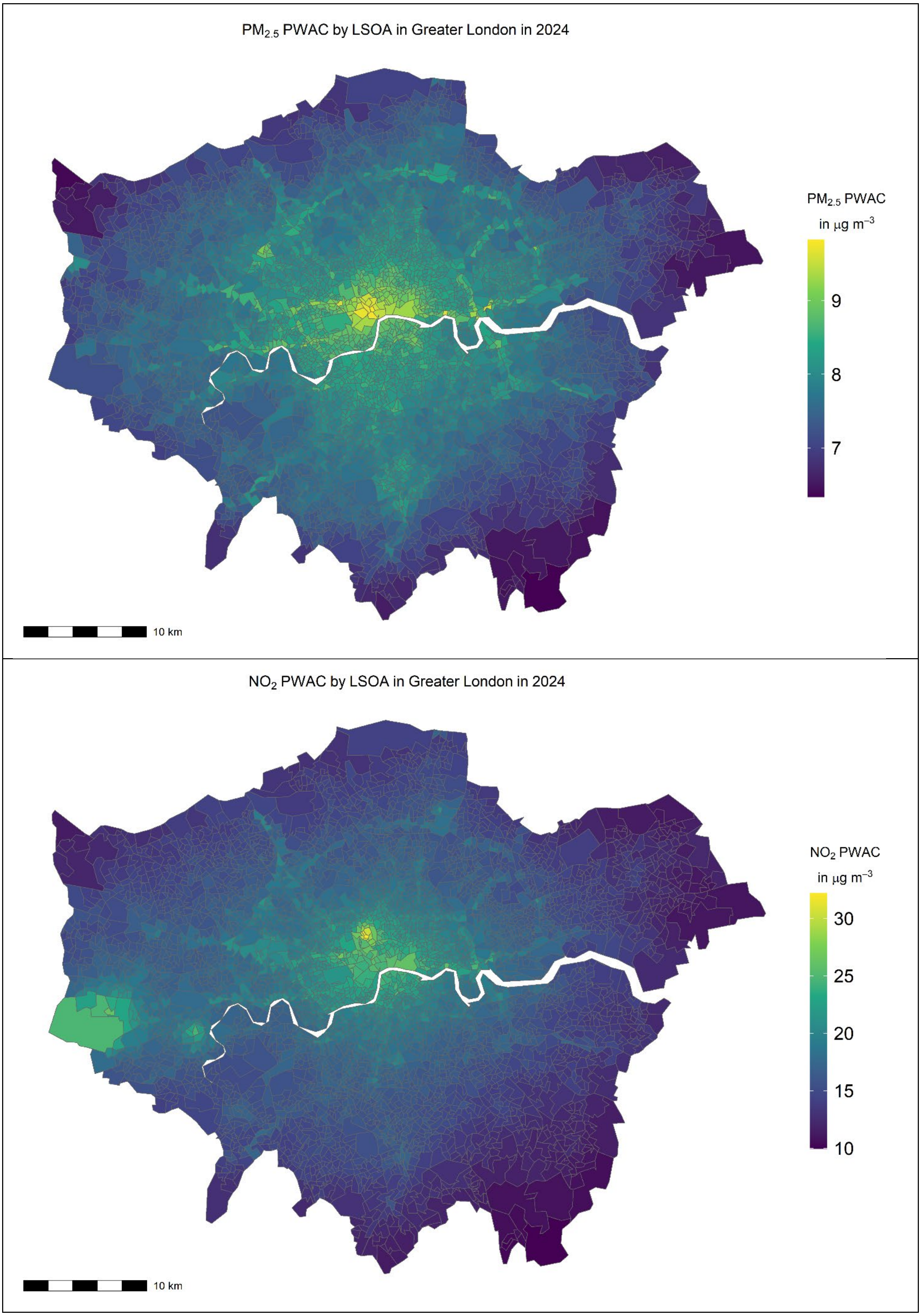


Figure 1 PM$_{2.5}$ (top panel) and NO$_2$ (no cut-off) (bottom panel) population weighted average concentration (PWAC from OA to LSOA level) in the Greater London area for the year 2024

4.2.2 2024 air quality outputs by borough

The spatial distribution of $PM_{2.5}$ and NO_2 PWAC at borough level are illustrated in Figure 2 across London while Table 7 presents the 2024 PWAC by borough (based on PWAC from OA to borough level) of $PM_{2.5}$ and NO_2 across all 33 London boroughs, ranked in descending order of concentration. Overall, a consistent spatial trend is observed across both pollutants, with inner London boroughs, particularly those in central London, recording the highest concentrations, while outer London boroughs record the lowest values.

$PM_{2.5}$ PWAC by borough (Table 7 and Figure 2, top panel)

$PM_{2.5}$ PWAC ranges from approximately 7 to 9.2 $\mu g\ m^{-3}$, a relatively narrow spread across boroughs, with the City of London recording the highest PWAC with 9.2 $\mu g\ m^{-3}$ followed closely by central London boroughs such as Westminster, Kensington & Chelsea, Islington, Tower Hamlets, Camden and Southwark. At the opposite end of the spectrum, Havering records the lowest concentration (7 $\mu g\ m^{-3}$) followed closely by other peripheral location in outer London such as Bromley, Hillingdon, Bexley, Harrow, Sutton and Kingston upon Thames.

NO_2 PWAC by borough (Table 7 and Figure 2, bottom panel)

NO_2 PWAC (no cut-off) range more widely, from 12.4 to 24.8 $\mu g\ m^{-3}$, with the City of London again ranking the highest with 24.8 $\mu g\ m^{-3}$ followed by broadly the same group of central London boroughs as identified above for $PM_{2.5}$, albeit in a slightly different order. Havering once again had the lowest concentration (12.4 $\mu g\ m^{-3}$), followed by other peripheral outer London boroughs in a pattern broadly consistent with that observed for $PM_{2.5}$, although in a slightly different order. A notable exception is Hillingdon and Hounslow, both of which rank considerably higher for NO_2 than for $PM_{2.5}$, reflecting the significant influence of Heathrow Airport and its associated road and air traffic on NO_2 concentrations in these areas. Camden is another exception, ranking higher for NO_2 than for $PM_{2.5}$, likely driven by NRMM emissions within the borough. Croydon also stands out as another exception, ranking higher for $PM_{2.5}$ than for NO_2, a pattern which may reflect the influence of construction dust related emission sources in this area.

Table 7 2024 $PM_{2.5}$ and NO_2 concentration (in µg m^{-3}) (PWAC annual mean) by borough

Zone	**$PM_{2.5}$**		**Zone**	**NO_2**	
	2024	**Ranking**		**2024**	**Ranking**
City of London	9.17	1	City of London	24.77	1
Westminster	8.66	2	Camden	22.01	2
Kensington and Chelsea	8.55	3	Westminster	21.99	3
Islington	8.43	4	Kensington and Chelsea	21.03	4
Tower Hamlets	8.41	5	Islington	20.91	5
Camden	8.39	6	Tower Hamlets	20.82	6
Southwark	8.32	7	Southwark	20.07	7
Hammersmith and Fulham	8.30	8	Hackney	19.44	8
Lambeth	8.26	9	Hammersmith and Fulham	19.23	9
Hackney	8.22	10	Lambeth	19.12	10
Wandsworth	8.04	11	Hounslow	18.60	11
Newham	8.01	12	Wandsworth	17.78	12
Brent	7.94	13	Brent	17.72	13
Lewisham	7.90	14	Newham	17.42	14
Haringey	7.86	15	Ealing	17.41	15
Greenwich	7.79	16	Haringey	17.14	16
Waltham Forest	7.75	17	Lewisham	16.77	17
Merton	7.74	18	Richmond upon Thames	16.47	18
Ealing	7.71	19	Hillingdon	16.46	19
Croydon	7.63	20	Greenwich	16.30	20
Hounslow	7.60	21	Waltham Forest	16.22	21
Barnet	7.58	22	Merton	15.99	22
Richmond upon Thames	7.55	23	Barnet	15.96	23
Redbridge	7.55	24	Enfield	15.42	24
Enfield	7.53	25	Kingston upon Thames	15.39	25
Barking and Dagenham	7.46	26	Redbridge	14.94	26
Kingston upon Thames	7.46	27	Croydon	14.75	27
Sutton	7.44	28	Harrow	14.74	28
Harrow	7.36	29	Barking and Dagenham	14.69	29
Bexley	7.30	30	Sutton	14.44	30
Hillingdon	7.25	31	Bexley	13.81	31
Bromley	7.21	32	Bromley	13.24	32
Havering	6.95	33	Havering	12.41	33

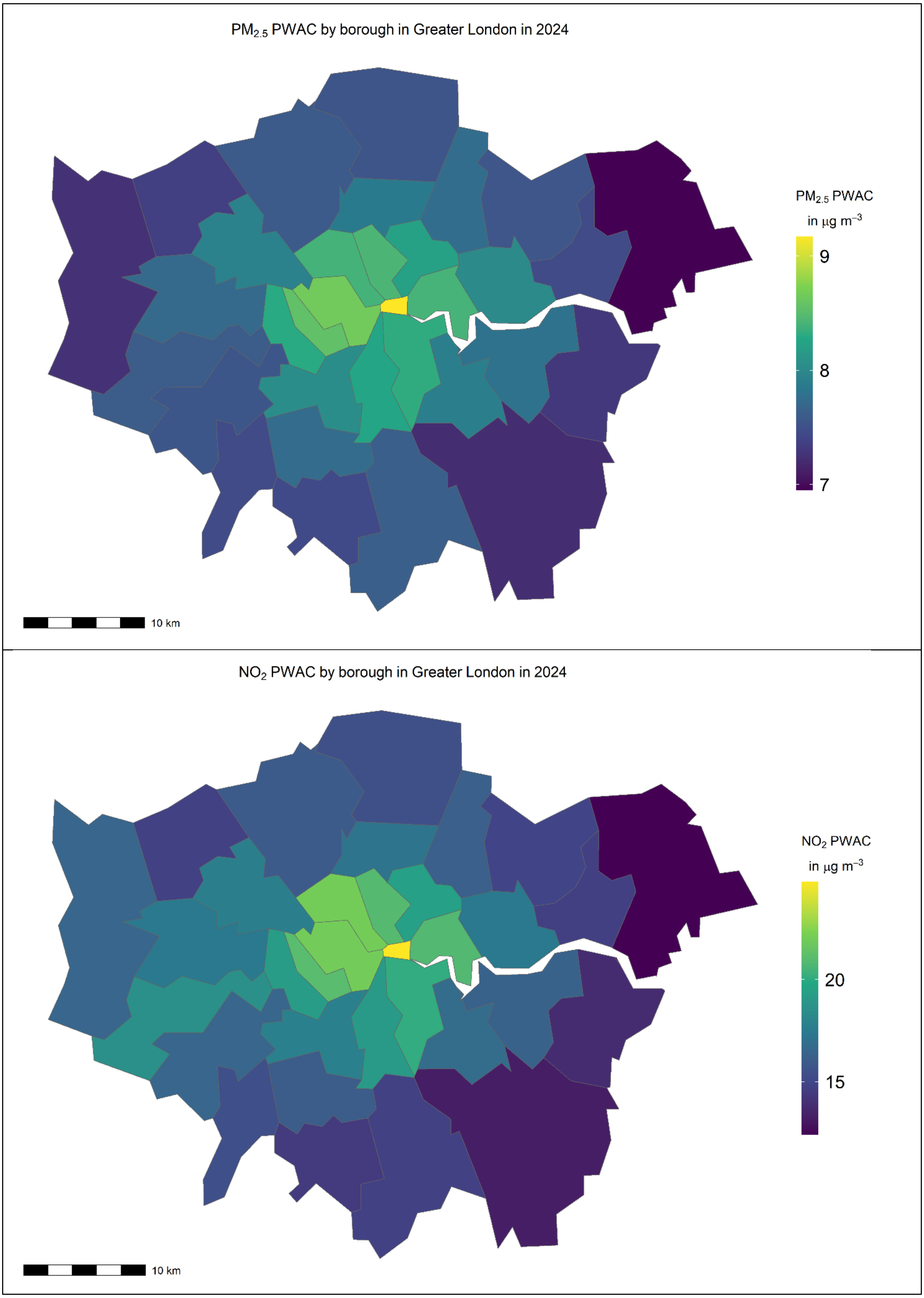


Figure 2 PM$_{2.5}$ (top panel) and NO$_2$ (bottom panel) population weighted average concentration (PWAC from OA to borough level) in the Greater London area for the year 2024

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

5.1 Burden background

The current 2024 burden calculations represent an update to the 2019 estimates published in Dajnak et al. (2021), incorporating two key improvements as outlined in the Methods section: the revised methodology for estimating the combined impacts of $PM_{2.5}$ and NO_2 set out in the HRAPIE-2 publication (WHO, 2025) and refreshed input data for 2024, including geographic boundaries, population and mortality figures as well as air pollution concentrations. It should be noted that the concentration-response functions underpinning these calculations continue to evolve as the evidence base develops over time. The calculations are based on deaths from all causes including respiratory and cardiovascular deaths, the health outcomes for which the evidence linking air pollution to adverse effects is considered strongest. In section 5.2, we provide burden estimates for $PM_{2.5}$ and NO_2 separately using exposure-response associations from single pollutant models. The maximum of the single pollutant analysis is also used as a proxy of the combined burden of the two pollutants. For the combined burden specifically, we estimate it in Section 5.3 using an updated methodological framework from the WHO HRAPIE-2 report. A summary of the findings and a comparison with our previous report are provided in sections 5.4 and 5.5, respectively.

