Liverpool City Region Combined Authority Health and Economic Impact Assessment study

**For:** British Lung Foundation and UK:100

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**Table of Contents**

[1.0 Executive Summary and Key results 3](#_Toc24456738)

[2.0 Introduction 6](#_Toc24456739)

[3.0 Method 6](#_Toc24456740)

[3.1 Air Quality data 6](#_Toc24456741)

[3.2 Health assessment 6](#_Toc24456742)

[3.3 Economic assessment 7](#_Toc24456743)

[4.0 Air Quality modelling 9](#_Toc24456744)

[5.0 Health Estimates of the mortality impact of air pollution and its economic valuation 12](#_Toc24456745)

[5.1 Mortality impact 12](#_Toc24456746)

[5.2 Life-expectancy from birth in 2011 17](#_Toc24456747)

[6.0 Health Estimates of the mortality burden of air pollution 19](#_Toc24456748)

[6.1 Burden background 19](#_Toc24456749)

[6.2 Combined estimate for PM2.5 and NO2 using multi pollutant model results 20](#_Toc24456750)

[6.3 Single pollutant model estimates 21](#_Toc24456751)

[6.4 Summary of burden results 22](#_Toc24456752)

[7.0 Discussion 23](#_Toc24456753)

[7.1 Impact of Air Pollution on Inequalities within LCR 23](#_Toc24456754)

[7.2 Comparison with results for Greater Manchester (GM), Birmingham City and London 26](#_Toc24456755)

[7.3 Ozone 29](#_Toc24456756)

[8.0 Appendix 30](#_Toc24456757)

[8.1 Additional tables- method 30](#_Toc24456758)

[8.2 Additional tables - impact 32](#_Toc24456759)

[8.3 Additional tables – burden 41](#_Toc24456760)

[8.4 Additional Health and economic assessment methods 45](#_Toc24456761)

[9.0 References 49](#_Toc24456762)

# Executive Summary and Key results

The British Lung Foundation and UK100 commissioned the Environment Research Group (ERG) at Kings’ College London (King’s) to produce a health and economic impact assessment associated with current[[1]](#footnote-2) and future pollution concentrations in the Liverpool City Region (LCR). ERG has previously carried out similar health impact calculations for London, Greater Manchester and Birmingham City, but to our knowledge this is the first time that the new health impact recommendations (COMEAP, 2018a)[[2]](#footnote-3) have been applied in practice to a large city using the NAEI 2017 PM2.5 and NO2 concentrations projected to 2030[[3]](#footnote-4).

Mortality impact (long –term exposure)

The population in Liverpool City Region would gain around 350,000 to 370,000 life years over a lifetime to 2134[[4]](#footnote-5) if air pollution concentrations improved as projected from 2011 to 2030[[5]](#footnote-6), compared with remaining at 2011 concentrations. The average life expectancy of a child born in Liverpool City Region in 2011 would improve by around 2 to 2.5 months for the same comparison.

Taking into account the UK Government’s projected future changes in air pollution concentrations from 2011 to 2030, the population would still be losing between 0.3 to 0.8 million life years in the LCR (a life year is one person living for one year). Put another way, **children born in 2011 are still estimated to die 1.5-5 months early[[6]](#footnote-7) on average, if exposed over their lifetimes to the projected future air pollution concentrations in Liverpool City Region**. Males are more affected than females, and this is due to the fact that men have higher death rates and die earlier than women.

The report provides figures for both PM2.5 and NO2 separately but then uses one or the other as the best indicator pollutant rather than adding results together to avoid large overestimation of the mortality impact of air pollution (details in the report below). The ‘best indicator’ approach may result in a small underestimate.

Economic costs

The monetised benefits over a lifetime[[7]](#footnote-8) of improvements to future anthropogenic PM2.5 and NO2 concentrations, compared with 2011 concentrations remaining unchanged, has been estimated to be between £200 - £210 million on average/year (at 2014 prices).

Despite the projected future improvements in air pollution concentrations from 2011 to 2030, **the economic health impact costs in the Liverpool City Region over a lifetime are still between £170 - £480 million on average per year.**

These are what is called ‘annualised’ figures - a term for an average per year when the result is not the same every year. Economists assign monetary values to the health benefits of reducing air pollution in cost-benefit analysis in order to compare with the costs of implementing a package of policies. The monetary value for each individual health outcome is then added up across time, people and the total health effects. They are not actual costs but a measure of the amount of money society believes it would be reasonable to spend on policies to reduce air pollution[[8]](#footnote-9) (to avoid the adverse health effects of the remaining pollution) or was reasonable to have spent on policies that have already reduced air pollution.

Mortality burden (long –term exposure)

Mortality burden calculations are a simplified calculation at one point in time. They are not suitable for analysing several years in succession because they do not have a mechanism for allowing the number of deaths the year before to influence the age and population size the following year (lifetables do this, see impact calculations above). Nonetheless, they provide a useful feel for the size of the air pollution problem.

In 2011 in the Liverpool City Region the equivalent of[[9]](#footnote-10) between 800 to 1,040 deaths are estimated to be attributable to anthropogenic PM2.5 and NO2. These deaths occur mostly at older ages, as is typical for deaths in the general population.

The results varied by local authority with the highest in Liverpool and the lowest in Halton. The ranking by local authority did not fully follow the ranking in pollutant concentrations. This is because the results are also influenced by the size of the population and variations in death rates by local authority, which in turn are driven in part by the proportion of elderly in the population and the level of deprivation.

Impact of Air Pollution on Inequalities

This study shows that adverse health impacts remain and that further pollution improvements beyond those already made are still needed, especially to tackle environmental inequality (in which socioeconomically disadvantaged populations are still among the most exposed). The most vulnerable individuals within the Liverpool City Region are more likely to be exposed to higher levels of air pollution and would benefit the most from further reduction of air pollution. The main clusters of areas associated with both the most deprived and highest levels of air pollution are located in a ring around Liverpool city centre, in central and northern Knowsley and within the central area of St Helens.

