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# Working Paper 4: Sensitivity analyses on spatial scale and population-weighted mean concentrations of nitrogen dioxide in London

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**Sensitivity analyses on spatial scale and population-weighted mean concentrations of nitrogen dioxide in London**

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## 1. Introduction

Defra use exposure data on a 1km grid square basis using the Pollution Climate Model (PCM) model in their health impact calculations for analysis of policies and this model is used for the burden calculations in the main report here. However, the Committee was aware that the original epidemiological studies were at a variety of different spatial scales, some finer than 1 x 1 km, and that $NO_2$ exposure contrasts would be greater at finer scales that could distinguish near road exposures from the background. There is concern that this may be lost when using an average concentration across a 1km grid square. If just averaging concentrations based on the same emissions data across a large area, finer or larger scale grids would not matter, as the area average would be the same. However, fine scale modelling is usually based on more detailed emissions data giving, for example, higher concentrations close to roads that would then increase the average concentration if averaged up to a larger area. For the population-weighted concentrations used in health impact calculations, the results could be different. This could occur if there were higher populations in the areas where $NO_2$ concentrations were higher, that was not balanced by low populations in areas where $NO_2$ concentrations were lower.

### 1.1 Context and purpose

This paper reports analysis that was done some time before the conclusions developed for the main report (COMEAP, 2018). It uses the coefficient from the interim statement (COMEAP, 2015) (a 33% reduction applied to a hazard ratio of 1.025 per 10 µg/m$^3$ $NO_2$). In addition, it should be noted that the burden calculations included are not intended to apply to $NO_2$ itself but to $NO_2$ and any other closely correlated pollutants. These closely correlated pollutants are likely to have a similar spatial distribution to that of $NO_2$ (i.e. closely related to traffic). In any case, the purpose of the Working paper is more about the way in which the assumptions affect the answers than about the answers themselves.

There is modelling available in London at a finer spatial scale, so this paper contains burden calculations using this finer scale modelling for comparison with the London portion of the national results calculated using the PCM model.

The national scale burden calculations in the main report are not broken down by region or local authority. As a result of earlier work (Walton et al., 2015), data inputs for London boroughs was already available. In addition, population and

[1] We acknowledge the contribution of Clare Heaviside, Public Health England who did the burden calculations using the PCM model results

mortality rates for boroughs are available broken down into 5 year age groups in London. This additional detail presented the opportunity to do sensitivity analyses on choices about the level of aggregation of input data. Although this was for 2010 rather than 2013, it was still considered that conclusions could be drawn by comparisons using different combinations of the 2010 data. Comparisons have also been made with some 2010 PCM results.

In summary, the purpose of doing a variety of sensitivity analyses in London was to provide information on the uncertainty due to different methodological assumptions around the PCM regional estimate for London, and also give some guidance as to the importance of spatial scale, breakdown by geographical area and breakdown by age group in calculations more generally.

### 1.2 Plan for sensitivity analyses

The following sensitivity analyses have been performed (all with counterfactuals of both 0 and 5 $\mu g/m^3$) (Table 1). The main report calculations have been done using PCM modelling for 2013.

a) Sensitivity 1. Difference in year for PCM modelling (2013 vs 2010),

b) Sensitivity 2. Difference in year for both modelling and population/mortality rates,

c) Sensitivity 3. Difference between PCM modelling 1 x 1 km and London Air Quality Toolkit (LAQT) modelling 20m x 20m,

d) Sensitivity 4 (vs 3). Difference between population weighting by total population and by total population 30+,

e) Sensitivity 5 (vs 3). Difference between population weighting by total population and by gender and 5-year age group over 30,

f) Sensitivities 6 (vs 5) Difference between population weighting by 20m x 20m modelling aggregated up to output area or 1 x 1 km grid, London overall,

g) Sensitivity 7 (vs 5) Difference between age-based population weighting by 20m x 20m modelling aggregated up to output area, for London overall or calculated separately by London borough and summed[2].

h) Sensitivity 8 (vs 6). Difference between age-based population weighting by 20m x 20m modelling aggregated up to 1 x 1 km grid, for London overall or calculated separately by London borough and summed.

i) Sensitivity 9 (vs 5). Difference between age-based population weighting by 20m x 20m modelling aggregated up to output area, for London overall or calculated separately by London borough and summed, using different mortality rates by borough.

j) Sensitivity10 (vs 6). Difference between age-based population weighting by 20m x 20m modelling aggregated up to 1 x 1 km grid, for London overall or

[2] While sensitivities 7 and 8 were not expected to be very different, they were also useful for isolating the effect of London vs borough mortality rates in sensitivities 9 and 10.

calculated separately by London borough and summed, using different mortality rates by borough.

k) Some additional analyses on population-weighted means rather than burden, and on burden with a range around the central coefficient.

## 2. Methods

Broadly, the methods followed those in COMEAP (2010) and those in the main report. The coefficients, counterfactuals and approach to cessation lag used were the same as in the main report. The difference in the methods to take advantage of more detailed data generally available in London follows the approach used by Walton et al. (2015). The details are summarised below. An overview of the calculation steps is given in Table 1

| **Calculation sequence** | |
|---|---|
| 1 | Year |
| 2 | Modelled concentration |
| 3 | Population-weighted mean concentration (x) |
| 4 | Relative Risk (RR) x/10 |
| 5 | (scaledRR-1)/scaled RR=Attributable fraction (AF) |
| 6 | AF*baseline deaths=attributable deaths (AD) |
| 7 | AD*baseline expected .remaining. Life expectancy |
| 8 | Life years lost |

**Table 1 Overview of health burden calculation steps. All RR 1.017 per 10 µg/m³ $NO_2$, London**

### 2.1 Modelled concentrations, PCM modelling, 1km x 1km (Step 2)

The calculations for London using the PCM model (Brookes et al, 2015) used the methods described in the main report for 2013.

### 2.2 Modelled concentrations 20m x 20m (Step 2)

The modelling used in this paper (the London Air Quality Toolkit, Kelly et al, 2011) differs from that used in COMEAP (2010) and the main report. The differences are discussed in more detail in section 3.2. In addition to using a different type of modelling, the year used was 2010, as this was the most recent version of the London Atmospheric Emissions Inventory (LAEI) available. In brief, the LAQT model uses a kernel modelling technique, based upon the ADMS 4 and ADMS-roads models (CERC, 2013), to describe the initial dispersion from each emissions source. The contribution from each source was summed onto a fixed 20 m x 20 m grid across London assuming that one can calculate the contribution of any source to total air pollution concentrations by applying each kernel and adjusting for the source strength. The kernels have been produced using an emissions source of unity, either 1 g /s (point and jet sources), 1 g/ $m^{-3}$ /s (volume sources) or a

1 g/ km/ s (road and railway sources) and have been created using hourly meteorological measurements from the UK Meteorological Office site at Heathrow. $NO_2$ annual mean concentrations at 20 m grid resolution were extracted from the LAEI2010 year 2010 air quality results and intersected with the latest Output Area (OA) layer from the Office of National Statistics (ONS) 2011 for the Greater London area (a total of 25,053 OAs). Each concentration grid point within each OA was further averaged at OA level, borough or Greater London area.

The concentrations were averaged up to output area level, as this was the smallest geographical scale at which population data by age was publicly available. They are defined by approximate population size rather than area but their boundaries are also aligned to natural urban/rural or population density boundaries (e.g. park boundaries) and nested within larger administrative areas such as super output areas and boroughs. They vary considerably by area from about 100 $m^2$ to about 12 $km^2$, being larger in outer London where the population is less dense and very small in central London.

For sensitivity analyses 6 ,8 and 10 (see below) the 20m x 20m modelled concentrations were averaged up to 1 x 1 km rather than to OA level.

### 2.3 Anthropogenic source (Step 2)

As in the main report, total $NO_2$ concentration was used as the state of knowledge (European Commission, 2011) does not allow for a natural part of $NO_2$ to be measured or quantified.

### 2.4 Population data (Steps 3 and 6)

Population data is relevant at 2 steps in the calculations – for population weighting (step 3, Table 1) and as the population determining the number of baseline deaths (step 6).

For the PCM 2013 calculations, ONS population data for 2011 was used for population-weighting and the baseline deaths related to the 2013 population. The population data was available by single year of age.

For the PCM 2010 calculations, the total population from the 2011 Census was also used for population-weighting. The baseline deaths related to the average of the 2009/2010/2011 population to match the LAQT/OA calculations (see below).