5.2 Effects of $PM_{2.5}$ and NO_2 using single-pollutant model estimates

Effects of $PM_{2.5}$ in Greater London

The premature mortality burden for long-term exposure to total $PM_{2.5}$ for Greater London's 2024 levels was estimated to be equivalent to **3,340 (95% confidence interval (CI): 2,310 to 4,350) attributable deaths, or 57,100 (95% CI: 39,500 to 74,500) life years lost** at typical ages (see Table 8). This result represents effects of the regional pollution mixture and partially represents the contribution from traffic pollution. Gender-specific estimates showed larger results for life years lost for males, i.e. 31,200 (21,500 to 40,600) compared to females, i.e. 26,000 (18,000 to 33,800), which can be attributed to the inherently higher baseline mortality rate at younger ages observed in the male population. The estimated annual cost of air pollution related mortality for $PM_{2.5}$ for the year 2024 in London is **£3,320 (£1,870 to £4,770) million** (in 2024 prices).

Table 8 Estimated mortality burden, Life Year Lost (LYL) and associated costs of total $PM_{2.5}$ (from single-pollutant model estimates) for 2024. Results show health effects using single-pollutant model estimates as inputs.

Greater London	**Central estimate (95% Confidence Interval)**		
	Attributable deaths	**Life years lost***	**Costs in £millions****
	$PM_{2.5}$ without cut-off		
Total (male and female)	3,336 (2,305-4,347)	57,143 (39,493-74,456)	3,318 (1,870-4,766)
Male	1,688 (1,167-2,200)	31,171 (21,544-40,613)	1,810 (1,020-2,600)
Female	1,648 (1,139-2,147)	25,972 (17,950-33,842)	1,508 (850-2,166)

Using concentration-response coefficient provided by the WHO HRAPIE-2 report of 1.095 (95% CI: 1.064 to 1.127) per 10 $\mu g\ m^{-3}$ of $PM_{2.5}$

* 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.

** Associated costs based on the Value Of a Life Year (VOLY) and calculated by gender, 1-year age groups and LSOA

Effects of NO_2 in Greater London

For NO_2, Table 9 reported results with and without the cut-off concentration of 5 µg m^{-3} for Greater London's 2024 levels. The NO_2 attributable burden was estimated at **3,810 (2,340 to 5,200) premature deaths or 65,600 (40,400 to 89,600) life years lost** at typical ages. Similarly to the $PM_{2.5}$ independent burden estimates, the life years lost were higher for males than females, i.e. 36,000 (22,100 to 49,100) compared to 29,700 (18,300 to 40,500), respectively. The corresponding estimates for calculations with cut-off were 2,680 (1,640 to 3,670) attributable deaths, or 46,400 (28,400 to 63,600) life years lost. The annual cost attributable to air pollution-related mortality from NO_2 in London in 2024 was estimated at **£3,810 (£1,950 to £5,670) million** in 2024 prices while the corresponding cut-off adjusted estimates were somewhat lower, at £2,690 (£1,370 to £4,020) million.

Table 9 Estimated mortality burden, Life Year Lost (LYL) and associated costs of NO_2 (with and without cut-off). Results show health effects using single-pollutant model estimates as inputs.

Greater London	**Central estimate (95% Confidence Interval)**		
	Attributable deaths	**Life years lost***	**Costs in £millions****
	NO_2 without cut-off		
Total (male and female)	**3,806** (2,343-5,196)	**65,634** (40,414-89,589)	**3,811** (1,950-5,672)
Male	1,932 (1,189-2,637)	35,961 (22,145-49,080)	2,088 (1,069-3,108)
Female	1,874 (1,154-2,559)	29,674 (18,269-40,509)	1,723 (882-2,565)
Zone Greater London	**NO_2 with cut-off**		
Total (male and female)	2,677 (1,641-3,671)	46,395 (28,438-63,607)	2,694 (1,369-4,019)
Male	1,362 (835-1,867)	25,498 (15,631-34,953)	1,481 (753-2,209)
Female	1,315 (806-1,804)	20,897 (12,807-28,653)	1,213 (617-1,810)

Using concentration-response coefficient provided by the WHO HRAPIE-2 report of 1.05 (95% CI: 1.03 to 1.07) per 10 µg m^{-3} of NO_2

* 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.

** Associated costs based on the Value Of a Life Year (VOLY) and calculated by gender, 1-year age groups and LSOA

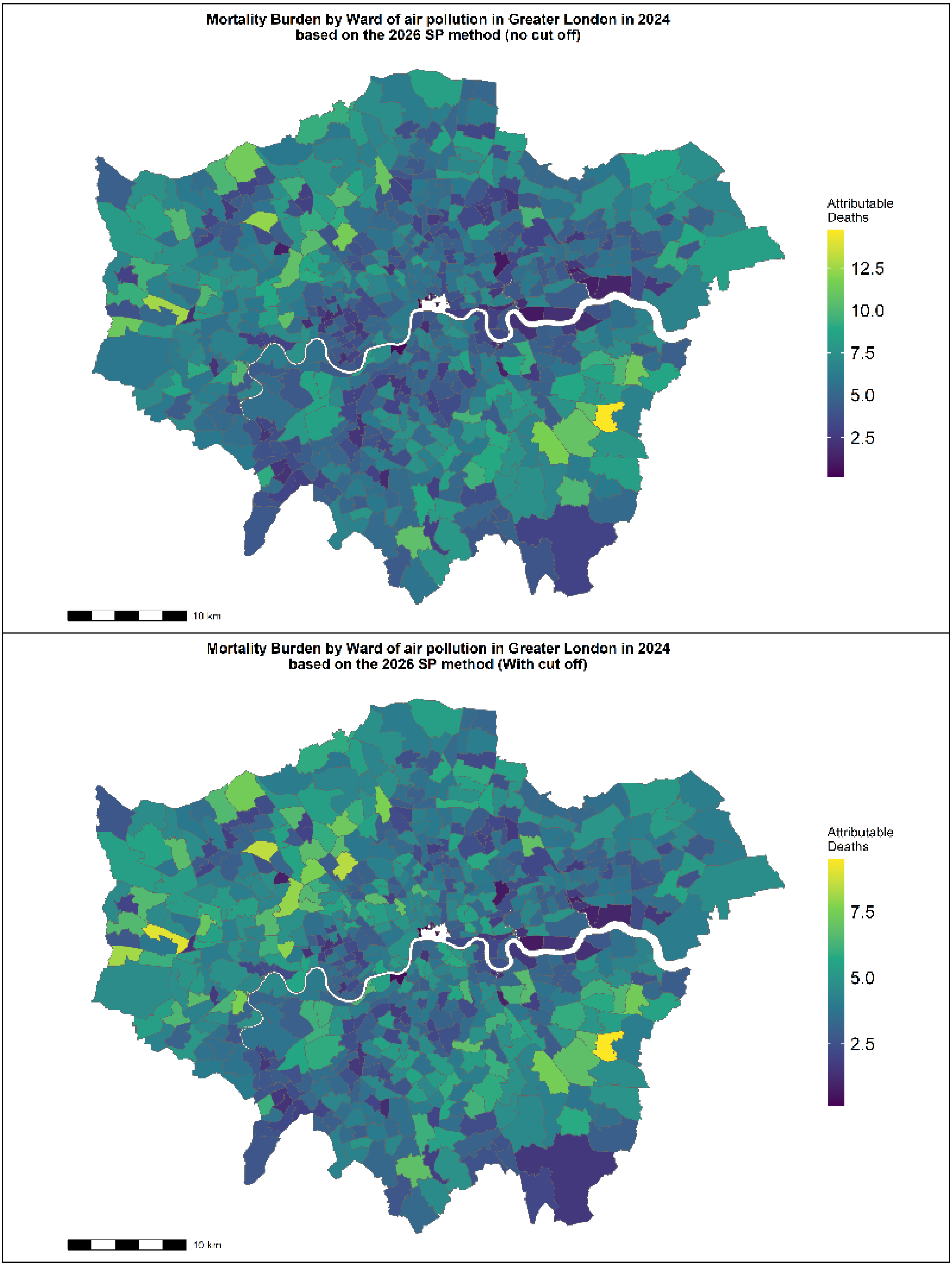
Overall summary using single-pollutant model estimates in Greater London

Across the burden estimates that quantified the impacts of long-term exposure to each pollutant using CRFs from single-pollutant models, the NO_2 results without cut-off (3,810 deaths) were higher than those estimated for $PM_{2.5}$ (3,340 deaths). The corresponding finding for NO_2 with cut-off was 2,680 deaths. However, due to the correlation between the two pollutants, it is not easy to disentangle their effects and quantify true independent effects of the two pollutants. Thus, one should interpret these findings with caution and not add up the numbers. The COMEAP recommendation suggests that the maximum of these burden estimates might approximate the combined effect, rather than the independent effect of that pollutant. More details, and an estimate of the combined effects of $PM_{2.5}$ and NO_2 are provided in Section 5.3 below.

The results reported above are for the Greater London area. However, as indicated in Table 5, the analysis was performed at LSOA level, and mortality burden (MB) estimates were also provided by smaller spatial scale than the entire London area, i.e. ward and borough level.

Effects of $PM_{2.5}$ and NO_2 by wards

Figure 3 shows the spatial distribution of the NO_2-attributable deaths from air pollution across Greater London's wards for 2024, estimated using single-pollutant model CRFs from the WHO HRAPIE-2 report. We chose to show NO_2 results, as NO_2 resulted in the largest mortality burden compared to $PM_{2.5}$. In our previous report (Dajnak et al., 2021), these estimates were also assumed to represent the combined effect of the two pollutants according to COMEAP recommendations (see more details below in Section 5.3). Figure 3 presents two maps comparing results with and without a concentration cut-off. Both maps reveal considerable spatial variation, with inner and parts of outer London bearing a disproportionately higher burden, and a notable hotspot in south-east London. The no cut-off map (top panel) yields higher attributable death estimates by assuming that all pollution concentrations contribute to mortality, while the cut-off map (bottom panel) applies a minimum concentration threshold, below which no effect is assumed, resulting in more conservative estimates. Further ward-level analysis and interpretations based on the MP model method are covered in Section 5.3 (below), with additional commentary provided in the discussion (section 6).



Note that not all the wards in the City of London satisfy the population thresholds associated with Census 2021 output areas. As a result, the wards that are primarily commercial in nature may not have enough residential households to feature on the maps and are instead shown in white to reflect this absence of data.