Comparison with results for Greater Manchester (GM) and Birmingham City

The results for life years lost (after pollution improvements) and attributable deaths (from 2011) in the Liverpool City Region were smaller than the results in Greater Manchester. Although LCR death rate (1.49%) is higher than in GM (1.36%), these results can be explained primarily by the population in LCR (around 1.5 million) being much smaller than Greater Manchester (2.7 million) and furthermore by LCR having somewhat lower PM2.5 and NO2 pollution concentrations compared with GM[[10]](#footnote-11).

In considering the lower concentrations in some cities rather than others, it should be noted that the epidemiological evidence shows that health impacts are still seen at concentrations below the limit values and WHO guidelines.

The results for life years lost (after pollution improvements) and attributable deaths (from 2011) in the Liverpool City Region were similar to the results for Birmingham City. The population (around 1.5 million in LCR vs 1 million in Birmingham) and death rate (1.49% in LCR vs 1.33% in Birmingham) were higher in the Liverpool City Region but the lower PM2.5 and NO2 pollution concentrations in LCR versus Birmingham City counteract the influence of these factors.

The loss of life expectancy (which is independent of population) is higher in Greater Manchester and even greater in Birmingham City. Gains in life years are smaller in the Liverpool City Region and Birmingham City than in Greater Manchester, again mainly due to differences in population size and the ranking across the cities in the size of the reduction in pollution concentrations over time.

Limitations

The main report presents a wider range of uncertainty around the results for the mortality burden, mortality impacts and economic costs than the figures shown here.

The study was focused on air pollution changes within the Liverpool City Region. Reductions in emissions will also have benefits for air pollution concentrations in the wider region (Northern England and beyond). For example, reductions in NOx emissions will reduce nitrate concentrations and thus PM2.5 concentrations in the wider region. The health benefits of this are not reflected here, although they are likely to be smaller than those in the LCR itself.

There will be further impacts from ozone concentrations out to 2030 and beyond. The long-term ozone exposure (representative of summer smog ozone concentrations metric) is projected to decrease over time compared with 2011 but less than other pollutants such as NO2 and PM2.5. This impact of ozone needs to be investigated further, while it is currently regarded as having smaller and more uncertain effects on life-expectancy than PM2.5, for example, there is the possibility that effects are being masked in the original studies due to negative correlations with other pollutants (COMEAP, 2015b; WHO, 2013). Ozone also has other health effects (see next paragraph).

This study addressed the effect of air pollution on deaths and loss of life-expectancy. This included all causes of death grouped together so covers, for example, respiratory, lung cancer and cardiovascular deaths for which there is good evidence for an effect of air pollution. It does not, however, cover the effect of air pollution on health where this does not result in death. So well established effects (such as respiratory and cardiovascular hospital admissions, effects on asthma, low birth weight etc) and other outcomes more recently potentially linked with air pollution (such as dementia) are not included. Their inclusion would increase the benefit of policies to further reduce air pollution.

# Introduction

The British Lung Foundation and UK100 commissioned the Environment Research Group (ERG) at King’s College London (King’s) to help produce a health impact and economic assessment associated with air pollution levels of Liverpool City Region (LCR) combined authority. In order to do that, ERG first downloaded the air pollution data of the six combined local authority districts of Halton, Knowsley, Liverpool, St. Helens, Sefton and Wirral forming the Liverpool City Region, which then, combined with relationships between concentrations and health outcomes, were used to calculate the impacts on health from the air pollution emitted in each local authority.

# Method

## Air Quality data

From 1kmx1km grid data to ward concentration

Maps of particulate matter with diameter <2.5 m (PM2.5) and nitrogen dioxide (NO2) annual average concentration were produced for each of the six combined local authority forming the LCR. To do this, ERG downloaded PM2.5 and NO2 air pollution data for the regions of 'Northern England', 'Wales' and 'Midlands' from the DEFRA Local Air Quality Management webpages (<https://uk-air.defra.gov.uk/data/laqm-background-maps>). The 2011 data were downloaded from the 2011 model predictions, and the 2017 to 2030 data were downloaded from the newly released 2017 model predictions. Using these data of regular 1km by 1km pollutant points we then created a raster layer (for every year and pollutant) using the R statistical analysis package. Mean spatially-weighted concentrations for each Ward were then calculated, using the Ward boundaries from the Governments Open Data portal (<http://geoportal.statistics.gov.uk/datasets/wards-december-2016-generalised-clipped-boundaries-in-the-uk>).

From ward to population-weighted local authority concentration

Population-weighting average concentration (PWAC): Population-weighting was done at ward level. The ward concentrations were multiplied by the population aged 30 plus for each gender and the resulting population-concentration product summed across all wards in each local authority and then divided by the local authority population. The local authority population-weighted means were then used directly in the health impact calculations across all six local authorities (This process allows one health calculation per local authority rather than calculations in each separate ward). A map of Liverpool City Region combined authority of Halton, Knowsley, Liverpool, St. Helens, Sefton and Wirral can be found in Figure 1.

## Health assessment

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

The concentration-response functions used and the spatial scales of the input data is given in Table 13, Table 14 and Table 15 in the Appendix. The concentration-response functions are based on the latest advice from the Committee on the Medical Effects of Air Pollutants in 2018 (COMEAP, 2018a). Previously, burden calculations were based only on concentrations of PM2.5 (COMEAP, 2010). The new COMEAP report considers whether there is an additional burden or impact from nitrogen dioxide or other pollutants with which it is closely correlated.

Results are given with and without a cut-off[[11]](#footnote-12) of 7 µg m-3 for PM2.5 and 5 µg m-3 for NO2.

This study uses this epidemiological evidence to estimate the health impacts of the changes in air pollutant concentrations discussed in the air quality modelling section below.

## Economic assessment

Economists assign monetary values to the health benefits in order to compare the benefits with the real costs of implementing a package of policies. The largest proportion of the monetary value comes from a survey asking 170 members of the public how much they would be willing to pay to reduce their risk of experiencing a loss of one month of life (in good health) due to air pollution (Chilton et al, 2004). Added up across time, people and the total health effects, this is then used to represent the amount society thinks should be spent to reduce these risks. NHS costs and loss of productivity are not included.