For 2010 burden calculations with the LAQT model, the population data was downloaded from ONS[3.] As the deaths had been averaged over 3 years to avoid problems with small numbers, the same was done for the population. The population data was given by single year of age at OA level and has been further averaged for 2009/2010/2011 to represent 2010. Where necessary, the population was summed by gender and 5-year age groups for aged 30 and above for each

[3] http://www.ons.gov.uk/ons/about-ons/business-transparency/freedom-of-information/what-can-i-request/published-ad-hoc-data/pop/november-2013/index.html

OA, each borough and for London overall. The division of population by gender and 5-year age groups matched the deaths data, except in certain sensitivity analyses examining methods for population weighting.

### 2.5 Population-weighted average concentration (Step 3)

One possible approach to the burden calculations summarised in Table 1 is to do separate calculations in each small geographical area and then add up the attributable deaths across London. The result in each area would be affected by the pollutant concentration and the population in that area (as the population in turn affects the baseline number of deaths). If the relationship is approximately linear, it is more convenient to derive one population-weighted mean (or a small number for e.g. boroughs) and then do just one, or a smaller number of full calculations of mortality burden.

For the PCM modelled concentrations, population-weighting was done by 1 x 1 km grid square as described in the main report using the total population for 2011.

The London area was defined by the borough boundaries of the outer London area. This boundary is contiguous with output area boundaries but not 1km grid boundaries. The 1km grid London boundary was set by including all grid squares[4] where 50% or more of the area overlapped with the borough boundaries around the edge of London.

For calculations that go as far as calculating the burden in life years lost, it is important to calculate the attributable deaths separately by gender and 5-year age group, as expected remaining life expectancy varies substantially with age. It therefore makes sense to population-weight by these populations as well. These populations by age group were not easily available at 1 x 1 km grid square level for the population weighting done in the main report but was available for London as a result of previous work (Walton et al., 2015). The calculations using the LAQT modelling in London, therefore made use of this information. Whether this additional population detail for population-weighting made enough difference to warrant using this approach for the national data was examined in sensitivity analyses 3-5.

For the LAQT modelled concentrations, the 20x20m concentrations averaged up to output area were population-weighted at borough level i.e. the OA concentrations were multiplied by the OA population for the relevant gender and 5-year age group[5] to give a population-concentration product that was then summed to borough level and divided by the borough population. This gave a series of gender and 5-year age group specific population-weighted mean for each borough that was combined with mortality data at borough level to give results for mortality burden. Only 5-year age groups above 30 years of age were used. For the sensitivity analyses mentioned above, population-weighting was done with the total OA population aged

[4] The 1km grid squares are fixed geographically as per the Ordnance Survey.

[5] The upper age group was aged 85+.

30 and above, and the total OA population overall, without splitting by 5-year age group.

When assuming a counter-factual of 5 μg/m$^3$, this value of 5 was subtracted from the 20 x 20 m grid concentrations in each OA and the difference was then averaged up to OA level to be used in the population-weighting. For example, for a 20 x 20 m grid concentration of 30 μg/m$^3$, a concentration of 25 μg/m$^3$ was used in subsequent averaging up to OA level and then population weighting by gender and 5-year age group. Any 20 x 20 m grid concentrations that were negative after subtracting 5 μg/m$^3$ were set to zero. (There were no examples of this in London in 2010).

To determine the effect of spatial scale at the population-weighting step, an analysis was done to compare the population-weighted mean concentration for London derived via data at OA level with the population-weighted mean concentration for London derived from the same 20m x 20m modelling data but averaged up to 1x1 km grid squares for the first step of population-weighting. The 1x1 km grid square populations were derived from intersections with output area populations for the relevant gender and age group. For this exercise, we did not have population data for output areas outside London, so the populations of these boundary 1km grid squares will be underestimated to some degree. This population-weighted mean concentration information was used in sensitivity 5/6 (London overall); 7/8 (concentrations by borough) and 9/10 (concentrations and mortality rates by borough).

For the counterfactual of 5 μg/m$^3$, this value of 5 was subtracted from the 1 x 1 km grid square concentrations, with any concentrations below 5 set to zero. Again, this did not actually apply in London.

### 2.6 Calculations of attributable deaths (steps 4 and 5)

The calculations followed COMEAP (2010), Gowers et al (2014) and the method described for single coefficient not paired coefficient calculations in the main report. The relative risk (RR) per 10 μg/m$^3$ was scaled to a new relative risk for the appropriate population-weighted average concentration for each borough. The coefficient we used for these analyses (which were completed some time before the overall conclusions of the main report were finalised) was 1.017. This is as recommended in the interim statement (COMEAP, 2015) i.e. a 33% reduction of the single pollutant model coefficient of 1.025 per 10 μg/m$^3$ $NO_2$. The equation used to scale the coefficient by concentration was:

$$RR(x) = 1.017^{x/10}$$

where x is the population-weighted average concentration of interest (weighted by the relevant gender and 5-year age group aged above 30; except for sensitivity analyses d) and e) where it was weighted by the total population above 30) or the total population respectively.

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.

### 2.7 Calculations of attributable deaths (step 6)

For the calculations using the population weighted mean from the PCM model, deaths data from ONS for age 30+ for the year 2013 were used. For 2010, for comparative purposes the same deaths data as used for the calculations using the LAQT population-weighted means was used (see below). Only deaths data summed to London overall were used for the PCM based calculations.

For the calculations using the population weighted mean from the LAQT model, the deaths data were extracted from ONS data by the PHE London Knowledge and Intelligence Team. The deaths data were given by 5-year age groups, averaged for 2009/2010/2011 at London borough level. This is taken to be a figure for 2010 with the random year-to-year variability in age groups with small numbers of deaths stabilised by averaging with the surrounding years.

For sensitivity analyses using London overall (sensitivities 3-6), the deaths were summed from the borough data.

For the PCM model calculations, the attributable fraction was just multiplied by the baseline deaths over 30 years of age.

With the above source data for the LAQT model calculations, the attributable fraction derived from each of the population-weighted means was multiplied by the number of deaths in the relevant gender and 5-year age group aged 30+ for London overall or by borough to give the number of attributable deaths.

The attributable deaths were then summed across the 5-year age groups above aged 30, for both males and females, to give a total for London directly or for the borough to be summed across London.

### 2.8 Calculations of life-years lost (step 7)

To calculate the loss of life years associated with these deaths, the deaths and population data were input into the South East Public Health Observatory (SEPHO) Life Expectancy Calculator http://www.sepho.org.uk/viewResource.aspx?id=8943. This provides the expected remaining life expectancy for specified 5-year age groups. This was calculated separately for males and females[6]. (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 attributable deaths.) The relevant values for expected remaining life expectancy in an age group were then multiplied by the number of attributable deaths to estimate the total life years lost.

[6] Available from the authors on request.

The calculations above were done at the borough level and the results for deaths and life years summed to give a total for London. This allows different death rates in different boroughs to influence the results. The use of population-weighting across the whole of London requires an assumption that the death rate is the same across London.

For some sensitivity analyses, the calculation of attributable deaths and life years lost was repeated for the lower (1.006) and upper (1.027) confidence intervals around the relative risk, derived as explained in section 3.5.

### 2.9 Reference table of inputs and assumptions for different sensitivity analyses

To aid interpretation of the results section, Tables 2 to 4 below summarise the different sensitivity analyses with their different inputs and assumptions. Comparison across the columns shows which sensitivity analysis comparisons test which assumptions. Some of these comparisons address key issues that arose in the discussions for the main report. As some of the input data and methodology was taken from previous work that did not match in all respects, some sensitivity analyses are part of a sequence that allows separation of the assumption to be tested. For example, a different year and method of population-weighting was used for the previous work in London (Walton et al., 2015) built upon here. Note that it is always possible to track back through a series of comparisons to the core analysis.