Figure 3 Mortality burden associated with NO_2 by wards in Greater London for the year 2024; no cut-off (top panel) and with cut-off (bottom panel). NO_2 resulted in the largest attributable deaths, compared to $PM_{2.5}$, using the CRFs from single-pollutant models.

Effects of $PM_{2.5}$ and NO_2 by boroughs

Table 10 and Figure 4 below show the burden estimates for the 33 London boroughs using pooled CRF for NO_2 from single-pollutant models reported in the WHO HRAPIE-2 report. Figure 4 shows that Barnet, Croydon, Ealing, Bromley and Brent were found to have the largest number of deaths associated with exposure to NO_2 (i.e. 180, 178, 167, 159 and 154 attributable deaths, respectively) while the City of London, Barking and Dagenham, Kensington and Chelsea, Kingston upon Thames and Hammersmith and Fulham (with 4, 78, 78, 79 and 79 attributable deaths, respectively) had the lowest absolute burden. These estimates are based on a set of variables included in the burden calculations. To provide a more direct comparison of the estimates for the different boroughs in Table 10, the boroughs were sorted by mortality burden per 100,000 people (population-weighted MB), largest first, and a ranking was also provided for other important parameters, such as the population and death rates for those aged 30 years or above, population-weighted average concentrations and unweighted mortality burden estimates. The population-weighted MB estimates showed that Bexley, Camden, Kensington and Chelsea, Westminster and Hillingdon resulted in the largest mortality burden, with 86, 85, 84, 79 and 79 attributable deaths per 100,000 residents, respectively. Additional borough-level analysis and interpretations derived from the MP model method are presented in Section 5.3 (below), with further discussion provided in section 6.

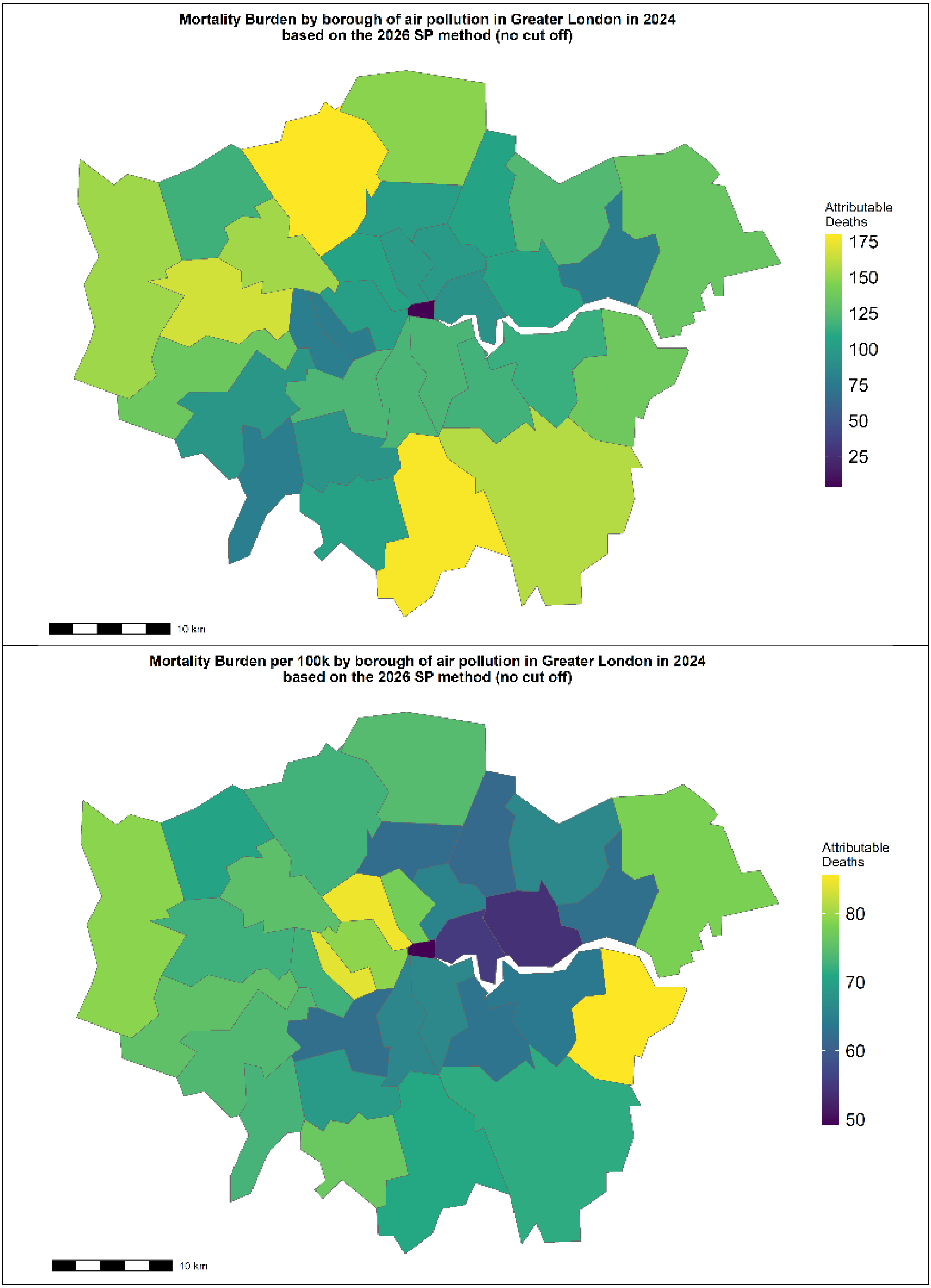


Figure 4 Mortality burden (top panel) and MB per 100,000 population (bottom panel) associated with NO_2 (no cut-off value) by boroughs in Greater London for the year 2024. NO_2 resulted in the largest attributable deaths, compared to $PM_{2.5}$, using the CRFs from single-pollutant models.

Table 10 Comparisons of the Mortality Burden (MB) between boroughs with largest and smallest results for attributable deaths per 100k (largest of the new Single Pollutant (SP26) approach associated with NO_2, No Cut-Off (No CO), male and female combined)

Borough	**Population 30Plus**	**Rank**	**Death Rate 30Plus Per 10k**[a]	**Rank**	**PWAC NO2 No CO**	**Rank**	**MB SP26 No CO**	**Rank**	**MB SP26 No CO Per 100k**	**Rank**
Bexley	160,166	21	133.0	2	13.81	31	137.1	8	85.6	**1**
Camden	124,363	28	87.2	20	22.01	2	105.5	20	84.8	**2**
Kensington and Chelsea	92,814	32	90.0	17	21.03	4	78.0	31	84.0	**3**
Westminster	128,386	26	80.9	25	21.99	3	101.8	22	79.3	**4**
Hillingdon	193,401	9	108.2	5	16.46	19	153.0	6	79.1	**5**
Havering	171,773	17	135.4	1	12.41	33	134.3	10	78.2	**6**
Islington	128,301	27	84.6	24	20.91	5	99.6	24	77.6	**7**
Sutton	136,520	24	114.6	4	14.44	30	104.5	21	76.6	**8**
Hounslow	180,904	14	89.0	18	18.60	11	136.4	9	75.4	**9**
Brent	204,495	5	93.1	15	17.72	13	153.7	5	75.2	**10**
Enfield	198,520	6	104.9	7	15.42	24	147.8	7	74.4	**11**
Richmond upon Thames	129,866	25	97.5	11	16.47	18	96.0	26	73.9	**12**
Kingston upon Thames	107,479	31	102.7	9	15.39	25	78.6	30	73.1	**13**
Barnet	246,753	2	100.1	10	15.96	23	179.6	1	72.8	**14**
Hammersmith and Fulham	108,645	30	85.1	22	19.23	9	79.0	29	72.7	**15**
Ealing	230,293	3	91.0	16	17.41	15	167.0	3	72.5	**16**
Bromley	221,342	4	116.9	3	13.24	32	158.5	4	71.6	**17**
Croydon	250,210	1	107.3	6	14.75	27	178.0	2	71.2	**18**
Harrow	165,463	19	103.5	8	14.74	28	116.7	16	70.5	**19**
Merton	137,138	23	94.9	14	15.99	22	94.7	27	69.0	**20**
Redbridge	186,112	10	96.6	12	14.94	26	123.3	11	66.3	**21**
Southwark	182,351	13	75.7	30	20.07	7	120.7	13	66.2	**22**
Lambeth	183,101	12	79.5	27	19.12	10	120.7	14	65.9	**23**
Hackney	150,218	22	77.7	29	19.44	8	98.3	25	65.4	**24**
Greenwich	178,950	15	88.6	19	16.30	20	114.5	17	64.0	**25**

Borough	**Population 30Plus**	**Rank**	**Death Rate 30Plus Per 10k**[a]	**Rank**	**PWAC NO2 No CO**	**Rank**	**MB SP26 No CO**	**Rank**	**MB SP26 No CO Per 100k**	**Rank**
Lewisham	185,390	11	85.7	21	16.77	17	117.3	15	63.2	**26**
Barking and Dagenham	124,040	29	95.8	13	14.69	29	77.8	32	62.7	**27**
Wandsworth	194,250	8	78.8	28	17.78	12	121.5	12	62.5	**28**
Haringey	163,028	20	80.6	26	17.14	16	101.5	23	62.3	**29**
Waltham Forest	172,709	16	85.0	23	16.22	21	106.7	18	61.8	**30**
Tower Hamlets	169,701	18	63.4	32	20.82	6	93.7	28	55.2	**31**
Newham	196,538	7	70.7	31	17.42	14	106.3	19	54.1	**32**
City of London	8,025	33	45.3	33	24.77	1	4.0	33	49.2	**33**

[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.

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

Combined effects of $PM_{2.5}$ and NO_2 in Greater London

Using the CRFs reported in the WHO HRAPIE-2 report (WHO, 2025) and applying adjustment factors for two-pollutant models by Chen et al. (2024), the 2024 premature mortality burden in Greater London attributed to long-term exposure to air pollution (represented by $PM_{2.5}$ and NO_2) was estimated to be equivalent to 4,250 (3,210 to 5,280) attributable deaths, or 73,100 (55,300 to 91,000) life years lost when a cut-off value of 5 µg m^{-3} was assumed for NO_2. Without a cut-off level[7], the combined burden was estimated to **5,100 (3,820 to 6,380) attributable deaths, or 87,700 (65,700 to 110,000) life years lost** at typical ages (see Table 11). The associated cost attributable to air pollution-related mortality (without a cut-off) in London in 2024 was estimated at **£5,090 (£3,380 to £6,800) million** in 2024 prices. When a cut-off adjustment was applied, this estimate decreases to £4,250 (£2,850 to £5,650) million. Again, as in section above, the results for males are greater than for females, due to the higher baseline mortality rate in younger ages for males.

These estimates consider the correlations of the two pollutants by using correction factors for the mutually adjusted coefficients for $PM_{2.5}$ and NO_2, as recommended recently by the WHO HRAPIE-2 report (WHO, 2025). These combined coefficients resulted in higher burden estimates compared to the estimations for the independent effects for the two pollutants, as detailed in the previous section. Previously, the maximum of the two estimates has been used as a proxy for the combined burden (following the COMEAP recommendation), which may be an underestimation of the true combined impacts (Walton et al, 2025).

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[7] The no cut-off approach was preferred for our key findings, as the studies that looked at health effects of air pollution at low levels have increased recently. COMEAP recommendation suggests no cut-off analysis for $PM_{2.5}$, which is an approach followed in the current analysis (COMEAP, 2023).

Table 11 Estimated mortality burden, Life Years Lost (LYL) and costs of effects on annual mortality for 2024 levels of the combined $PM_{2.5}$ and NO_2 total. Results are provided without and with cut-off for NO_2. The estimates were derived using adjustment factors from multi-pollutant model estimates.