In undertaking a valuation in monetary terms of the mortality impacts described in the previous section, we have used the methods set out in an earlier report from ERG on the health impacts of air pollution in London (Walton et al., 2015) and in an ERG project funded by NIHR and reported in their journal library (Williams et al., 2018b). This built on previous work by the study team for Defra and the Inter-departmental Group on Costs and Benefits (IGCB) within the UK government. The methods are therefore consistent with those used in government in the UK.

Life years lost were valued using values recommended in Defra guidance[[12]](#footnote-13), updated to 2014 prices. Consistent with this guidance, values for future life years lost were increased at 2% per annum, then discounted using the declining discount rate scheme in the HMT Green Book.[[13]](#footnote-14) The economic impact was then annualised back to 2014, i.e. divided by the total number of years but front-loaded to take into account that benefits accrued sooner are valued more than those accrued later.



**Liverpool City Region**

Figure 1 Map of Liverpool City Region combined authority formed of Halton, Knowsley, Liverpool, St. Helens, Sefton and Wirral[[14]](#footnote-15)

# Air Quality modelling

Halton[[15]](#footnote-16), Knowsley[[16]](#footnote-17), Liverpool[[17]](#footnote-18), St. Helens[[18]](#footnote-19), Sefton[[19]](#footnote-20) and Wirral[[20]](#footnote-21) air quality annual status and air quality plan reports show that some parts of the Liverpool City Region have been in breach of both the national air quality objective for NO2 and the World Health Organization (WHO) guideline for PM2.5. Epidemiological evidence shows that health impacts are still seen at concentration below the limit values and WHO guidelines. Tackling pollutant emission sources is therefore essential to improve air quality to meet both the UK limit values and the WHO guidelines, and ultimately to achieve the lowest possible levels of pollution. Liverpool City Region has created an environment where the combined six local authorities can seek to work collaboratively to mitigate the impact of pollution sources outside of each individual local authority’s direct influence.