**Table 2: Methods for core and sensitivity analyses (S1/S2) in London using PCM modelling (all RR 1.017 per 10 μg/m³ $NO_2$ with counterfactuals of 0 and 5 μg/m³)**

| **Sensitivity→ Input/assumption↓** | **Core PCM 2013 (Pop. weight 2011)** | **Sensitivity 1 PCM 2010, (other inputs as core)** | **Sensitivity 2 PCM 2010, (Pop. weight 2011; 2009/10/11 mortality rate)** |
|---|---|---|---|
| Year | 2013 | 2010 for concentrations/ otherwise 2013 | 2010 for concentrations/ ave2009/10/11 for population and deaths |
| Model and Scale | PCM, 1 x 1 km | PCM, 1 x 1 km | PCM, 1 x 1 km |
| Year used for meteorology | 2013 | 2010 | 2010 |
| Population and age group for population-weighting | 8,209,428 Total all ages, 2011 | 8,209,428 Total all ages, 2011 | 8,209,428 Total all ages, 2011 |
| Scale of population-weighting | 1 x 1 km | 1 x 1 km | 1 x 1 km |
| Geographical area | London overall | London overall | London overall |
| Mortality rate 30+ per 100,000 | 943.8 (2013) | 943.8 (2013) | 998.24 (2009/10/11) |
| Population 30+ | 4923817 (2013) | 4923817 (2013) | 4656316 (2009/10/11) |
| Baseline deaths 30+ | 46469 (2013) | 46469 (2013) | 46481 (2009/10/11) |
| Baseline expected remaining life expectancy age group interval | Not estimated (NE) | NE | NE |
| Comparator | None (this is core) | Core | Core, sensitivity 1 (S1) |
| Assumption/ input being tested | | Comparison vs core: Use of concentration from different year | Comparison vs core: Use of different year for all inputs<br><br>Comparison vs S1: Use of different year for population and mortality data |
| Step from Table 1 being tested | | 1 | 1 |

**Table 3: Methods for sensitivity analyses (S2/S3) in London, comparison of PCM and LAQT modelling (all RR 1.017 per 10 µg/m³ $NO_2$ with counterfactuals of 0 and 5 µg/m³)**

| Sensitivity→ Input/ Assumption↓ | Sensitivity 2 (PCM 2010, 2010[7] population and death data) | Sensitivity 3 (LAQT modelling 2010, 2010 population and death data) Pop weighting by total population. |
|---|---|---|
| Year | 2010 for concentrations/ave2009/10/11 for population and deaths | 2010 for concentrations/ave2009/10/11 for population and deaths |
| Model and Scale | PCM, 1 x 1 km | LAQT 20m x 20m |
| Year used for metereology | 2010 | 2010 |
| Emissions inventory | NAEI 2009 | LAEI 2010 |
| Population and age group for population-weighting | Total all ages, 2011 Census<br><br>(8,209,428) | Total all ages, ave2009/10/11<br><br>(8,069,499) |
| Scale of population-weighting | 1 x 1 km | Output area (OA) |
| Geographical area | London overall | London overall |
| Mortality rate 30+ per 100,000 | 998.24 | 998.25 |
| Population 30+ | 4656300 | 4,656,316 |
| Baseline deaths 30+ | 46,481 | 46,481 |
| Baseline expected remaining life expectancy age group interval | NE | By 5 year age group for ages 30+ |
| Life years lost | NE | 41,404 |
| Comparator | See table.2 | Sensitivity 2 |
| Assumption/input being tested | See table 2 | Comparison vs S2: Effect of using different modelling methods |
| Step being tested | See table 2 | 2 |

[7] 2011 for population-weighting; 2009/10/11 average for deaths data.

**Table 4: Methods for sensitivity analyses (S3/S4/S5) in London, comparison of age groups for population-weighting, LAQT modelling (all RR 1.017 per 10 µg/m$^3$ $NO_2$ with counterfactuals of 0 and 5 µg/m$^3$)**

| Sensitivity→ Input/ Assumption↓ | Sensitivity 3 (LAQT modelling 2010, 2010 population and death data) Pop weighting by total population. | Sensitivity 4 (as sensitivity 3 but pop weighted by 30+ population) | Sensitivity 5 (as sensitivity 3 but pop weighted by each 5 year age group, 30+ ) |
|---|---|---|---|
| Year | 2010 for concentrations/ ave2009/10/11 for population and deaths | 2010 for concentrations/ ave2009/10/11 for population and deaths | 2010 for concentrations/ ave2009/10/11 for population and deaths |
| Model and Scale | LAQT 20m x 20m | LAQT 20m x 20m | LAQT 20m x 20m |
| Population and age group for population-weighting | Total all ages, ave2009/10/11 (8,069,499) | Total 30+ (4,656,316) | Separately by gender and 5 year age group for all ages over 30 (total still 4,656,316) |
| Scale of population-weighting | Output area (OA) | OA | OA |
| Geographical area | London overall | London overall | London overall |
| Mortality rate 30+ per 100,000[a] | 998.25 | 998.25 | 998.25 |
| Population 30+[a] | 4,656,316 | 4,656,316 | 4,656,316 |
| Baseline deaths 30+[a] | 46,481 | 46,481 | 46,481 |
| Baseline expected remaining life expectancy age group interval | By 5 year age group for ages 30+ | By 5 year age group for ages 30+ | By 5 year age group for ages 30+ |
| Comparator | Sensitivity 2 | Sensitivity 3 | Sensitivity 4 |
| Assumption/input being tested | Comparison vs S2: Effect of using different modelling methods | Comparison vs S3: Effect of population weighting by 30+ rather than total population | Comparison vs S4: Effect of population weighting by gender and 5 year age group within 30+ rather than overall 30+ |
| Step being tested | 2 | 3 | 3 |

[a]Attributable deaths and life year calculations all done for population 30+, by gender and age.

**Table 5: Methods for sensitivity analyses (S5/S6) in London, comparison of OA or 1 x 1 km scale for population-weighting, LAQT modelling, London overall (all RR 1.017 per 10 µg/m$^3$ $NO_2$ with counterfactuals of 0 and 5 µg/m$^3$) (see also Table 6)**

| Sensitivity→<br>Input/<br>Assumption↓ | Sensitivity 5 (as sensitivity 3 but pop weighted by each 5 year age group, 30+ ) | Sensitivity 6 (as sensitivity 5 but pop weighted at 1km grid rather than OA) |
|---|---|---|
| Year | 2010 for concentrations/ ave2009/10/11 for population and deaths | 2010 for concentrations/ ave2009/10/11 for population and deaths |
| Model and Scale | LAQT 20m x 20m | LAQT 20m x 20m, aggregated to 1 km$^2$ |
| Population and age group for population-weighting | Separately by gender and 5 year age group for all ages over 30 (total still 4,656,316) | Separately by gender and 5 year age group for all ages over 30 (total still 4,656,316) |
| Scale of population-weighting | OA, London overall | 1 km$^2$ grid, London overall |
| Geographical area | London overall | London overall |
| Mortality rate 30+ per 100,000 | 998.25 | 998.25 |
| Population 30+ | 4,656,316 | 4,656,316 |
| Baseline deaths 30+ | 46,481 | 46,481 |
| Baseline expected remaining life expectancy age group interval | By 5 year age group for ages 30+ | By 5 year age group for ages 30+ |
| Comparator | | Sensitivity 5 |
| Assumption/input being tested | | Comparison vs S5: Effect of population weighting at 1km grid scale rather than OA level |
| Step being tested | | 3 |

**Table 6: Methods for sensitivity analyses (S7 - S10) in London, comparing population-weighting by OA or 1 x 1 km grid, LAQT modelling, borough concentrations +/- mortality rates by borough (all RR 1.017 per 10 µg/m³ $NO_2$ with counterfactuals of 0 and 5 µg/m³)**

| Sensitivity→ Input/ Assumption↓ | Sensitivity 7 (as S5 but separately by borough PWM) | Sensitivity 8 (as S6 but separately by borough PWM) | Sensitivity 9 (as sensitivity 5 but calculated separately by borough PWM and mortality rates) | Sensitivity 10 (as sensitivity 6 (1 Km grid) but calculated separately by borough PWM and mortality rates) |
|---|---|---|---|---|
| Year | 2010 for concentrations/ ave2009/10/11 for population and deaths | | | |
| Model and Scale (all LAQT) | 20m x 20m, OA | 20m x 20m, then 1 km² | 20m x 20m, OA | 20m x 20m, then 1 km² |
| Population and age group for population-weighting | Separately by gender and 5-year age group for all ages over 30 (total still 4,656,316) | | | |
| Scale of population-weighting | OA, London boroughs | 1 km² grid, London boroughs | OA, London boroughs | 1 km² grid, London boroughs |
| Geographical area | London boroughs summed for London | | | |
| Mortality rate 30+ per 100,000 | From 32.9 (female 30-34, London) to 14,691 (male 85+, London) | From 32.9 (female 30-34, London) to 14,691 (male 85+, London) | 0 (male 30-34, male/female 35-39, City of London) to 17,471 (male, 85+, Greenwich) | 0 (male 30-39, male/female 35-39, City of London) to 18,296 (male, 85+, Greenwich) |
| Population 30+ | 4,656,316 | 4,656,316 | 4,656,316 | 4,656,316 |
| Baseline deaths 30+ | 46,481 | 46,481 | 46,481 | 46,481 |
| Baseline expected remaining life expectancy | By 5-year age group for ages 30+ | | | |
| Comparator | Sensitivity 5/8 | Sensitivity 6/8 | | |
| Assumption/input being tested | Comparison vs S5: Effect of disaggregating concentrations by London borough (OA pop weighting) | Comparison vs S5: Effect of population weighting at 1km grid scale rather than OA level | | |
| Step being tested | 3 | 3 | | |

## 3 Results

The results section is organised according to the list given in section 1.2

### 3.1 Results for London using method from main report and effect of changing year (Sensitivities 1 and 2)

The results for London regarded as 'core' in the context of this paper is given in Table 7. It can be seen that the concentrations were higher in 2010 and that makes a 10.4 or 12.6% difference to the attributable deaths result for a 0 or 5 µg/m$^3$ cut-off. The effect of the difference in concentrations from one year to another was much greater than the effect of the change in mortality rates between years. This is important to bear in mind, as the finer scale modelling for London was only available for 2010. Comparing the two different modelling methods is discussed in the next section. (The mortality rate was taken from the average of 2009/10/11 for the purpose of later comparisons, the attributable deaths for 2010 PCM concentrations using 2010 mortality rates was 2513 for no cut off and 2137 for a 5 µg/m$^3$ cut-off.)