Greater London	**Central estimate (95% Confidence Interval)**		
	Attributable deaths	**Life year lost***	**Costs in £millions****
	$PM_{2.5}$ and NO_2 without cut-off		
Total (male and female)	**5,101** (3,822-6,379)	**87,714** (65,712-109,716)	**5,093** (3,384-6,803)
Male	2,586 (1,937-3,234)	47,968 (35,931-60,006)	2,785 (1,850-3,721)
Female	2,515 (1,885-3,145)	39,746 (29,781-49,710)	2,308 (1,534-3,082)
		$PM_{2.5}$ and NO_2 with cut-off	
Total (male and female)	**4,246** (3,211-5,280)	**73,134** (55,304-90,963)	**4,247** (2,847-5,647)
Male	2,154 (1,629-2,679)	40,038 (30,274-49,802)	2,325 (1,558-3,091)
Female	2,092 (1,582-2,601)	33,096 (25,030-41,161)	1,922 (1,288-2,555)

Using the adjusted concentration-response coefficient of 1.062 (1.042-1.083) per 10 µg m^{-3} of $PM_{2.5}$ and of 1.037 (1.023-1.052) per 10 µg m^{-3} of NO_2, after applying adjustment factors informed by two-pollutant model estimates.

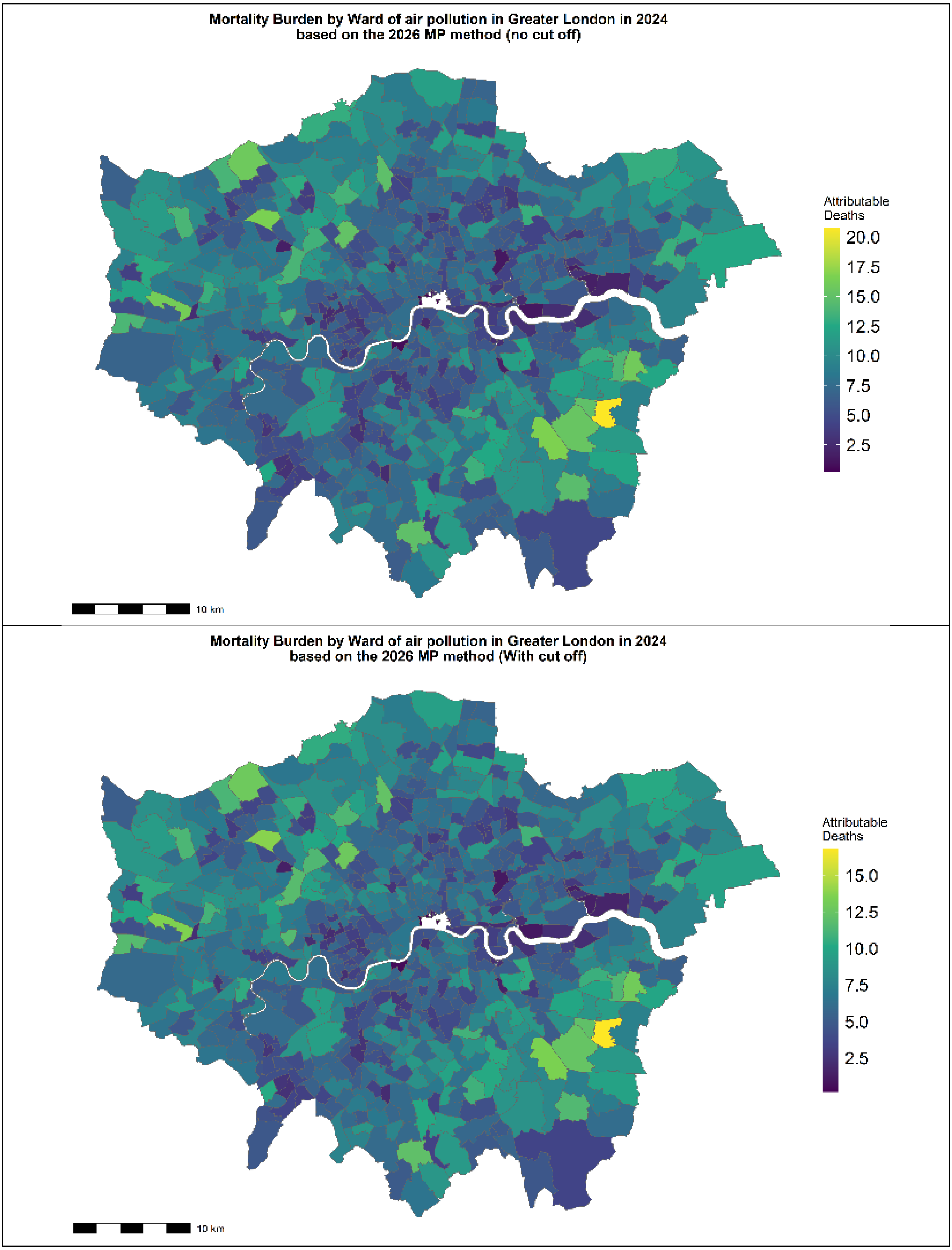
* Associated life years lost, age 30+ and calculated by gender and 1-year age groups, by LSOA then summed up to wards/boroughs/Greater London level.

** Associated costs based on the Value Of a Life Year (VOLY) and calculated by gender, 1-year age groups and LSOA

Combined effects of $PM_{2.5}$ and NO_2 by wards

Figure 5, below, illustrates the spatial distribution of attributable deaths due to air pollution (total $PM_{2.5}$ and NO_2 combined) across Greater London's wards for 2024, estimated using adjustment factors from multiple-pollutant models. Figure 5 comprises two maps comparing results under different cut-off assumptions (top panel: no cut-off, bottom panel: with cut-off). Both maps show considerable spatial variation in attributable deaths with broadly similar pattern across Greater London's wards, with certain wards, particularly in inner and parts of outer London, bearing a disproportionately higher burden of attributable deaths. A notable hotspot of high attributable deaths (yellow) is visible in south-east London, standing out distinctly from surrounding wards.

The no cut-off map (Figure 5, top panel) assumes that all pollution concentrations, no matter how low, contribute to mortality and therefore results in higher attributable death estimates across wards, as there is no threshold below which pollution effects are disregarded. The cut-off map (Figure 5, bottom panel) applies a minimum concentration threshold, below which pollution is assumed to have no attributable effect on mortality. This produces more conservative estimates, with fewer attributable deaths recorded across wards compared to the no cut-off map.



Note that not all the wards in the City of London satisfy the population thresholds associated with Census 2021 output areas. As a result, the wards that are primarily commercial in nature may not have enough residential households to feature on the maps and are instead shown in white to reflect this absence of data.

Figure 5 Mortality burden of air pollution ($PM_{2.5}$ and NO_2 combined) by wards in Greater London for the year 2024. Results are provided without (top panel) and with cut-off (bottom panel) for NO_2. The estimates were derived using adjustment factors from multi-pollutant model estimates.

Combined effects of $PM_{2.5}$ and NO_2 by boroughs

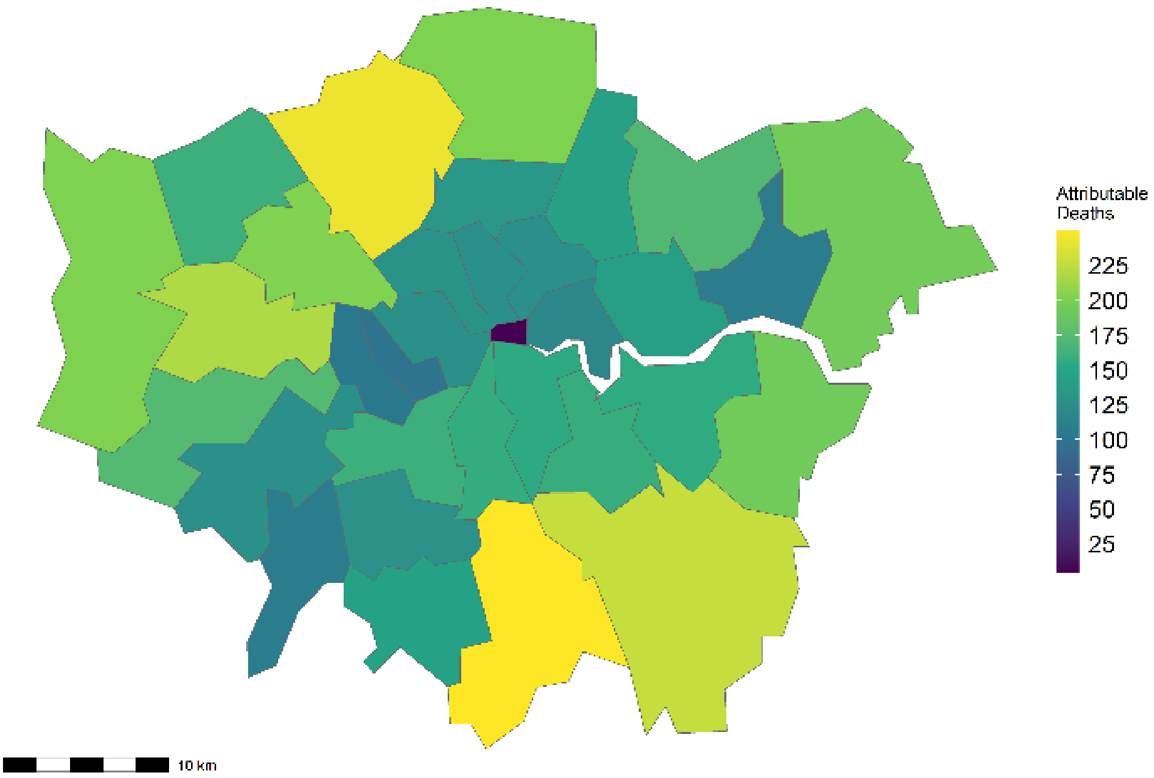
Figure 6 illustrates the spatial distribution of attributable deaths due to $PM_{2.5}$ and NO_2 combined across Greater London's boroughs for 2024, estimated using the WHO recommendation for combining the health impacts of the two correlated pollutants. As expected, the pollution levels by ward (Figure 5) varied more than by borough (Figure 6) due to the higher variability in the input variables, i.e., population, baseline mortality and air pollution levels, at the finer spatial scale. Table 12 provides a detailed breakdown of the factors underlying the MB results, enabling a comparison between boroughs with the largest and smallest attributable deaths per 100,000 population.

Some outer London boroughs dominate the highest absolute attributable death counts, as expected given their greater population sizes (Table 12): Croydon (250 deaths, ranked 1st), Barnet (243 deaths, ranked 2nd), Bromley (227 deaths, ranked 3rd), Ealing (219 deaths, ranked 4th) and Brent (203 deaths, ranked 5th) stand out as the highest burden boroughs (all of them also in the top 5 highest population), appearing in bright yellow-green in Figure 6 (top panel). Inner London boroughs tend to show moderate to lower absolute burdens, partly reflecting smaller population sizes (*Table 12*): for example, Kensington and Chelsea (99 deaths, ranked 32nd) and Hammersmith and Fulham (103 deaths, ranked 31st) record among the lowest absolute attributable deaths (ranked 32nd and 30th in population size, respectively). Kingston Upon Thames (107 deaths, ranked 30th) and Barking and Dagenham (108 deaths, ranked 29th) are outer boroughs recording relatively low attributable deaths, also consistent with their comparatively smaller population sizes (ranked 31st and 29th, respectively) as can be found in Table 12.