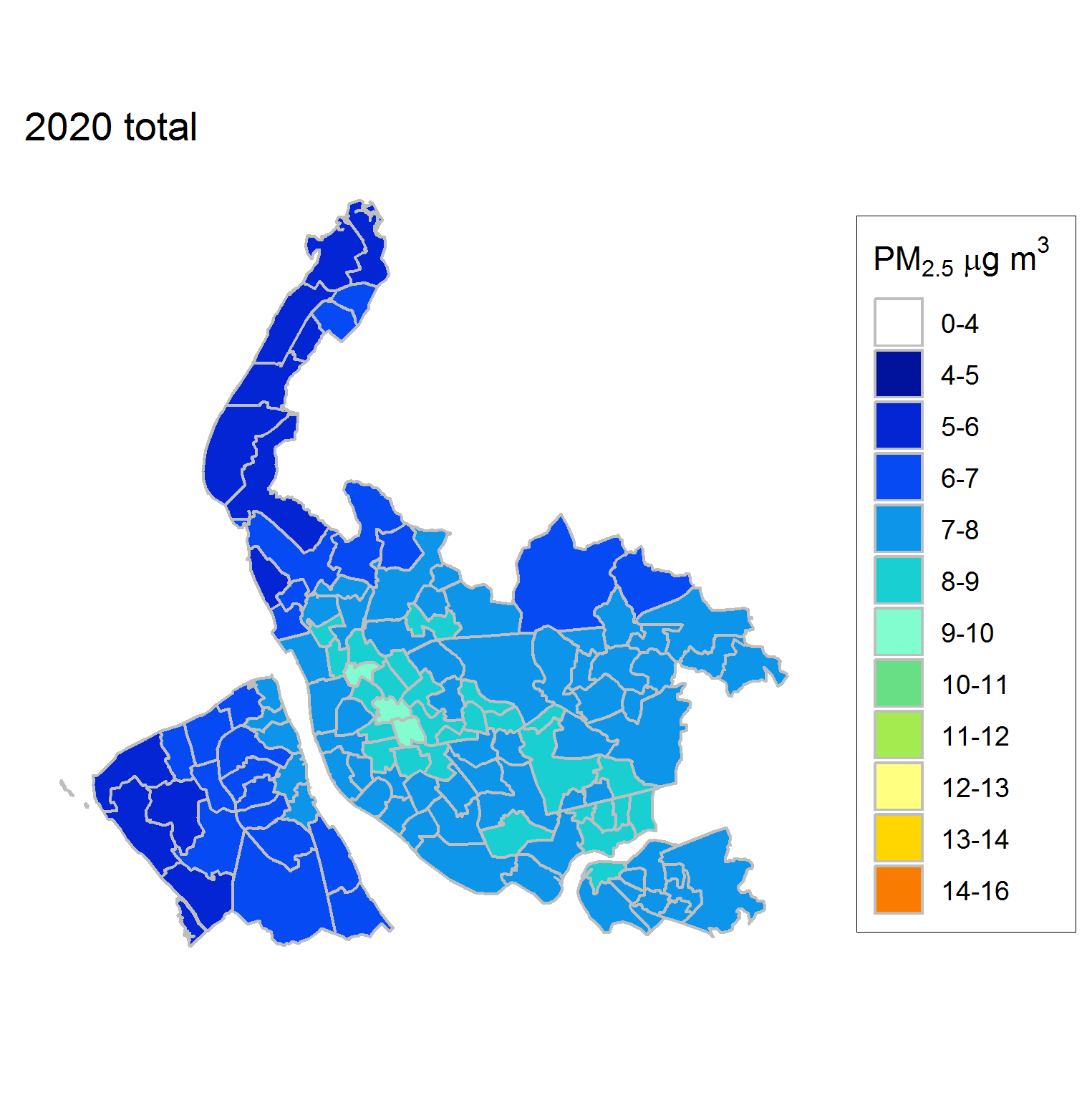
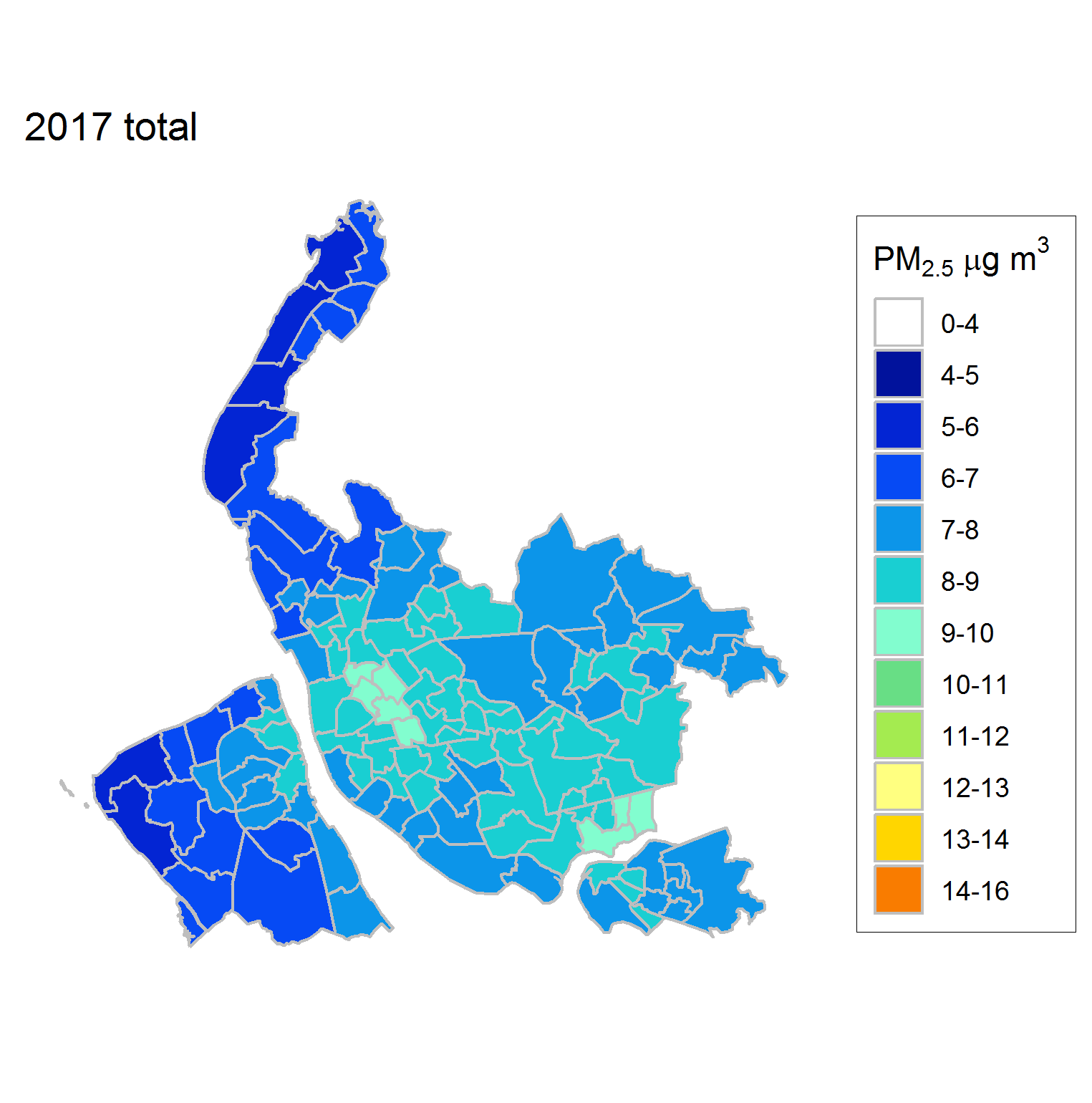
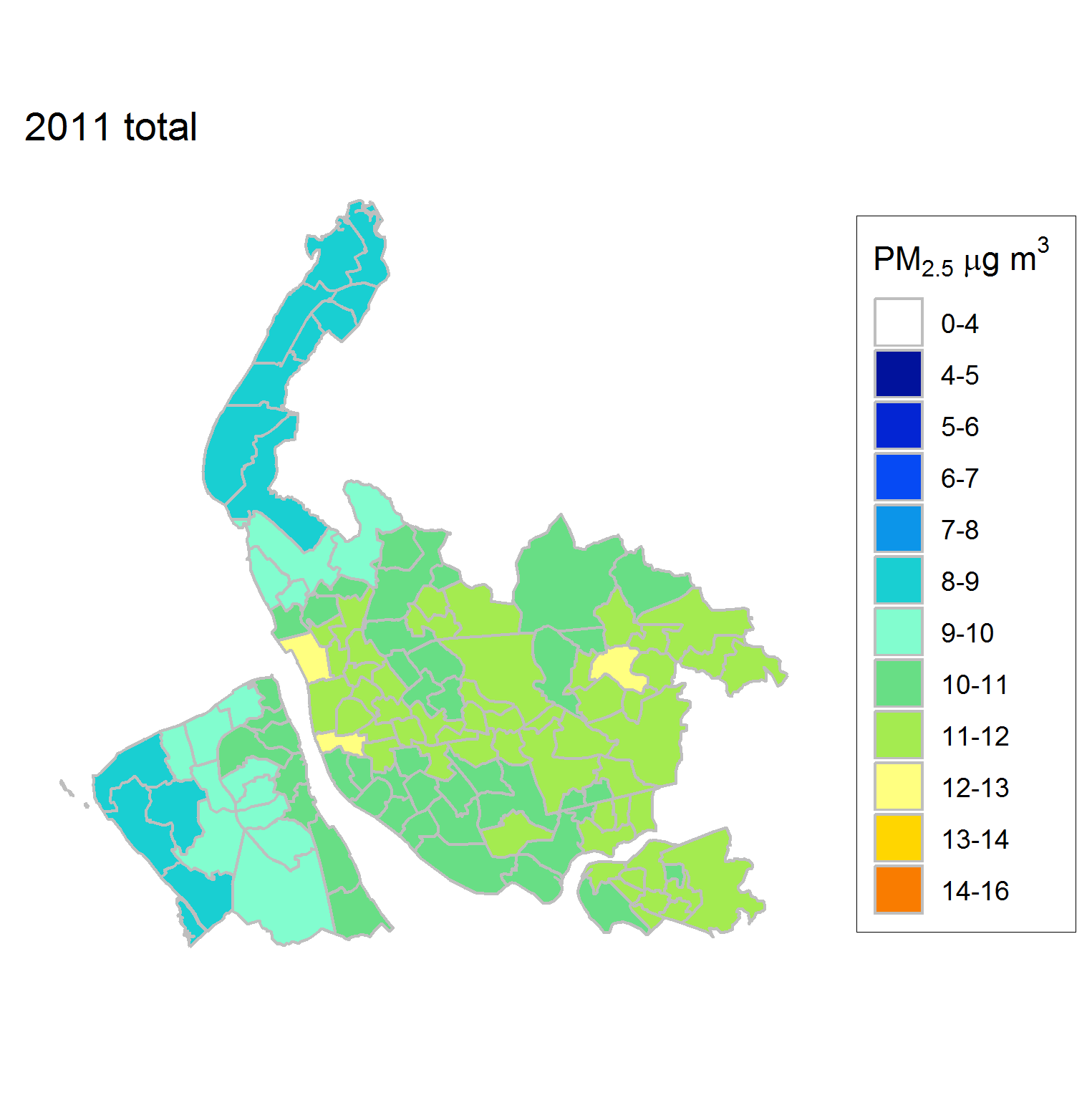
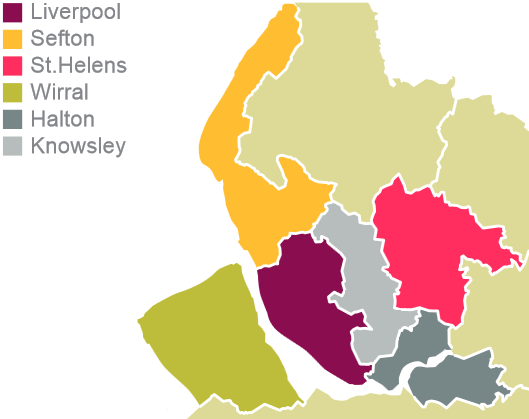
2011 and 2017 concentrations representing current reference years and any future years in 2020, 2025 and up to 2030 have been estimated from the 2017 baseline. A summary of the population-weighted average concentration (PWAC) between 2011 and 2030 in each local authority is shown in Table 1 and Table 2 for anthropogenic PM2.5 and NO2, respectively. Maps of Liverpool City Region total[[21]](#footnote-22) PM2.5 and NO2 annual mean concentration by wards are shown in Figure 2 and Figure 3, respectively. The reader should refer to the Background Maps User guide (<https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html#about>) for information on an estimated breakdown of the relative sources of pollution and on how pollutant concentrations change over time.