### 3.2 Results for London in 2010 – comparison of results with PCM (1 x 1 km) and LAQT (20m x 20m, OA) modelled concentrations (Sensitivity 3)

Sensitivities 2 and 3 are matched in almost all respects except for the modelling method. The only other difference was that the 2010 PCM modelling population-weighted mean available from previous projects was population-weighted using population data from the 2011 Census rather than the average population for 2009/10/11 as used for the 2010 LAQT population-weighted means. It should also be noted that the 20 x 20m modelling in London was population-weighted at output area level, areas larger than 20 x 20m but generally smaller than 1 x 1 km. The effect of population-weighting at OA compared with 1 km grid square scale is discussed in section 3.4. Nonetheless, the major reason for the 12-14% higher result with the LAQT model in Table 8 is likely to be the different modelling methods used. This is expected for finer scale modelling picking up higher more local concentrations but there are also other possible explanations.

The PCM model uses emissions estimates from the National Atmospheric Emission Inventory, concentrations are calculated using an air dispersion model with the regional contribution being derived from ambient measurement data. The model is calibrated using measurement data from the UK national monitoring network. The model estimates background concentrations at a 1km x 1km scale. Road link information is added separately onto the background estimates for compliance assessment and policy assessments but for the calculations presented here only the 1 km x 1 km background concentrations were used. This model has been used for the burden assessment in the main report.

To aid the understanding of the differences between modelling at this slightly broader scale and finer scale modelling that is potentially closer to the scale used in the epidemiological studies, we did a comparison within London of the concentrations from the London Air Quality Toolkit model used at King's averaged up to 1km x 1km grids and the concentrations from the PCM model at the same scale. It is also useful to understand the differences for the purpose of interpreting other comparisons.

**Table 7: Results for London using PCM modelling for 2013 and for 2010 concentrations with 2013 or 2010 population and mortality data (all RR 1.017 per 10 µg/m³ $NO_2$ with counterfactuals of 0 and 5 µg/m³)**

| Sensitivity→<br>Result↓ | **Core<br>PCM 2013** | **Sensitivity 1<br>(PCM 2010, other inputs as core)** | **Sensitivity 2<br>( PCM 2010, 2010 population and death data)** |
|---|---|---|---|
| Year for concentrations | 2013 | 2010 | 2010 |
| Year for mortality rate | 2013 | 2013 | Ave 2009/10/11 |
| **Counterfactual 0 µg/m³** | | | |
| Population-weighted mean µg/m³ | 29.5 | 32.7 | 32.7 |
| Attributable deaths | 2257 | 2492 | 2493 |
| % change for 2013 vs 2010 concentrations (S1vs core) | | 10.4% | |
| % change for 2013 vs 2009/10/11 mortality rates (S2vsS1) | | | 0.04% |
| % change for 2013 vs 2010 concentrations and mortality rates (S2vs core) | | | 10.5% |
| **Cut-off 5 µg/m³** | | | |
| Population-weighted mean µg/m³ | 24.5 | 27.7 | 27.7 |
| Attributable deaths | 1883 | 2120 | *2120* |
| % change for 2013 vs 2010 concentrations (S1vs core) | | 12.6% | |
| % change for 2013 vs 2010 mortality rates (S2vsS1) | | | 0% |
| % change for 2013 vs 2010 concentrations and mortality rates (S2vs core) | | | 12.6% |

**Table 8: Results for London in 2010 – comparison of results with PCM (1 X 1 km) and LAQT (20m x 20m) modelled concentrations (all RR 1.017 per 10 µg/m³ $NO_2$ with counterfactuals of 0 and 5 µg/m³)**

| Sensitivity→<br>Result↓ | **Sensitivity 2<br>( PCM 2010)** | | **Sensitivity 3<br>(LAQT 2010)** | |
|---|---|---|---|---|
| Modelling scale | 1 x 1 km | | 20 x 20m | |
| Scale for population-weighting | 1 x 1 km | | Output area (OA) | |
| Population age and year for population-weighting | All ages 2011 | | Average 2009/10/11 all ages | |
| **Counterfactual** | **0 µg/m³** | **5 µg/m³** | **0 µg/m³** | **5 µg/m³** |
| Population-weighted mean µg/m³ | 32.7 | 27.7 | 36.7 | 31.7 |
| Attributable deaths | 2493 | 2120 | 2,787 | 2417 |
| % change for result from PCM vs LAQT modelled concentrations | | | 11.8% | 14% |

The differences are shown in the Table 9 below. The average of the grid square concentrations for $NO_2$ across London is lower for the PCM model (29.0 µg/m³) than for the LAQT model (33.4 µg/m³). The minimum and maximum concentrations are also lower for the PCM model. This is compatible with the idea that the finer scale modelling input at 20m x 20m, even after averaging to 1km x 1km scale, may be picking up higher $NO_2$ concentrations (e.g. beside roads) to a greater degree than the PCM model done at a broader scale. However, it should be emphasised that the scale of the inputs is not the only difference between the models, there are also other differences (see Table 3). Thus, it is by no means proven that difference in scale is the main reason for the differences. The differences between the emission inventories used, including the emission factor assumptions and the dispersion modelling methods used for specific sources, such as emissions at airports or from shipping, will also contribute to the differences between the model results.

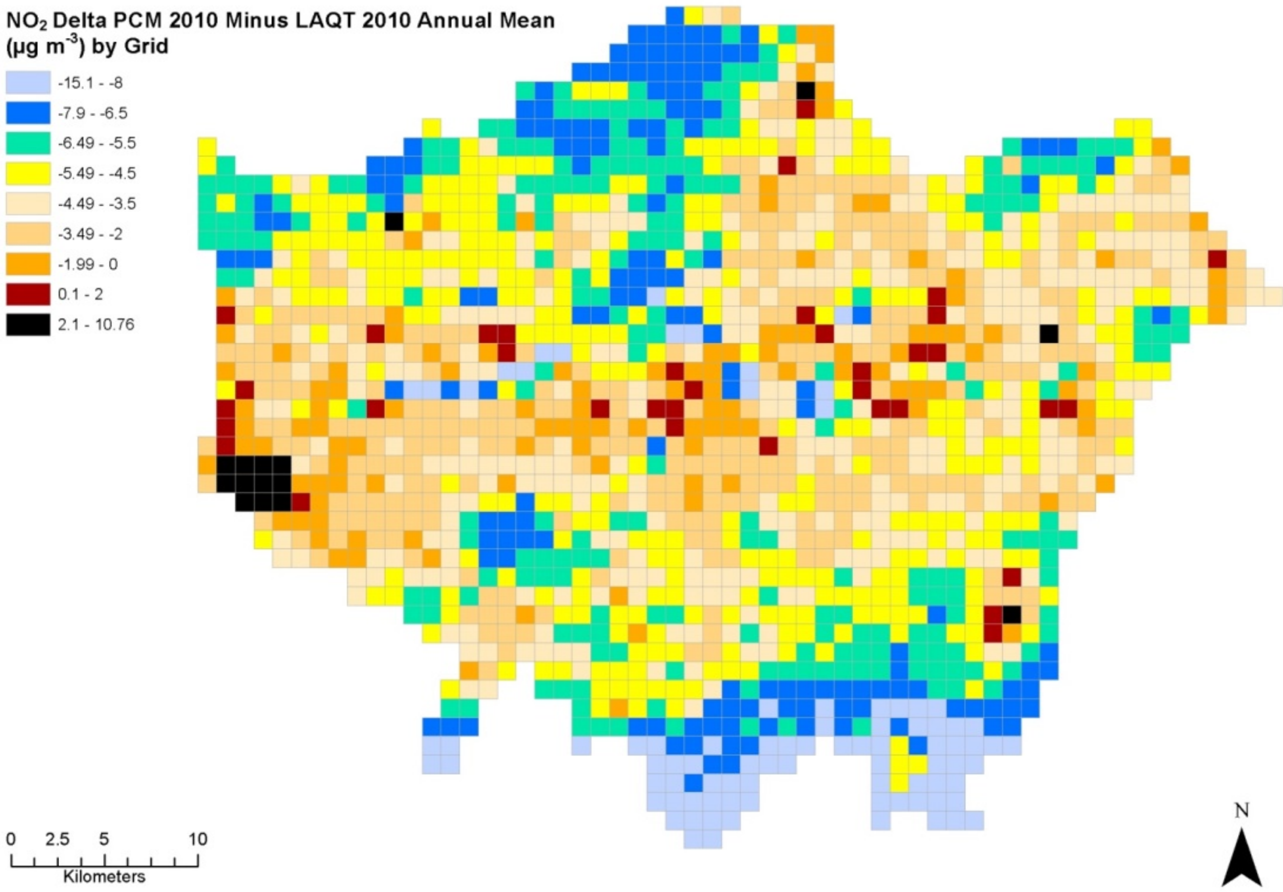
**Table 9 Differences in predicted concentrations of $NO_2$ µg/m³ between the PCM model 2010 at 1km x 1km and the LAQT model 2010 (20m x 20m averaged up to 1km x 1km)**