Figure 6 (bottom panel) normalises the mortality burden by population, providing an estimate of attributable deaths per 100,000 population. When adjusted for population size, the spatial pattern shifts considerably compared to the absolute burden map. Several outer London boroughs including Bexley (121 deaths per 100k, Rank 1), Havering (114 deaths per 100k, ranked 2nd) and Sutton (107 deaths per 100k, ranked 3rd) emerge as the boroughs with the highest in per-capita mortality burden, appearing in bright yellow-green in Figure 6 (bottom panel), despite not ranking as highly in absolute terms (Table 12). This is driven primarily by their high baseline death rates among the 30+ population, i.e. the death rate for all deaths, not just those attributed to air pollution, (ranked 2nd, 1st and 4th, respectively) and older demographic profiles, despite having relatively lower pollution concentrations (PWAC $PM_{2.5}$ and NO_2 rankings range 28th to 33rd) as seen in Table 12. Some more centrally located boroughs, such as Kensington and Chelsea (107 deaths per 100k, ranked 4th) and Camden (106 deaths per 100k, ranked 5th) also appear among the five boroughs with the highest per-capita burden, largely attributable to their elevated pollution concentrations, with their PWAC $PM_{2.5}$ and NO_2 rankings ranging from 2nd to 6th (Table 12). Overall, central London appears notably darker, indicating that despite high pollution concentrations, the per-capita mortality burden is relatively lower in these boroughs, likely influenced by younger population profiles and lower death rates. Several inner London boroughs including Tower Hamlets (70 deaths per 100k, ranked 32nd), Newham (72 deaths per 100k, ranked 31st) and Wandsworth (83 deaths per 100k, ranked 30th) record the lowest per-capita burdens across London (Table 12). This is primarily driven by their relatively low background death rates among the 30+ population, despite these boroughs having comparatively higher pollution concentrations, as reflected in their PWAC $PM_{2.5}$ and NO_2 rankings.

In both maps (Figure 6), a distinct dark purple spot is visible in central London, corresponding to the City of London. This reflects its exceptionally low residential population and low background death rate, both ranking last (33rd) in Table 12, despite the City of London recording the highest pollution concentrations across Greater London, ranking first for both $PM_{2.5}$ and NO_2 PWACs. It should be noted that the methodology does not account for its significantly larger daytime population.

Mortality Burden by borough of air pollution in Greater London in 2024
based on the 2026 MP method (no cut off)



Mortality Burden per 100k by borough of air pollution in Greater London in 2024
based on the 2026 MP method (no cut off)

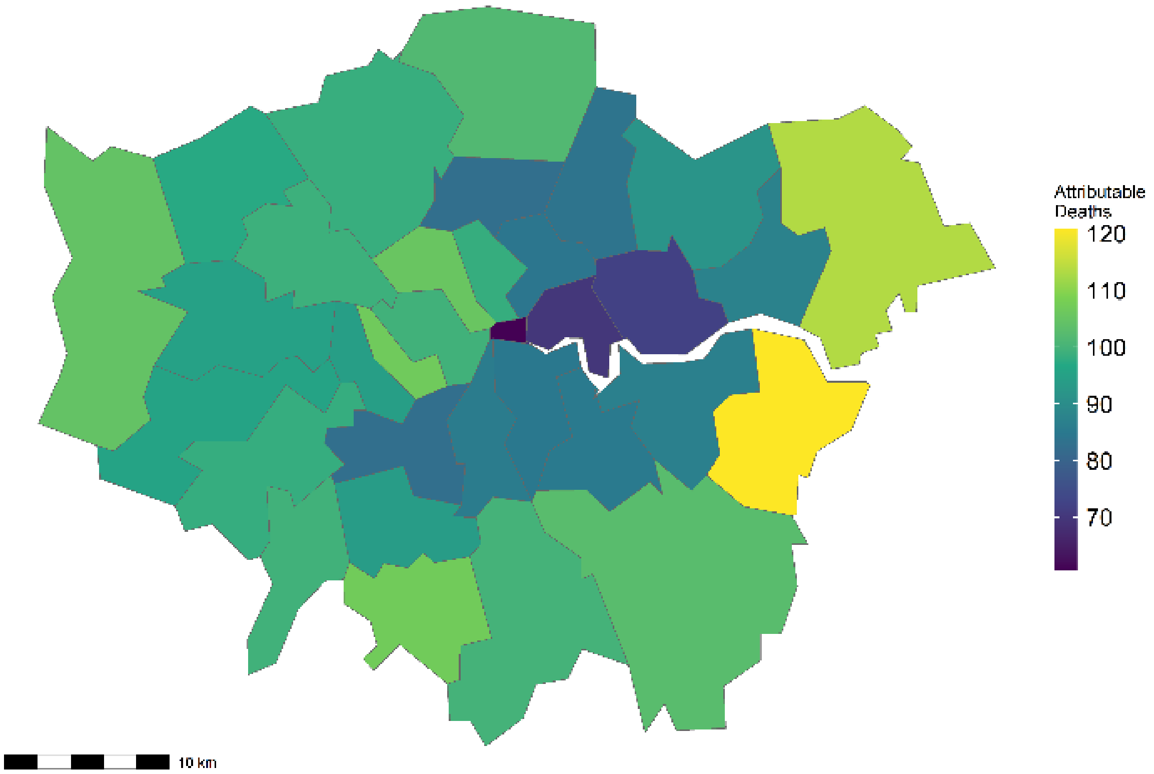


Figure 6 Mortality burden of air pollution (total $PM_{2.5}$ and NO_2 combined) per 100,000 population by boroughs in Greater London for the year 2024. Results are provided without (top panel) and with cut-off (bottom panel) for NO_2. The estimates were derived using adjustment factors from multi-pollutant model estimates.

Table 12 Comparisons of the Mortality Burden (MB) between boroughs with largest and smallest results for attributable deaths per 100k (new Multi Pollutant (MP26) approach, No Cut-Off (No CO), male and female combined)

Borough	**Population 30Plus**	**Rank**	**Death Rate 30Plus Per 10k[a]**	**Rank**	**PWAC $PM_{2.5}$ No CO**	**Rank**	**PWAC NO2 No CO**	**Rank**	**MB MP26 No CO Absolute**	**Rank**	**MB MP26 No CO Per 100k**	**Rank**
Bexley	160,166	21	133.0	2	7.3	30	13.81	31	193.5	9	120.8	**1**
Havering	171,773	17	135.4	1	6.95	33	12.41	33	194.9	8	113.5	**2**
Sutton	136,520	24	114.6	4	7.44	28	14.44	30	146.0	18	107.0	**3**
Kensington and Chelsea	92,814	32	90.0	17	8.55	3	21.03	4	99.0	32	106.7	**4**
Camden	124,363	28	87.2	20	8.39	6	22.01	2	131.2	22	105.5	**5**
Hillingdon	193,401	9	108.2	5	7.25	31	16.46	19	202.3	6	104.6	**6**
Bromley	221,342	4	116.9	3	7.21	32	13.24	32	227.3	3	102.7	**7**
Enfield	198,520	6	104.9	7	7.53	25	15.42	24	201.9	7	101.7	**8**
Croydon	250,210	1	107.3	6	7.63	20	14.75	27	249.9	1	99.9	**9**
Westminster	128,386	26	80.9	25	8.66	2	21.99	3	127.7	24	99.5	**10**
Kingston upon Thames	107,479	31	102.7	9	7.46	27	15.39	25	106.8	30	99.4	**11**
Brent	204,495	5	93.1	15	7.94	13	17.72	13	202.6	5	99.1	**12**
Barnet	246,753	2	100.1	10	7.58	22	15.96	23	243.0	2	98.5	**13**
Islington	128,301	27	84.6	24	8.43	4	20.91	5	126.2	27	98.3	**14**
Richmond upon Thames	129,866	25	97.5	11	7.55	23	16.47	18	127.7	25	98.3	**15**
Harrow	165,463	19	103.5	8	7.36	29	14.74	28	160.8	12	97.2	**16**
Hounslow	180,904	14	89.0	18	7.6	21	18.6	11	172.8	10	95.5	**17**
Ealing	230,293	3	91.0	16	7.71	19	17.41	15	219.0	4	95.1	**18**
Hammersmith and Fulham	108,645	30	85.1	22	8.3	8	19.23	9	102.5	31	94.4	**19**
Merton	137,138	23	94.9	14	7.74	18	15.99	22	128.7	23	93.9	**20**
Redbridge	186,112	10	96.6	12	7.55	24	14.94	26	170.8	11	91.8	**21**
Barking and Dagenham	124,040	29	95.8	13	7.46	26	14.69	29	108.3	29	87.3	**22**
Greenwich	178,950	15	88.6	19	7.79	16	16.3	20	155.5	16	86.9	**23**

Borough	Population 30Plus	Rank	Death Rate 30Plus Per 10k[a]	Rank	PWAC $PM_{2.5}$ No CO	Rank	PWAC NO2 No CO	Rank	MB MP26 No CO Absolute	Rank	MB MP26 No CO Per 100k	Rank
Lambeth	183,101	12	79.5	27	8.26	9	19.12	10	157.0	15	85.8	**24**
Lewisham	185,390	11	85.7	21	7.9	14	16.77	17	158.3	14	85.4	**25**
Southwark	182,351	13	75.7	30	8.32	7	20.07	7	154.8	17	84.9	**26**
Hackney	150,218	22	77.7	29	8.22	10	19.44	8	126.7	26	84.3	**27**
Waltham Forest	172,709	16	85.0	23	7.75	17	16.22	21	144.7	19	83.8	**28**
Haringey	163,028	20	80.6	26	7.86	15	17.14	16	134.9	21	82.8	**29**
Wandsworth	194,250	8	78.8	28	8.04	11	17.78	12	160.7	13	82.7	**30**
Newham	196,538	7	70.7	31	8.01	12	17.42	14	141.6	20	72.0	**31**
Tower Hamlets	169,701	18	63.4	32	8.41	5	20.82	6	118.5	28	69.8	**32**
City of London	8,025	33	45.3	33	9.17	1	24.77	1	4.9	33	60.8	**33**

[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.

5.4 Summary of mortality burden results

In this report, we estimated the mortality burden that can be attributed to $PM_{2.5}$ and NO_2 separately, as well as the combined effect of the two pollutants. Both approaches, i.e. estimating separate and combined pollutant effects, can serve complementary roles in quantifying the health impacts of air pollution, informing policies that target either specific pollutants or the air pollution mixture as a whole.

If we assume that the health impacts of air pollution are evident even at very low concentrations, i.e., no cut-off calculations for NO_2 (a good indicator of traffic pollution), and using the latest recommendation of WHO from the HRAPIE-2 report on single-pollutant model estimates, we showed that 3,810 (95%CI: 2,340-5,200) deaths, or 65,600 (40,400-89,600) life years lost can be attributable to NO_2 exposure in 2024 (see Table 9). With a cut-off, the results for NO_2 were estimated to be 2,680 (1,640-3,670) deaths or 46,400 (28,400-63,600) life years lost. For $PM_{2.5}$, the corresponding estimates (see Table 8) are 3,340 deaths (2,310-4,350), or 57,100 life-years lost (39,500-74,500).

Based on existing COMEAP recommendations, the maximum of the burden estimates for $PM_{2.5}$ and NO_2 can be used as a proxy of the combined effects of the two pollutants. This means that the NO_2 no cut-off estimate of 3,810 (2,340-5,200) attributable deaths can be assumed as the mortality burden of air pollution as a mixture.

However, recent discussions in COMEAP suggest that based on new evidence from multi-pollutant model estimates, this approach might underestimate the combined effects of $PM_{2.5}$ and NO_2 (Dimitris Evangelopoulos is one of the authors of this report and an associate member of COMEAP as well as a member of the COMEAP subgroup on the quantification of air pollution risks (QUARK)). Based on that and following potential updated approaches being recommended by COMEAP, we decided to apply the Chen et al. 2024 approach to reduce single-pollutant estimates when undertaking a two-pollutant analysis, a method also supported by QUARK. Our burden calculations were larger compared to the maximum of the separate effects of $PM_{2.5}$ and NO_2. More specifically, assuming no cut-off concentrations for NO_2, the combined burden was estimated to be 5,100 (3,820-6,380) deaths or 87,700 (65,700-110,000) life years lost (see Table 11). The corresponding numbers assuming a cut-off of 5 $\mu g\ m^{-3}$ for NO_2 were 4,250 (3,210-5,280) deaths or 73,100 (55,300-91,000) life years lost. These findings for combined effects are substantially larger than for either pollutant alone, which shows that the approach to use the maximum of the separate effects of $PM_{2.5}$ or NO_2 may result in an underestimation of the true impacts of air pollution as a mixture. Nonetheless, there is still uncertainty around these estimates, but the evidence base has been evolving rapidly in recent years with a growing number of studies assessing the combined health effects of multiple air pollutants.