Table 1 Anthropogenic PM2.5 PWAC[[22]](#footnote-23) (in μg m-3) (annual) by local authority

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Local authority | 2011 | 2017 | 2020 | 2025 | 2030 |
| Halton | 10.88 | 7.98 | 7.65 | 7.35 | 7.30 |
| Knowsley | 11.06 | 8.14 | 7.84 | 7.55 | 7.52 |
| Liverpool | 10.64 | 8.12 | 7.79 | 7.50 | 7.47 |
| St. Helens | 11.01 | 7.67 | 7.36 | 7.11 | 7.06 |
| Sefton | 9.37 | 6.53 | 6.23 | 5.95 | 5.93 |
| Wirral | 9.37 | 6.70 | 6.39 | 6.10 | 6.07 |

Table 2 NO2 PWAC (in μg m-3) (annual) by local authority

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Local authority | 2011 | 2017 | 2020 | 2025 | 2030 |
| Halton | 20.69 | 15.92 | 14.04 | 11.88 | 10.72 |
| Knowsley | 21.31 | 17.50 | 15.38 | 12.78 | 11.38 |
| Liverpool | 21.99 | 18.41 | 16.30 | 13.78 | 12.46 |
| St. Helens | 18.99 | 14.84 | 12.99 | 10.93 | 9.84 |
| Sefton | 15.07 | 11.78 | 10.69 | 9.32 | 8.67 |
| Wirral | 15.77 | 12.22 | 10.88 | 9.16 | 8.26 |