| | **LAQT_2010** | **PCM_2010** | **Delta $NO_2$ PCM minus LAQT** |
|---|---|---|---|
| Max | 66.56 | 62.59 | 10.76 |
| Min | 20.87 | 14.00 | -15.18 |
| Average | 33.38 | 28.98 | -4.40 |
| SD | 6.62 | 7.67 | 2.35 |
| Median | 32.06 | 28.07 | -4.47 |
| 25th %ile | 28.77 | 23.65 | -5.76 |
| 75th %ile | 36.78 | 33.196 | -3.20 |
| IQR | 8.02 | 9.54 | 2.56 |

To investigate the differences further, the differences between the $NO_2$ concentrations in each grid for the two models were calculated. Information on the distribution of these differences are shown in the 4$^{th}$ column of Table 9. This shows that on an individual grid square basis the PCM model concentrations are usually quite a bit lower than the estimate from the LAQT model (by about 4.4 µg/m$^3$ on average). There were a minority of grid squares where the PCM model predicted very much higher or lower concentrations (by 10.8 or 15.2 µg/m$^3$.respectively) but these were outliers with the 25$^{th}$ and 75$^{th}$ percentiles both indicating lower concentrations by 5.8 and 3.2 µg/m$^3$. We plotted the differences on a map to see whether the concentration differences were randomly distributed spatially (Figure.1). (The yellow squares are for a concentration range containing the mean difference, and the red and black squares are positive rather than negative differences). This was not the case for the more extreme differences, with the areas where the PCM model was substantially higher than the LAQT model being concentrated around Heathrow (probably due to a difference in emissions estimates) and the substantially lower areas being concentrated in North and South London (perhaps due to differences in regional backgrounds used between the two models). Otherwise, the medium differences were fairly evenly spread. Differences will also reflect the different emission inventories used.

There are always differences between different models and these uncertainties need to be mentioned alongside burden calculations using one particular model. The possibility that choosing a model with a broader scale may underestimate exposures to $NO_2$ remains as it is compatible with the comparison done here but it is too difficult to disentangle this influence from other differences between the models at different scales to be sure.

**Figure 1 Map of differences between 20 x 20m LAQT modelling averaged up to 1 x 1 km grid and PCM 1 x 1 km modelling of $NO_2$ in London**



### 3.3 Population weighting by 5-year age groups above 30 years, total population above 30 years or total population (Sensitivities 4 and 5)

Before moving on to consider further issues relating to population weighting using different scales, it is necessary to consider the issue of whether or not to disaggregate by gender and 5-year age group for population-weighting. There are two aspects to this:

- Attributable deaths are calculated separately by gender and 5-year age groups because these are then multiplied by the baseline expected remaining life-expectancy in each gender and 5-year age group to generate an approximate answer for the burden in terms of life-years lost. (This has to be done as life-expectancy varies by age.) Ideally, the population-weighted mean within each of these sub-calculations of attributable deaths should be population-weighted by the relevant gender and 5-year age group. (5-year age groups are what were used in the previous London work but the same point applies to other finely divided age-group intervals).
- Age distribution and mortality rates affect the numerical value of the burden result and also have spatial variability. How these align with the spatial scale of the modelling and population-weighting may therefore be a relevant issue for determining to what degree the spatial scale of the modelling used for health impact assessment actually matters.

In the main report, the PCM model was population-weighted by the total population across the UK. The sensitivity analyses so far, have therefore also used the total population of all ages. It is not a quick process to do this for sub-groups of the population, particularly as 1 x 1 km square grids are not a standard area for population statistics. Although this is theoretically preferable, it was unclear whether this made enough difference to be worthwhile. It was therefore decided to examine the issue within London using the LAQT model and population-weighting by output area (which is a standard area for population statistics). The results are shown in Table 10.

The attributable deaths are smaller by 3.6 to 4.2% when using population-weighted means by age group above 30 years compared with using the total population, with the majority of that being due to the separation by gender and age group (result smaller by 3 – 3.5%) rather than the change from the total to the 30+ population (30+ PWM calculation smaller by 0.7-0.8%. than the total PWM calculation).

The results for life years lost are an identical proportion smaller for 30+ vs total and lower by a similar but smaller proportion when using PWMs by gender and age group.

**Table 10 Burden calculations using different methods of population weighting (all LAQT modelled concentrations 20x 20m averaged up to OA, weighting at OA level, average population 2009/10/11, RR 1.017 per 10 µg/m³ $NO_2$) (counterfactuals of 0 and 5 µg/m³)**

| Sensitivity→ Result↓ | Sensitivity 3 | Sensitivity 4 | Sensitivity 5 |
|---|---|---|---|
| Population age for population-weighting | Total all ages, (8,069,499) | Total 30+ (4,656,316) | Separately by gender, 5 year age group for all ages over 30 |
| **Counterfactual 0 µg/m³** | | | |
| Population-weighted mean µg/m³ | 36.7 | 36.4 | From 34.97 (female 85+) to 38.36 (male 30-34) |
| Attributable deaths | 2,787 | 2,768 | 2686 |
| Life years lost | 41,404 | 41,123 | 40,224 |
| % change PWM by age group deaths vs total | | -0.68% | -3.61% |
| % change for PWM by age group deaths vs 30+ | | | -2.95% |
| % change for PWM by age group life years lost vs total | | -0.68% | -2.85% |
| % change for PWM by age group life years lost vs 30+ | | | -2.19% |
| **Counterfactual 5 µg/m³** | | | |
| Population-weighted mean µg/m³ | 31.7 | 31.4 | From 29.97 (female 85+) to 33.36 (male 30-34) |
| Attributable deaths | 2417 | 2398 | 2315 |
| Life years lost | 35,908 | 35,626 | 34,719 |
| % change for PWM by age group deaths vs total | | -0.79% | -4.20% |
| % change for PWM by age group deaths vs 30+ | | | -3.44% |
| % change for PWM by age group life years lost vs total | | -0.79% | -3.31% |
| % change for PWM by age group life years lost vs 30+ | | | -2.55% |

In summary, for London overall, the net results showed that, while using population-weighted means using the total population rather than the more correct separation by gender and 5 –year age group overestimates the results, this is not too large an overestimation.  Therefore, in further sensitivity analyses, we used either population-weighted means using the 30+ population or by the 30+ population split by gender and age group, as these were available from the previous London work.

The difference might have been expected to be more as the population-weighted means for the different gender age group pairs varied by as much as 3 µg/m$^3$. However, above 30 years, the population-weighted means declined with age (Figure.2), and mortality rates increase with age, ameliorating the difference.  The decline in population-weighted concentration with age is probably a result of the fact that there is a higher proportion of younger people in Inner London where pollution is higher, with people tending to move out to the suburbs as they get older, earn more and have families.  This pattern may also apply to other major cities to some extent but does not occur for the rest of England as a whole (Trust for London and New Policy Institute, 2015; ONS, 2014).  Thus, the sensitivities investigated here for London, should be investigated for the UK in the future, as it may be more important to population weight by age group in other locations.