Figure 7 below summarises the results as a whole. As outlined above, condensing these findings into a single central estimate is difficult. 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 figure depends on which assumptions are preferred, e.g. whether separate or combined $PM_{2.5}$ and NO_2 effects are investigated. There are three key assumptions to consider such as:

- First, the use of the new multi-pollutant estimates based on the work by Chen et al. (2024) is an improvement over previous methods as it is based on epidemiological findings from 17 cohort studies while previous approaches, such as that in Dajnak et al. (2021), were based on smaller number of studies.

- Second, we reported results with and without a cut-off concentration for NO_2. While there is good evidence for $PM_{2.5}$ effects at lower levels, the relationship between NO_2 and mortality is based on more sparse data points at lower concentrations and there is more uncertainty at lower levels. COMEAP chose to give results both with and without cut-off.
- Finally, there is still debate over the independent effects of NO_2 and $PM_{2.5}$ due to the correlation between the two pollutants. Following the recommendation of the WHO HRAPIE-2 report and in line with discussions held within the QUARK subgroup of COMEAP, the Chen et al. (2024) method was adopted. This involved applying adjustment factors to the unadjusted coefficients derived from the summary single-pollutant model. This approach accounted for the relationship between the two pollutants and adjusted the CRFs accordingly.

Concluding results

As shown above, a set of estimates for the combined effects of $PM_{2.5}$ and NO_2 were provided and can be used for risk quantification. One option would be to use the largest of the single pollutant model estimates, in this case the NO_2 estimate when no cut-off was used for both pollutants; and the $PM_{2.5}$ estimate when a cut-off was applied for NO_2 (no cut off was applied for $PM_{2.5}$ in this analysis, as it has been shown that effects may continue down to the lowest measurable levels). Accepting that it may represent an underestimate, it can still act as a reasonable marker of the air pollution mixture. This would give a range from 3,340 to 3,810 attributable deaths (57,100 - 65,600 life years lost), corresponding to $PM_{2.5}$ through to NO_2 no cut-off.

Another approach would be to define a range based on the recent WHO recommendation on the incorporation of multiple-pollutant model results in the health impacts calculations. This would give a result of 4,250 to 5,100 attributable deaths or 73,100 to 87,700 life years lost i.e. MP data with and without cut-off.

A final option, as used in this report and presented in Figure 7, is to use the combination of the largest estimate between the two pollutants, in this case that for NO_2, and the method supported by the WHO HRAPIE-2 report (WHO, 2025) and accepting extrapolation to lower concentrations with sparse data-points (no cut-off) would give **3,810 to 5,100 attributable deaths (or 65,600 to 87,700 life years lost)**. Results using the same combination but with the cut-off for NO_2 (2,680 to 4,250 attributable deaths or 46,400 to 73,100 life years lost) are also part of this option.

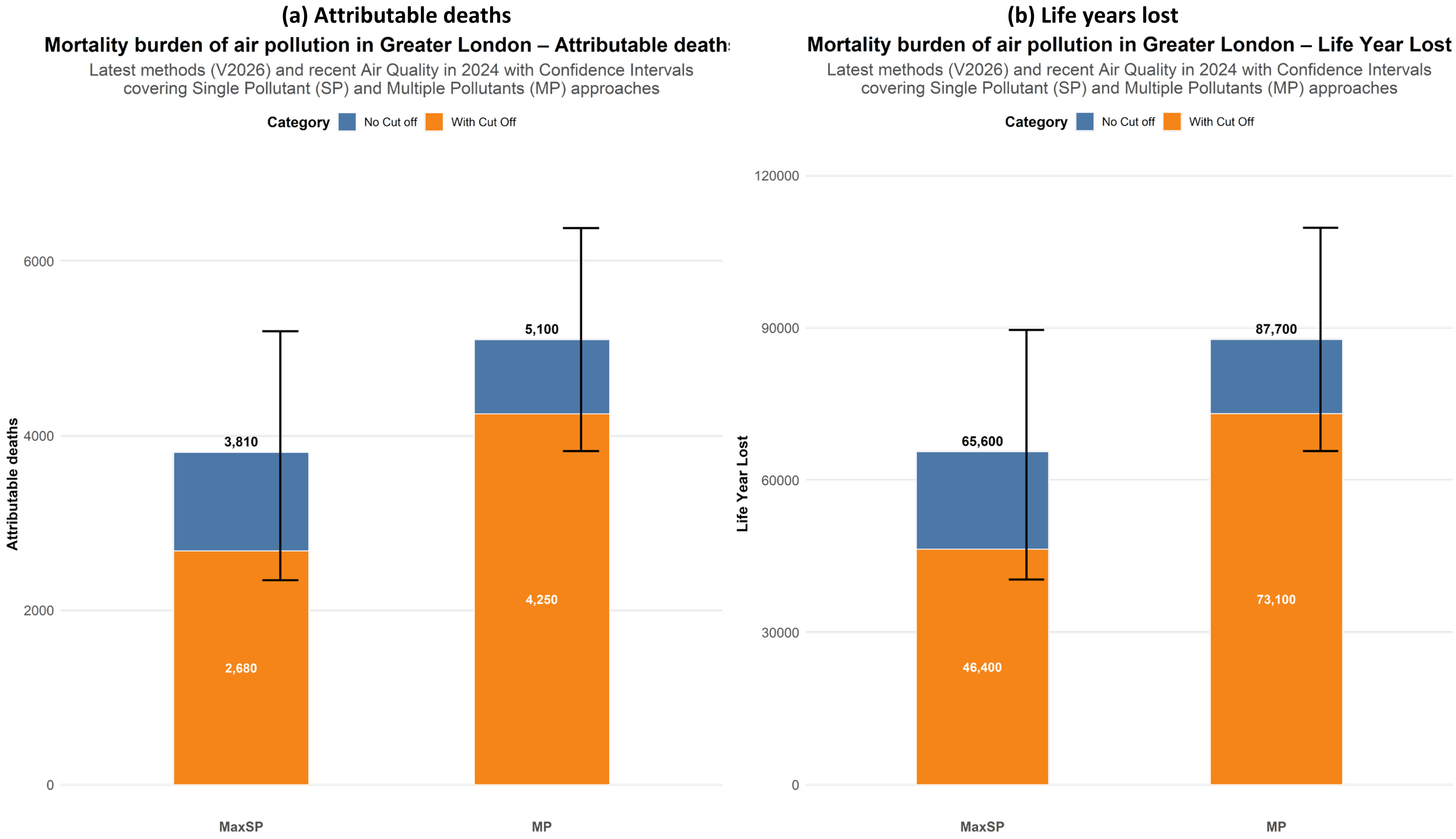


Figure 7 Mortality burden of the combined effects of air pollution in Greater London in 2024. Left panel (a): attributable deaths. Right panel (b): life years lost. MaxSP: maximum estimate of $PM_{2.5}$ and NO_2 effects using single-pollutant model results without adjustment. MP: estimates of the combined $PM_{2.5}$ and NO_2 effect using adjustment factors informed by multi-pollutant models results.

5.5 Comparing previous (2019) and recent (2024) air quality mortality burden

Figure 8, below, presents the total attributable deaths from air pollution in Greater London, i.e. combined effects of $PM_{2.5}$ and NO_2, comparing air quality conditions in 2019 (AQ2019) and 2024 (AQ2024), both assessed using the latest epidemiological evidence up to 2026 (V2026 methodology). Results are shown across the two analytical approaches applied in this report, i.e., maximum estimate of $PM_{2.5}$ and NO_2 effects using single-pollutant model results without CRF adjustment (MaxSP) and the combined $PM_{2.5}$ and NO_2 effect using CRF adjustment factors informed by multi-pollutant models results (MP) including their respective confidence intervals. Both results are presented using "No Cut-off" and "With Cut-off".

Both sets of results have been derived using a consistent methodological framework, ensuring direct comparability between the two scenarios. Specifically:

- Geographic boundaries are based on the 2021 Census including OAs, LSOAs, wards, and borough polygons.
- Population and death data for the reference year 2024 are drawn from the 2021 Census.

The sole distinction between the two sets of results presented in Figure 8 is the air pollution concentrations used as input: the shaded colours represent air quality conditions for 2019 (AQ2019), while the more vivid colours represent air quality conditions for 2024 (AQ2024). All other inputs and parameters remain identical across both sets of results. This ensures that any observed differences in mortality burden estimates can be attributed solely to changes in air pollution concentrations between 2019 and 2024.

Using a hypothetical scenario based on a consistent methodological framework to allow for direct comparability, the burden estimates are lower under air quality in 2024 compared with 2019, across both methods, i.e. from 6,390 to 3,810 attributable deaths (MaxSP method) and from 8,040 to 5,100 attributable deaths (MP method). The health benefits estimated across London reflect the improvements in air quality, over the five-year period, achieved through a combination of long-term pollution trends and targeted air quality policies.

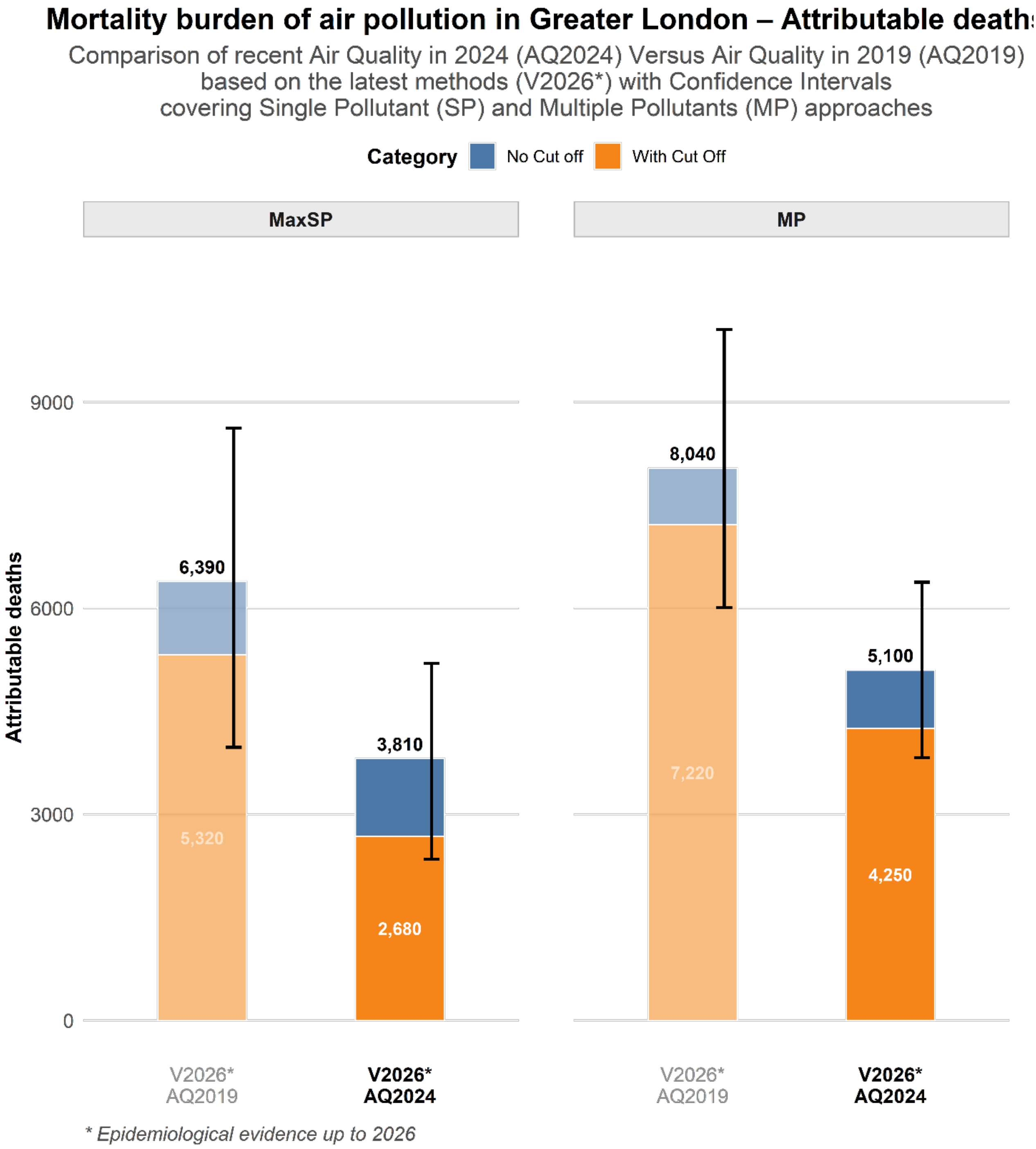


Figure 8 Mortality burden (as attributable deaths) of air pollution in Greater London in 2019 and 2024. MaxSP: maximum estimate of $PM_{2.5}$ and NO_2 effects using single-pollutant model results without CRF adjustment. MP: estimates of the combined $PM_{2.5}$ and NO_2 effect using adjustment factors informed by multi-pollutant models results (exact mortality burden values including the 95% confidence intervals can be found in Table 17 and Table 18 of Appendix Section 7.3).