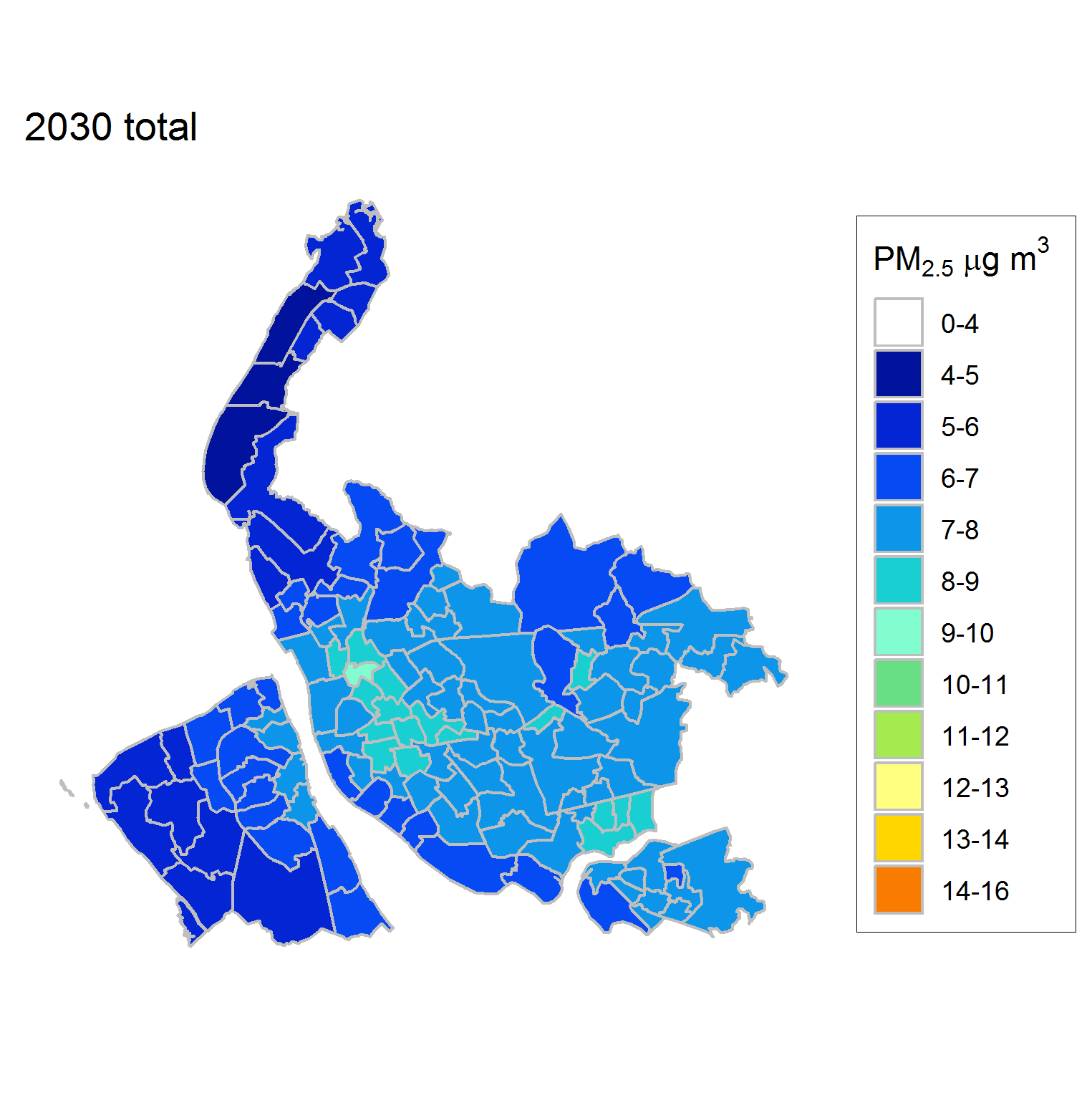
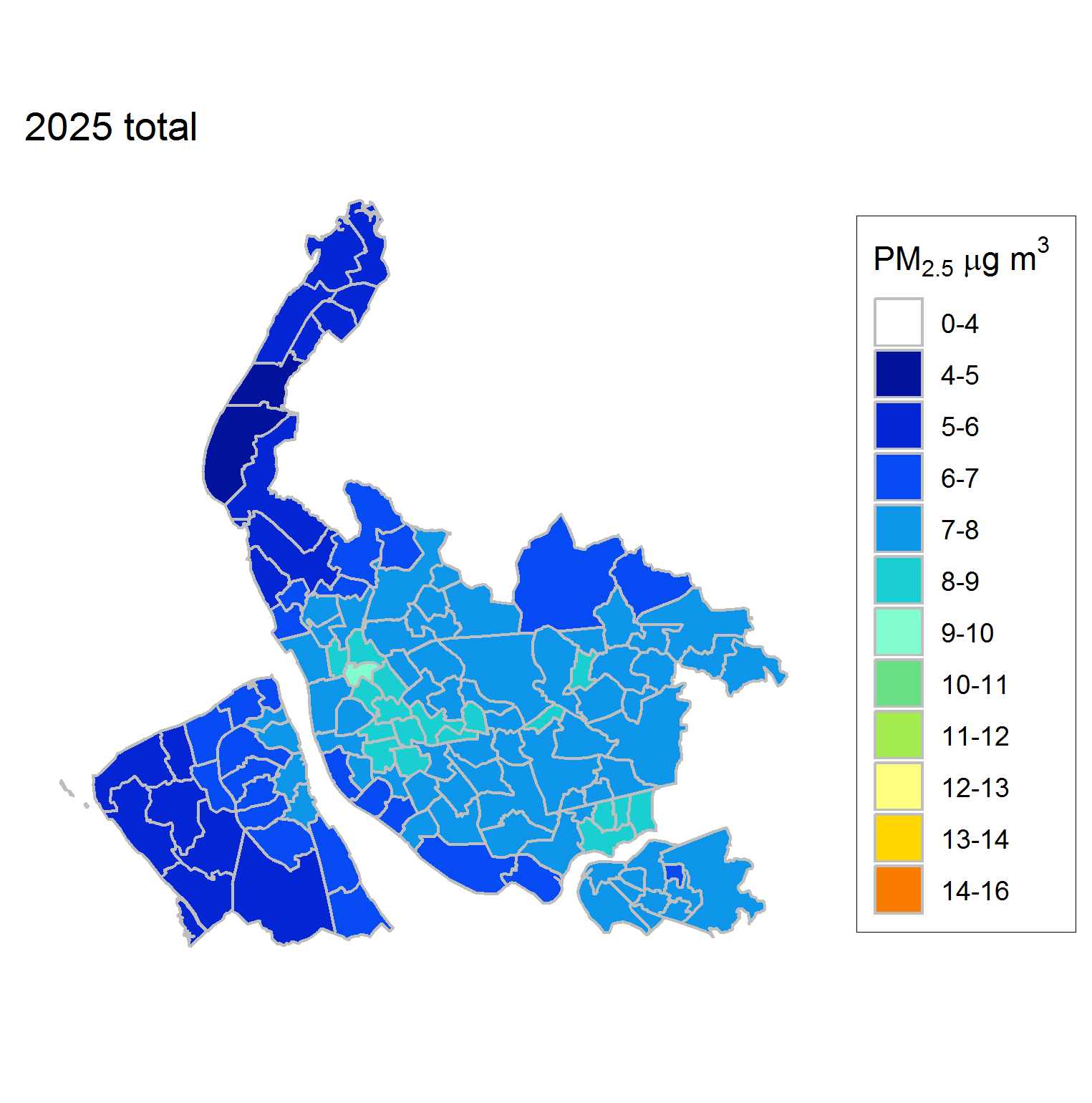
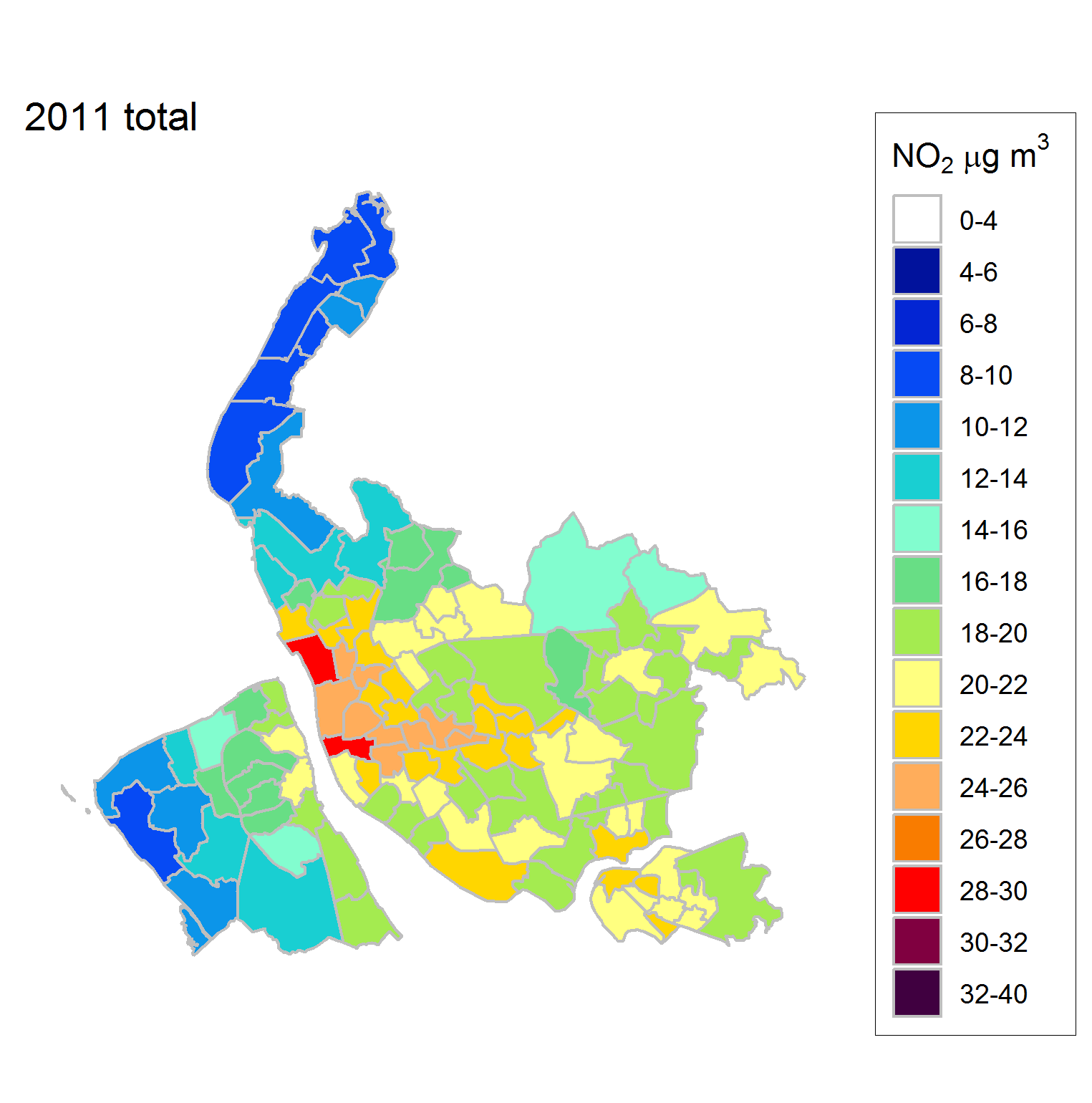