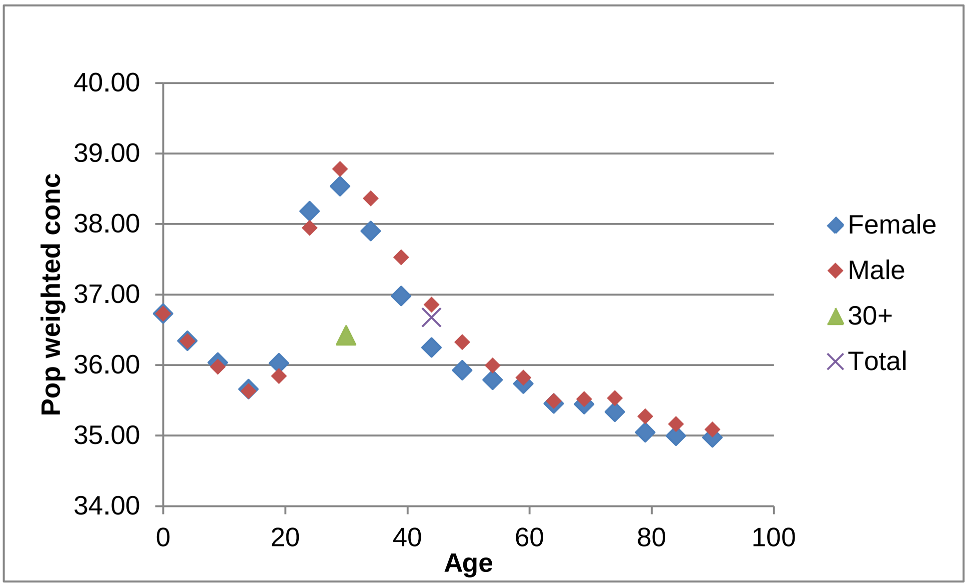



**Figure 2 Population-weighted concentrations by age in London.**

### 3.4 Effect of scale on population-weighted mean concentrations and implications for burden calculations (Sensitivity 6)

Section 3.2 compared the results of modelling methods that differed in their scale, as well as in other respects. The comparison also differed in terms of the scale of the population weighting, with the PCM model results being population-weighted at 1 x 1 km grid level, and the LAQT results being population-weighted at output area level. To understand the impact of this difference, an analysis was done to compare the population-weighted mean concentration for London derived via data at OA level with the population-weighted mean concentration for London derived from the same 20m x 20m modelling data but averaged up to 1x1 km grid squares for the first step of population-weighting.

The overall results are given in Table 11. First, it should be noted that the sum of the population is a bit lower for the 1km grid squares, although the area is a bit higher. This probably reflects the grid squares that are partly inside and partly outside the GLA area, and the fact that output area populations were not available for part of these grid squares. Second, the average of all 20 x 20m concentrations (33.43 or 28.43 depending on cut-off) is lower than the average of the output area concentrations derived from the 20 x 20m values (36.95 or 31.95)[8]. This is probably because, as OA size is determined by population, there are more of them in inner London where concentrations are higher. Finally, the population-weighted average concentrations and consequent burden results turn out to be quite similar between the methods.

It might have been thought that population-weighting at output area level would give larger results as it was more likely to pick up smaller areas where both the population and the concentrations are high. There are probably two reasons why this was not the case.

Firstly, some of the fine scale exposure contrast has already been lost as a result of the need to average up to output area level to get age group resolved population data. Secondly, while output areas do indeed pick up areas of higher concentration and population, they also pick up areas of lower concentrations and populations. We investigated this for population-concentration products using the overall 30+ population. The mapped concentration-population products can be seen in Figure 3 for OAs, where it can be seen that there are low population-concentration product areas in inner London and high population-concentration product areas in outer London. Figure.4 for the 1 x 1 km grids is less varied in particular areas. Note that the appearance of maps such as this is dependent on where the boundaries between the colours are set. To ensure comparability between the maps, we set the boundaries between the colours systematically by dividing the distribution by percentiles into six. The boundary between yellow and orange is the median. The distribution for the 1x1 km grids has a long upper tail so the final colour class will cover a wide range. This should be borne in mind when

[8] The average of the output area concentrations across London was a straight average. If it had been weighted by area it would be likely to give a closer answer to the average of all 20 x 20m concentrations. The point here though is to be aware of the fact that there are greater numbers of OAs where the population is higher, as this is relevant to later parts of the calculation

interpreting the maps. It should also be noted that output areas are larger in size in outer London where population density is lower, such that the 1km grids are actually a finer scale than the OAs. The large dark area in the west of the OA map is the area around Heathrow airport. This appears differently in the 1km grid map, presumably because of the low population in the area of the actual airport, which is mixed in with the surrounding residential area in the OA map.

The distribution of the population-concentration products was examined (not shown). This indicated a symmetrical bell curve for the OAs but a skewed distribution for the 1 x 1 km grids, with a high frequency of low values (probably corresponding with the ring around outer London), but also a longer tail at the high end. Despite these different distributions, it may be that once everything is averaged back up to London overall, the same underlying concentration field (the 20x 20m concentrations) and population field (the 1 x 1 km grid square populations were derived from intersections with OA populations), ultimately gives the same answer.

This similarity in population-weighted mean concentrations would not be the case if there were 20 x 20m concentrations below a specified counterfactual. While the effect of a variety of counterfactuals was investigated (not shown), the population-weighted means were still similar, as no 20 x 20m concentrations in London were below 20 $\mu g/m^3$, the highest counterfactual used. This is not the case in other parts of the UK (see main report), although even then, the proportion of the population below the recommended counterfactual of 5 $\mu g/m^3$ is small).

It is possible that doing calculations separately by borough and adding up the results across London may be more sensitive to differences in the scale of population weighting. This is discussed in section 3.5

**Table 11: Results for sensitivity analyses (S5/S6) in London, comparison of OA or 1 x 1 km scale for population-weighting, LAQT modelling, London overall (all RR 1.017 per 10 µg/m³ $NO_2$ with counterfactuals of 0 and 5 µg/m³) (see also Table 6)**

| Sensitivity→<br>Result↓ | Sensitivity 5 | Sensitivity 6 |
|---|---|---|
| Scale of concentrations before population-weighting | 20 x 20m averaged to OA | 20 x 20m, averaged to 1 x 1 km |
| Scale of population-weighting | OA | 1 x 1 km |
| Population age and year for population-weighting | 2009/10/11, by gender and 5 year age group over 30 (4,656,316) | 2009/10/11, by gender and 5 year age group over 30 (4,645,275) |
| Geographical area | London overall (area 1,595 km²) | London overall (area 1,607 km²) |
| | **Counterfactual 0 µg/m³** | |
| Average concentration (unweighted) µg/m³ | 33.43 (20 x 20m), 36.95 (via OAs) | 33.38 |
| Population-weighted mean µg/m³ | 34..97 (female 85+) to 38.36 (male 30-34) | 34.95 (female 85+) to 38.2 (male 30-34) |
| Attributable deaths | 2,686 | 2,691 |
| Life years lost | 40,244 | 40,308 |
| % difference 1 km grid vs OA (attributable deaths) | | 0.19% |
| % difference 1 km grid vs OA (life years lost) | | 0.21% |
| | **Counterfactual 5 µg/m³** | |
| Average concentration (unweighted) µg/m³ | 28.43 (20 x 20m), 31.95 (via OA) | 28.38 |
| Population-weighted mean µg/m³ | 29.97 (female 85+) to 33.36 (male 30-34) | 29.95 (female 85+) to 33.2 (male 30-34) |
| Attributable deaths | 2315 | 2,320 |
| Life years lost | 34,719 | 34,803 |
| % difference 1 km grid vs OA (attributable deaths) | | 0.20% |
| % difference 1 km grid vs OA (life years lost) | | 0.24% |