6.0 Discussion

6.1 Comparing previous and current mortality burden methods

6.1.1 **Methods comparison**

Concentration-response functions used for separate and combined effects of $PM_{2.5}$ and NO_2
The recent epidemiological findings, recommended for quantification of the health effects of air pollution by WHO and used in the current document, have shown a large increase in the air pollution-mortality associations. More specifically, the new meta-analysis of studies of long-term exposure to $PM_{2.5}$ and NO_2 and mortality (Orellano et al. (2024) and Kasdagli et al. (2024)) reported relative risks of 1.095 (95% CI: 1.064-1.120) and 1.05 (1.03-1.07) for $PM_{2.5}$ and NO_2, respectively - Table 1. These are substantially larger compared with those used in our previous report (Dajnak et al. 2021), i.e. 1.06 (1.04-1.08) and 1.023 (1.008-1.037) for $PM_{2.5}$ and NO_2, respectively (Atkinson et al 2018; COMEAP 2018a - Table 13). COMEAP has also discussed these updated CRFs and plans to update its recommendations on quantification, taking into account the WHO's suggestions. The cut-off estimates used in this document are those recommended by COMEAP (COMEAP, 2018), while WHO HRAPIE-2 recommendation was to apply health risk assessments for pollutant concentrations down to the relevant WHO long-term air quality guideline level.

The CRFs were applied in our analysis both for the estimation of the separate effects of $PM_{2.5}$ and NO_2 and the combined effects of the two pollutants. For the former, the CRFs, which are based on single-pollutant model estimates, were used as reported in the systematic reviews without any adjustment. For the combined effects, the methodology employed in this report was an update of our previous analysis (Dajnak et al. 2021), which used an uncertainty range derived using findings from four cohort studies that applied multi-pollutant models. This was our first attempt to address the methodological issue of collinearity between $PM_{2.5}$ and NO_2 and potential overlap of their mortality estimates but was constrained by the limited number of studies available at that time. The evidence base has since expanded substantially, and the systematic review and meta-analysis by Chen et al. (2024) proposed a practical approach to estimate the combined population-attributable fraction using coefficient differences between single- and multi-pollutant model estimates. This methodological approach (used in this work) is recommended in the HRAPIE-2 report and is also supported by COMEAP which plans to revise their recommendations (WHO, 2025).

Despite the uncertainties present, the new method provided a more robust account of the overlap in the epidemiological study results between $PM_{2.5}$ and NO_2 as the proposed adjustment factors informed by multi-pollutant models are based on 17 studies (much more than our previous analysis based only on 4 studies which were available at the time of research). The adjusted CRFs for the combined effects of $PM_{2.5}$ and NO_2 are higher when the new method is used (1.062 (1.042-1.083) for $PM_{2.5}$ and 1.037 (1.023-1.052) for NO_2 - Table 2) compared to the previous method in which the central estimates of the CRFs ranged from 1.019 to 1.053 for $PM_{2.5}$ and 1.011 to 1.020 for NO_2 (Table 14).

6.1.2 Mortality burden estimates comparison

Following on from the results comparing previous 2019 and recent 2024 air quality mortality burden using the current V2026 method (see section 5.5 above), Figure 9 shows the mortality burden of air pollution in 2019 and 2024 using the old method, i.e., epidemiological evidence up to 2021 (V2021) alongside the latest 2024 burden estimates under current epidemiological findings (V2026).

Despite the improvement in air quality between 2019 and 2024, the 2024 burden estimates under V2026 remain higher (3,810 to 5,100 premature deaths based on MaxSP and MP, respectively) than those reported for 2019 under V2021 method in the earlier Dajnak et al. (2021) study (3,000 for Max SP and a range from 3,600 to 4,100 for MP, respectively). This apparent paradox is explained by the higher CRFs explained in the previous section. Indeed, the upward revision in CRFs has outweighed the downward effect of cleaner air. This means that if the older methodology (V2021) had been applied to 2024 air quality data, the estimates would have been lower (1,810 for Max SP and low to high MP ranging from 2,290 to 2,810, respectively) but the adoption of the new epidemiological evidence resets the baseline (AQ2019) upward (see Figure 8). It is worth noting that between 2019 and 2024, population, number of deaths, and death rates have each seen modest increases of 2%, 5%, and 3%, respectively (See Table 3) which also supports a slight increase in mortality burden estimates. However, these demographic shifts represent the least significant driver of change in the overall burden estimates compared to the other contributing factors such as air quality or exposure-response associations.

Conclusion

The updated methodology (V2026) represents a scientifically stronger approach to quantifying the health burden of air pollution, especially the combined effects of $PM_{2.5}$ and NO_2. The higher CRFs mean that the burden estimates are not directly comparable to those from earlier methodological versions. For this reason, when comparing mortality burden estimates between 2024 and 2019, policymakers should account for the reduction in air quality from 2019 to 2024, but also for the updated methodological framework. While a direct comparison of burden estimates between different years may not be appropriate as the inputs are different, we assessed scenarios in which population, number of total (baseline) deaths and geographical boundaries remain the same (V2026), and only the air pollution levels vary (2019 and 2024 levels). This hypothetical scenario-based analysis (in section 5.5) resulted in a reduction of 37% to 40%[8] in mortality burden (i.e. 6,390 to 8,040 attributable deaths for the 2019 scenario to 3,810 to 5,100 for the 2024 scenario), which is driven by the reduced air pollution levels.

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[8] The 40% reduction applies to the largest single-pollutant method (i.e. 6,390 Vs 3,810 deaths) while the 37% difference applies to the multiple-pollutant model method (i.e. 8,040 Vs 5,100 deaths).

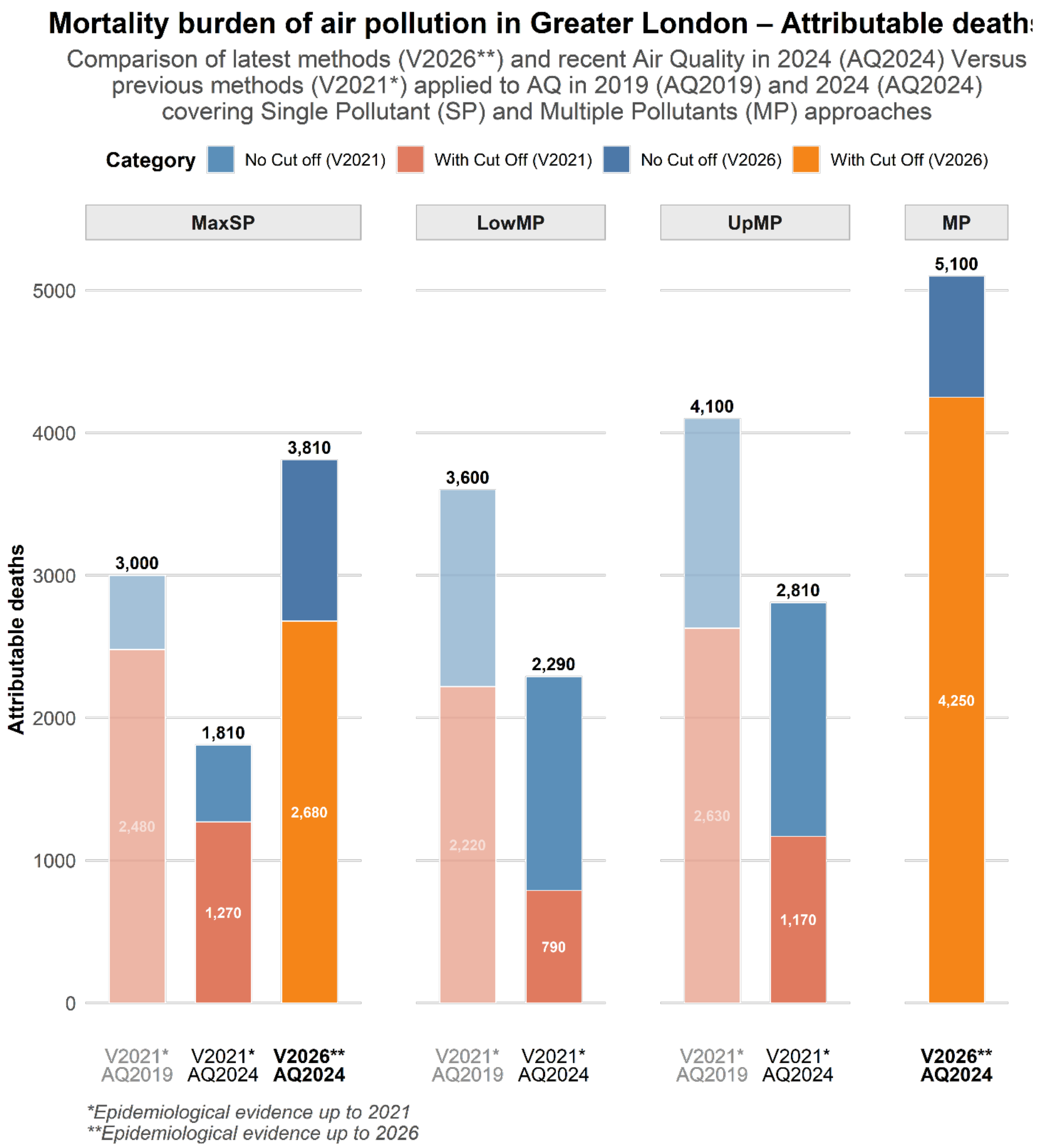

Figure 9 Mortality burden of air pollution in Greater London – Attributable deaths (exact mortality burden values including the 95% confidence intervals can be found in Table 19, Table 20 and Table 21 of Appendix Section 7.3).

6.2 Factors driving variation across London

The contrast between absolute and per-capita (attributable deaths per 100,000 residents) mortality burden results (see Table 10 and Table 12) underscores the importance of considering both metrics when assessing the health impact of air pollution across boroughs. Furthermore, these results are shaped by a combination of factors, including population size, pollutant concentrations, and variations in death rates across LSOAs within each borough.

Cross-borough comparisons have underscored the significant role that population susceptibility plays in shaping health outcomes. These variations are partly driven by the age composition of the population, particularly the proportion of elderly residents, as well as levels of deprivation. While a detailed examination of deprivation's influence falls outside the scope of this project (mainly because the epidemiological evidence on potential differential mortality effects by deprivation is weak), it is worth noting that more deprived areas tend to have a younger population profile. This younger demographic may, to some extent, offset the higher mortality rates typically associated with deprivation when compared across equivalent age groups. Notably, age remains one of the strongest drivers of mortality rates, and as such, can exert a greater influence on the air pollution mortality burden than many other contributing factors.