**Figure 3 Product of (2010 30+ population times LAQT $NO_2$ concentration) by OA**

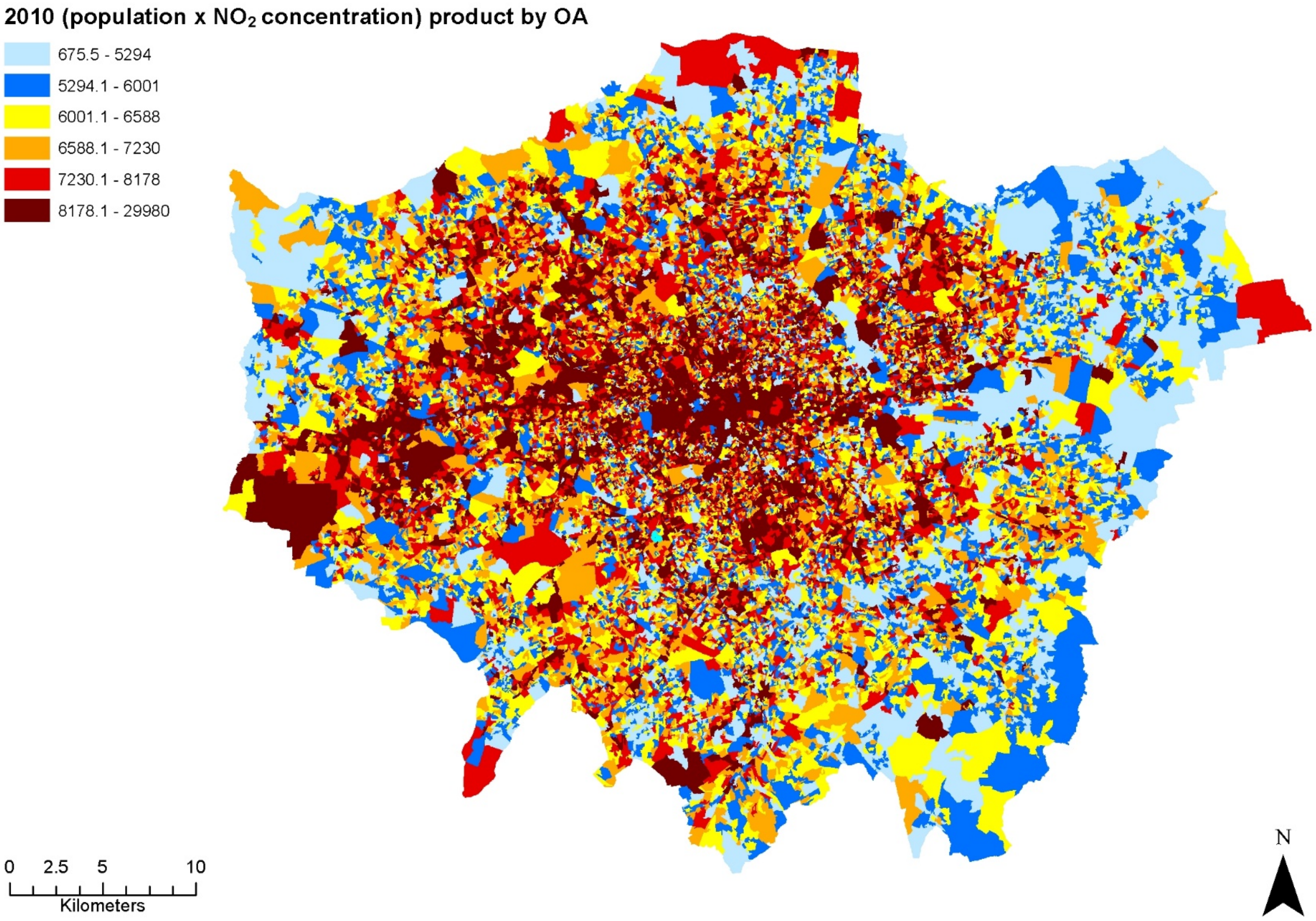
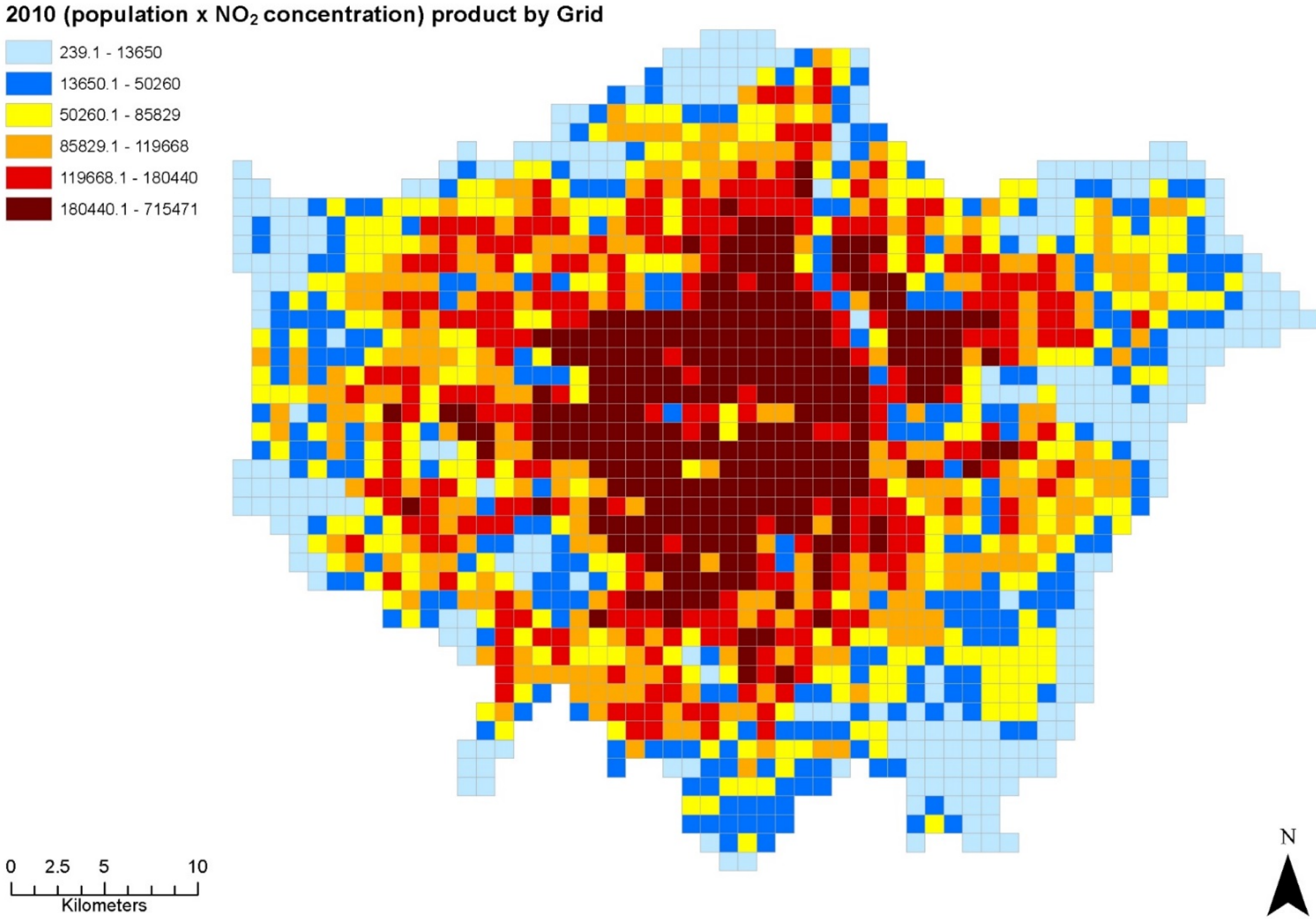


**Figure 4 Product of (2010 30+ population times L AQT NO2 concentration (person µg/m³) 1x1 km grid**



### 3.5 Producing results separately by borough, including using borough specific mortality rates, compared with London wide calculations

As previous sections have shown that the distribution of the concentration-population product used to derive population weighted means is different for output areas and 1 x 1 km grids, further work was done to examine whether the scale of population-weighting was more important when the burden calculations were disaggregated by borough, before being summed for London. This also provided the opportunity to examine two other spatial issues – disaggregation of concentrations and mortality rates by borough.

The results are shown in Table 12. Overall, all differences are very small. Within that, compared with the comparison of 1 x 1 km grid with OA for London overall, the results by 1 x 1 km grid give slightly lower results than by OA when disaggregated by borough concentrations alone and slightly higher results disaggregated by both borough concentrations and mortality rates. The latter difference between grid and OA was a little greater than the difference for London overall.

Within results by either OA or 1 x 1 km grids, separating concentrations by borough reduced the results slightly for attributable deaths, to a greater extent for grids. For OAs, separating concentration by borough reduced the results for attributable deaths but increased it slightly for life years, for 1 x 1 km grids results were smaller compared with London overall for both attributable deaths and life years. For population-weighting by OA or 1 x 1 km grid, separating both concentrations and mortality rates by borough increased the results compared with London overall, to a greater extent for 1 x 1 km grids.

Comparing results summed by borough with or without borough mortality rates, showed that inclusion of borough mortality rates usually increased the results slightly, to a somewhat greater extent for 1 x 1 km grids.

### 3.6 Results using different coefficients

All the results so far have been done with the hazard ratio of 1.17. The hazard ratio of 1.025 per 10 µg/m$^3$ $NO_2$ recommended in the interim statement had a range around it of 1.01 to 1.04. Applying a 33% reduction to these figures does not fully reflect the uncertainty as it does not take the uncertainty around the 33% reduction into account. So the options we chose are better considered as some example larger and smaller values to demonstrate the concept of the influence of the size of the coefficients on the results. The examples we chose were 1.006 and 1.027. This range is lower and higher than the subsequently derived summary estimate for $NO_2$ of 1.023 per 10 µg/m$^3$ and the various adjusted coefficient central estimates from 4 studies examined in detail (1.011 to 1.020 (see Working Paper 3 on burden).

It is also lower and higher than some of the possible confidence intervals discussed in that paper but probably[9] not as low or high as some of the others.

These examples have been used in the LAQT model results for many of the sensitivities described above. They will not be described in detail here, as the conceptual results are generally analogous to those for the central coefficient. Results are given in Table 13 for the LAQT sensitivity methods most similar and most different from that in the main report i.e. population-weighting by total population by OA, London overall (S3) and population-weighting by gender and 5 year age group by OA, with separate borough concentrations and mortality rates (S9). As expected, the range around the central coefficient had a substantial influence on the results, ranging from about 64% lower to around 55 % higher than the central estimate. In percentage terms, the ranges were similar for either the scenario most similar or most different to that used in the main report.

[9] See Working Paper 3 on burden for discussion of the technical difficulties of defining exact confidence intervals, particularly for some studies.

**Table 12 Burden calculations for OA or 1x1 km grid for London overall compared with summing calculations by borough concentrations +/- mortality rates by borough (all LAQT modelling, RR 1.017 per 10 µg/m³ $NO_2$ with counterfactuals of 0 and 5 µg/m³)**

| **Sensitivity→**<br>**Result↓** | **Sensitivity 7** | **Sensitivity 8** | **Sensitivity 9** | **Sensitivity 10** |
|---|---|---|---|---|
| Model and Scale (all LAQT) | 20m x 20m, OA | 20m x 20m, then 1 km² | 20m x 20m, OA | 20m x 20m, then 1 km² |
| Scale of population-weighting/geographical area | OA, London boroughs | 1 km² grid, London boroughs | OA, London boroughs | 1 km² grid, London boroughs |
| Mortality rate 30+ per 100,000 | By gender and age group, London | By gender and age group, London | By gender, age group and borough | By gender, age group and borough |
| | | **Counterfactual 0 µg/m³** | | |
| Attributable deaths | 2684 | 2680 | 2691 | 2697 |
| Life years lost | 40,346 | 40,298 | 40,351 | 40,453 |
| % difference deaths vs London overall (S5/6), grid vs equivalent OA (S7, S9), borough mortality rates vs one mortality rate (S7,S8) | -0.07% vs S5 | -0.40% vs S6<br>-0.16% vs S7 | 0.19% vs S5<br>0.26% vs S7 | 0.25% vs S6<br>0.24% vs S9<br>0.66% vs S8 |
| % difference life years vs London overall (S5/6), grid vs equivalent OA (S7, S9), borough mortality rates vs one mortality rate (S7,S8) | 0.3% vs S5 | -0.02% vs S6<br>-0.12% (vs S7) | 0.32% vs S5<br>0.01% vs S7 | 0.36% vs S6<br>0.25% vs S9<br>0.38% vs S8 |
| | | **Counterfactual 5 µg/m³** | | |
| Attributable deaths | 2313 | 2310 | 2320 | 2326 |
| Life years lost | 34,826 | 34,797 | 34,863 | 34,967 |
| % difference deaths vs London overall (S5/6), grid vs equivalent OA (S7, S9), borough mortality rates vs one mortality rate (S7,S8) | -0.09% vs S5 | -0.42% vs S6<br>-0.13% vs S7 | 0.22% vs S5<br>0.31% vs S7 | 0.3% vs S6<br>0.28% vs S9<br>0.71% vs S8 |
| % difference life years vs London overall (S5/6), grid vs equivalent OA (S7, S9), borough mortality rates vs one mortality rate (S7,S8) | 0.31% vs S5 | -0.02% vs S6<br>-0.09% vs S7 | 0.42% vs S5<br>0.11% vs S7 | 0.47% vs S6<br>0.3% vs S9<br>0.49% vs S8 |

**Table 13 Burden calculations with different coefficients 1.017 (1.006 – 1.027) per 10 µg/m³ $NO_2$ for population-weighting by total population and OA, London overall (S3) and for population-weighting by gender and age group by OA, separately by borough concentration and mortality rate (S9) (all LAQT modelling, counterfactuals of 0 and 5 µg/m³)**

| **Sensitivity→**<br>**Result↓** | **Sensitivity 3** | **Sensitivity 9** |
|---|---|---|
| Model Scale (all LAQT) | 20m x 20m, OA | 20m x 20m, OA |
| Scale of and age group for population-weighting/geographical area | OA, total population, London overall | OA, London boroughs |
| Mortality rate 30+ per 100,000 | By gender and age group, London | By gender, age group and borough |
| **Counterfactual 0 µg/m³** | | |
| Attributable deaths | 2,787<br><br>(1009 – 4327) | 2,691<br><br>(974 – 4179) |
| Life years lost | 41,404<br><br>(14,987 – 64,288) | 40,351<br><br>(14,606 - 62,652) |
| % difference deaths vs central estimate | -63.8 to +55.3 | -63.8 to +55.3 |
| % difference life years vs central estimate | -63.8 to +55.3 | -63.8 to +55.3 |
| **Counterfactual 5 µg/m³** | | |
| Attributable deaths | 2417<br><br>(872 – 3761) | 2302<br><br>(831 – 3583) |
| Life years lost | 35,908<br><br>(12,963 – 55,889) | 34,718<br><br>(12,535 – 54,031) |
| % difference deaths vs central estimate | -63.9 to +55.6 | -63.9 to +55.7 |
| % difference life years vs central estimate | -63.9 to +55.6 | -63.9 to +55.6 |

## 4 Overall discussion

In conclusion, the assumptions having most influence on the results in London are as follows:

- Choice of model year, with 2010 being about 10-12.5% higher than 2013 for the model analysed (PCM). Some of this may represent a real trend in burden over time because there are considerable year to year variations as a result of weather conditions and changes in emissions;

- Choice of model for $NO_2$ concentrations, with the LAQT model giving results about 12-14% higher than the PCM model. There are always differences between different models and these uncertainties need to be mentioned alongside burden calculations using one particular model. The possibility that choosing a model with a broader scale may underestimate exposures to $NO_2$ remains, as it is compatible with the comparison done here, but it is too difficult to disentangle this influence from other differences between the models at different scales to be sure.

- Choice of coefficient – the range around the selected coefficient lead to results from around 64% lower to 55% higher than the central results of the sensitivity analyses considered (both similar and different from the approach in the main report). This range in results was similar between the scenarios. (This might not be the case in locations where, unlike in London, there were concentrations near the cut-off.)

The results for the alternatives of a zero and 5 $\mu g/m^3$ counterfactual also vary considerably. Burden results were not calculated for other counterfactuals in London but the population-weighted means decreases by a proportionately greater degree as the counterfactual increases from 5 to 15 µg/m3 (no areas of London were below 15 $\mu g/m^3$).

### 4.1 The conclusions on geographical scale

The results comparing the PCM and LAQT model were compatible with an effect of modelling scale but this was hard to confirm given many other differences between the models.

Working up from 20 x 20m modelling, population-weighting by output area rather than 1 x 1 km grid did not actually make much difference, despite different underlying distributions of population and concentration by OA and 1 x 1 km grid. Output areas pick up both areas of low concentration and population in generally high concentration areas and areas of high concentration and population in generally low concentration areas. When all areas are above the relevant cut off, this probably averages back to a similar result.

Using more disaggregated inputs for both borough concentrations and mortality rates very slightly increased the difference between population-weighting by output area and 1 x 1 km grid but they were still very similar.

Comparing disaggregating by borough concentration with London overall, the results for attributable deaths were slightly lower disaggregated by borough. This applied both to population-weighting by OA or by 1 x 1 km grid. For life years, the result when population-weighting by 1 x 1 km grid were also lower but this was not the case for population-weighting by OA.

Inclusion of both borough concentrations and mortality rates increased the size of the burden slightly compared with the calculation for London overall for both .population-weighting by OA or 1 x 1 km grid.

Use of borough specific mortality rates increased the results very slightly compared with disaggregating borough concentrations alone.

Overall, while the scale of the modelling method may have some effect, other aspects of the geographic scale of inputs and calculations did not have much influence for the particular examples tested.

It is possible that some of these sensitivities would behave differently in locations different from London. For example, there were no areas approaching the cut-off of 5 µg/m$^3$. At the time this work was started, 20x 20m modelling was only available in London but it is now possible to embed modelling at this scale into urban areas in national modelling[10], allowing extension of the type of analyses and comparisons investigated here to the GB scale.

Population-weighting by gender and age group, while theoretically preferable, did not have a marked influence on the results. However, there was a marked decline in population-weighted means by age that was cancelled out by the increase in mortality rates with age. This suggests that this aspect needs further investigation in areas where the age distribution of the population relative to the distribution of concentrations may be different from that in a major city such as London.

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[10] http://www.londonair.org.uk/Research/custom/modelling-no2-pollution-in-the-uk.html

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