The mortality burden in Outer London, for instance, can be equally - or even more - pronounced than in Inner London, despite lower pollution levels, owing to the higher proportion of older residents in those areas. It is important to recognise, however, that lower mortality figures in some Inner London boroughs do not necessarily translate to better outcomes across all health indicators. Conditions such as childhood asthma admissions, for example, are more prevalent in boroughs with younger populations, regardless of air pollution concentrations. Taken together, these findings make a compelling case for pursuing air pollution reductions across all London boroughs, without exception, in line with WHO recommendations. Policies targeting specific boroughs (e.g. those with higher air pollution levels) might be inadequate to reduce the associated health burden in London. Not only do emissions travel between boroughs, meaning that efforts to reduce air pollution in one borough will have beneficial effects on neighbouring boroughs as well, but also, as shown in this report, boroughs with lower pollution levels might have higher mortality burden estimates due to their population characteristics. It is therefore crucial that all boroughs collectively commit to improving air quality, as the health benefits of doing so will extend beyond their own boundaries and contribute to a cleaner, healthier London for all.

Finally, the analysis was performed for 2024, while our previous report was for 2019. In between these years, the driving factors mentioned above were highly influenced by the Covid-19 pandemic. In particular, both the ambient air pollution levels and the baseline rates of multiple health outcomes including mortality changed dramatically during the pandemic. Lockdowns reduced traffic substantially but also may have increased indoor-sourced pollution levels as people spent more time indoors. Mortality rates were also affected and cause-specific mortality trends changed during that time. The analysis was conducted using 2024 data, a year in which the impacts of COVID-19 on both air quality and the underlying baseline health data were not substantial. There is a possibility of a harvesting effect, i.e. more vulnerable people may have been affected by air pollution and Covid-19 in the previous years. To account for that, and also to rule out the possibility of including only 2024 data that might be thought as a “wash-out” year for Covid-19, we used 3-year averaged (2022-2024) for our population and mortality data. This method is consistent with previous analyses (Dajnak et al. 2021).

6.3 Strengths and limitations

A key strength of this study is the inclusion of the most recent epidemiological evidence which further strengthens the confidence in a causal relationship between ambient air pollution exposure and the risk of mortality. From a methodological standpoint, the analysis benefits from the use of the latest available population and mortality data, drawn from the 2021 Census, alongside the most recent geographic boundaries derived from the same source. Further methodological strengths included calculation of the mortality burden at fine spatial scale, down to the LSOA level. This was achieved by combining population-weighted average concentrations, derived from high-resolution air pollution predictions on a 20 m × 20 m grid, with population data at the finest available spatial scale, the OA level. A snapshot of the recent London air pollution levels for the year 2024 was estimated using the well-established “London Toolkit” model, which integrated the latest emissions data and accounted for the operational status of a wide range of policies already in place at the time, most notably the ULEZ.

A sensitivity analysis was undertaken, estimating the maximum burden for each of the two pollutants individually at LSOA level and subsequently aggregated to the ward and London-wide scales. The findings were found to be broadly consistent (<3% difference), and in most cases identical to those produced by selecting the larger value from the total sum of each single-pollutant model results. Given that this approach did not produce any substantial difference in the estimates, it was not adopted in the main analysis. Nevertheless, it should be considered in future for health impact assessments conducted over multiple successive years, particularly those designed to quantify the health benefits of policies interventions with differential impacts on $PM_{2.5}$ and NO_2. Such an approach would better capture the combined effects of air pollution exposure, rather than independently summing the impacts of each pollutant and subsequently selecting the maximum of the two values.

PWACs were used throughout the analysis, as this approach is generally preferrable in health impact assessments by accounting for the number of people exposed at each location, rather than treating all locations equally. It assumed that the area-level exposure used is representative of individual exposure. Future work could build on this by incorporating population mobility into the exposure estimates, which may be particularly important for London, where commuter trips via the Underground have been shown to increase personal exposure above residence-based estimates (Wood et al. 2025). Moreover, change of residential address, especially for older populations, may affect the death rates in specific boroughs and, also, introduce exposure misclassification issues. Accounting for this could refine the heath burden estimates further. Other aggravating environmental factors not captured in the analysis may also contribute to the local pollution levels.

This study also has some limitations. Our analysis included data for all-cause mortality from ONS which includes accidental deaths, which may not be associated with air pollution exposure. All-cause mortality statistics are routinely collected and publicly available, while deaths broken down by cause at fine spatial scale may not be published due to data confidentiality issues. However, as mentioned in Orellano et al. (2024), the proportion of deaths caused by accidents are typically small, i.e. less than 10% of all-cause mortality, and CRFs for natural cause mortality can be considered equivalent to all-cause mortality. Thus, the best available approach given the data availability was used. Moreover, we included only $PM_{2.5}$ and NO_2 in the analysis, which might underestimate the combined effects of air pollution as a mixture. Other pollutants, such as ozone (O_3) might also contribute to respiratory mortality impacts (Kasdagli et al. 2024). However, the evidence for all-cause mortality is more robust for $PM_{2.5}$ and NO_2 and we decided to restrict our analysis to these two pollutants.

This study included mortality as the health outcome under investigation, but there is good evidence (as well as a strong logic given the impact on mortality) that air pollution is related to several morbidity outcomes as well, i.e. health outcomes that do not result in death (Forastiere et al. 2024). These include asthma in children, chronic obstructive pulmonary disease, stroke, hypertension and lung cancer, among others. While morbidity analysis was outside the scope of this report, we have previously shown that the health and associated economic impacts of air pollution on morbidity outcomes are substantial and comparable with the mortality effects (Walton et al. 2025).

The estimates in this report represent a snapshot of the mortality burden within a specific year associated with long-term exposure to air pollution, under the assumption that the pollutant concentrations have remained constant at 2024 levels over the preceding years. Unlike a lifetable-based health impact assessment, it does not allow consideration of the changes in age distribution nor population size over time, in the presence or absence of an air quality improvement. For these reasons, such approaches are not appropriate for use across multiple successive years. For consecutive year policy impact assessments, a lifetable-based health impact assessment is the preferred approach, providing a more thorough and reliable quantification of health benefits, the outputs of which can also inform cost-benefit analyses.

Conclusion

This study provides a valuable and methodologically rigorous assessment of the mortality burden attributable to ambient air pollution in London for the year 2024. Our approach provides solid and credible evidence for informing and guiding future air quality policy decisions and public health strategies in London. This analysis also reinforces the importance of continued investment in high-quality data, advanced modelling approaches, and evidence-based air quality policy.

7.0 Appendix

7.1 Additional tables - previous MB method (V2021)

Table 13 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	1.060	1.040-1.080 1.010-1.120*	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 14 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 15 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

7.2 Additional health assessment methods - previous MB method (V2021)

Prior to our 2021 report, the burden calculations were based only on concentrations of $PM_{2.5}$ (COMEAP, 2010). The new COMEAP report (COMEAP, 2018a) at the time considered whether there is an additional burden or impact from nitrogen dioxide or other pollutants with which it is closely correlated. This method considered both pollutants together, as correlations between the pollutants mean that health studies in the population for either pollutant alone actually overlap with the effects of the other pollutant.

The previous MB method (V2021) used the following data and calculation method:

Mortality burden data

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[9] 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[10] and averaged for 2012/2013/2014 to represent 2013. OA data by gender and 1-year age groups was then aggregated up to ward 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[11] 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[12] and requested directly from ONS for the years 2012-2014. LSOA data by gender and 1-year age groups was then aggregated up to ward 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 calculations

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 µg 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.

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

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

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

[12] 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 14) according to the relevant pollution concentration. In this case though, there are more calculations (16) because these 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 is expressed as the range for the sums across the 4 studies. This can be illustrated by examining Table 16 (without cut-offs). It can be seen for Greater London (*Table 16*) 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 16 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[13] (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[14] (with City of London wards merged).

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

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

7.3 Additional tables – burden results in the Greater London area

Table 17 Estimated mortality burden, Life Year Lost (LYL) and costs (from the estimates derived by using information from the highest single pollutant model estimate based on SP method V2026) of effects on annual mortality in 2019 and 2024 of 2019 and 2024 levels of NO_2 (without and with cut-off)

Greater London	**Central estimate (95% Confidence Interval)**			
	Attributable deaths		**Life year lost***	
	NO_2 without cut-off			
	2019	**2024**	**2019**	**2024**
Total (male and female)	6,385 (3,975-8,623)	3,806 (2,343-5,196)	109,774 (68,350-148,233)	65,634 (40,414-89,589)
	NO_2 with cut-off			
Total (male and female)	5,320 (3,297-7,217)	2,677 (1,641-3,671)	91,632 (56,796-124,279)	46,395 (28,438-63,607)

Using WHO HRAPIE-2's recommended concentration-response coefficient of 1.05 per 10 µg m^{-3} of NO_2 for the central estimate (lower estimate RR of 1.03 and upper estimate RR 1.07)

* 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 18 Estimated mortality burden, Life Year Lost (LYL) and costs (from the estimates derived by using information from multi-pollutant model estimate based on MP method V2026) of effects on annual mortality in 2019 and 2024 of 2019 and 2024 levels of $PM_{2.5}$ and NO_2 (without and with cut-off)

Greater London	**Central estimate (95% Confidence Interval)**			
	Attributable deaths		**Life year lost***	
	$PM_{2.5}$ and NO_2 without cut-off			
	2019	**2024**	**2019**	**2024**
Total (male and female)	8,036 (6,011-10,060)	5,101 (3,822-6,379)	137,943 (103,179-172,707)	87,714 (65,712-109,716)
	$PM_{2.5}$ and NO_2 with cut-off			
Total (male and female)	7,217 (5,435-9,000)	4,246 (3,211-5,280)	123,989 (93,355-154,623)	73,134 (55,304-90,963)

Using WHO HRAPIE-2's recommended concentration-response coefficient of 1.062 per 10 µg m^{-3} of $PM_{2.5}$ for the central estimate (lower estimate RR of 1.042 and upper estimate RR 1.083) and of 1.037 per 10 µg m^{-3} of NO_2 for the central estimate (lower estimate RR of 1.023 and upper estimate RR 1.052)

* 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 19 Estimated burden (from single-pollutant model summary estimate based on SP method V2021) of effects on annual mortality in 2019 and 2024 of 2019 and 2024 levels of $PM_{2.5}$ (without and with cut-off)

Greater London	**Central estimate (95% Confidence Interval)**			
	Attributable deaths		**Life year lost***	
	$PM_{2.5}$ without cut-off			
	2019	**2024**	**2019**	**2024**
Total (male and female)	2,955 (2,010-3,864)	2,169 (1,470-2,844)	50,556 (34,384-66,099)	37,149 (25,189-48,715)
	$PM_{2.5}$ with cut-off			
Total (male and female)	1,136 (768-1,495)	203 (137-268)	19,601 (13,247-25,787)	3,606 (2,430-4,758)

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 1.04 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.

Table 20 Estimated burden (from single pollutant model summary estimate based on SP method V2021) of effects on annual mortality in 2019 and 2024 of 2019 and 2024 levels of NO_2 (with and without cut-off)

Greater London	**Central estimate (95% Confidence Interval)**			
	Attributable deaths		**Life year lost***	
	NO_2 without cut-off			
	2019	**2024**	**2019**	**2024**
Total (male and female)	2,999 (1,073-4,700)	1,813 (643-2,864)	51,606 (18,474-80,859)	31,270 (11,096-49,391)
	NO_2 with cut-off			
Total (male and female)	2,484 (886-3,906)	1,267 (448-2,009)	42,850 (15,285-67,358)	21,969 (7,768-34,811)

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.

Table 21 Estimated burden (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies based on MP method V2021) of effects on annual mortality in 2019 and 2024 of 2019 and 2024 levels of $PM_{2.5}$ and NO_2 (without and with cut-off)

Greater London	**$PM_{2.5}$ and NO_2 (without cut-off)**		**$PM_{2.5}$ and NO_2 (with cut-off)**	
	Attributable deaths using coefficients derived from information in 4 studies below* (Life years lost)**			
	2019	**2024**	**2019**	**2024**
Total (male and female)	3,598 - 4,096 (61,818 - 70,224)	2,294-2,808 (39,483-48,204)	2,220 - 2,627 (38,308 - 45,313)	794-1,171 (13,842-20,333)

*Using COMEAP's recommended concentration-response coefficients of 1.029, 1.033, 1.053 and 1.019 per 10 $\mu g\ m^{-3}$ of $PM_{2.5}$ 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 $\mu g\ m^{-3}$ 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.

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