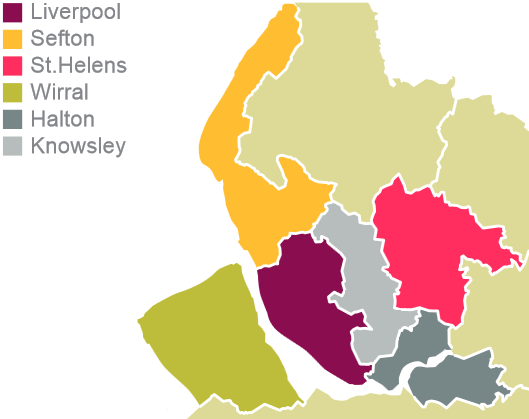
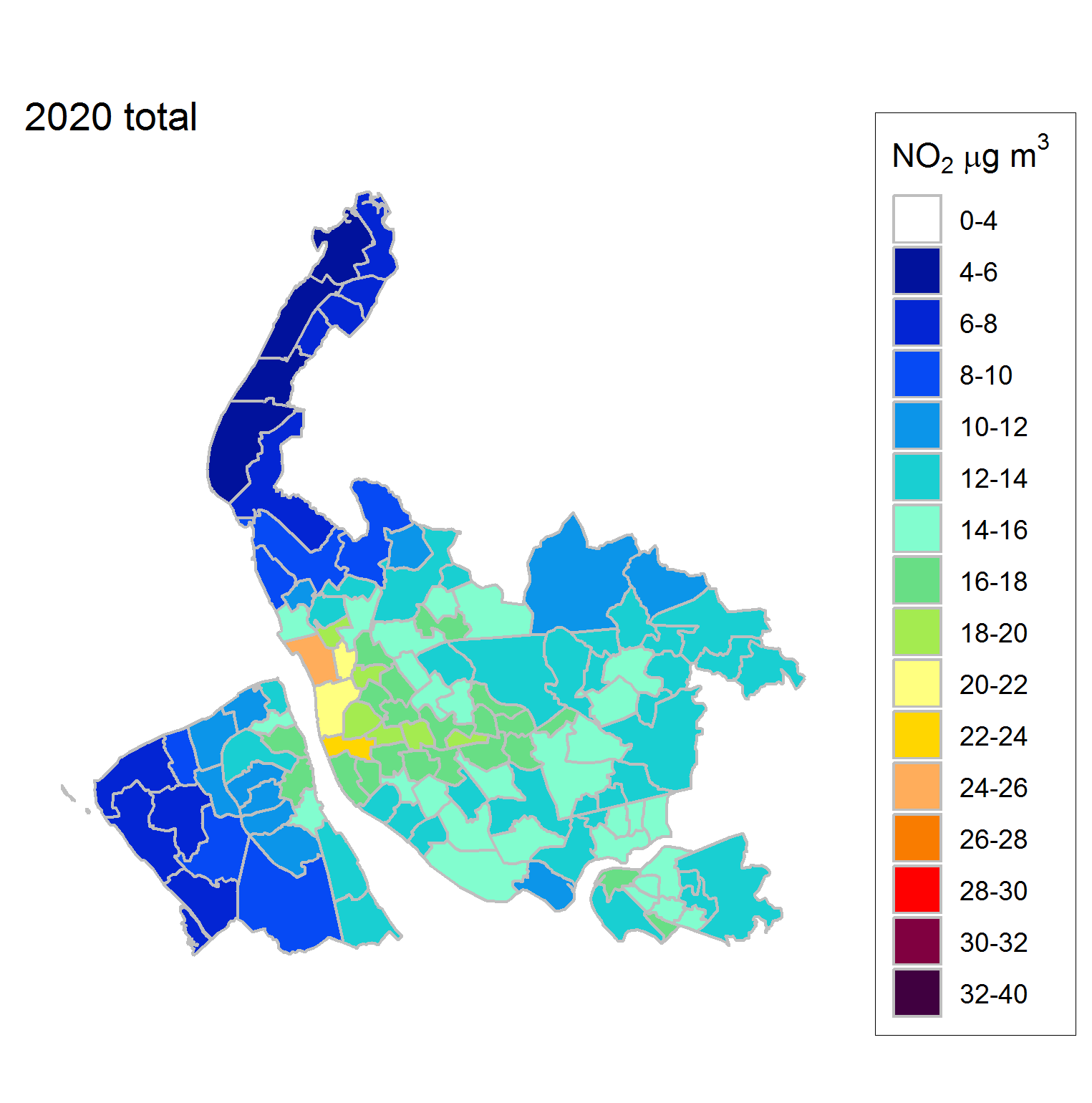
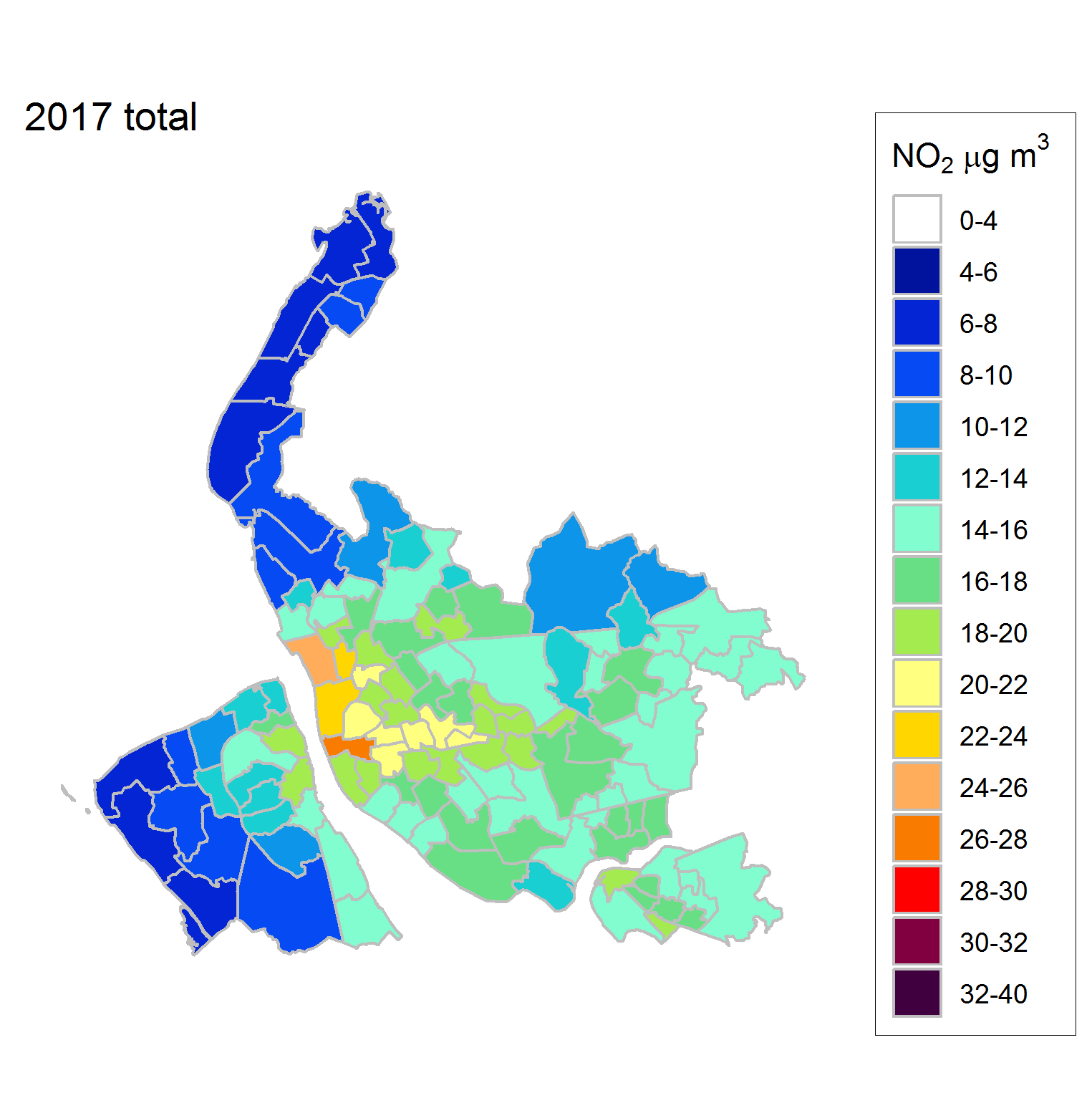


Figure 2 Annual mean PM2.5 concentrations (in μg m-3) by wards between 2011 and 2030[[23]](#footnote-24)





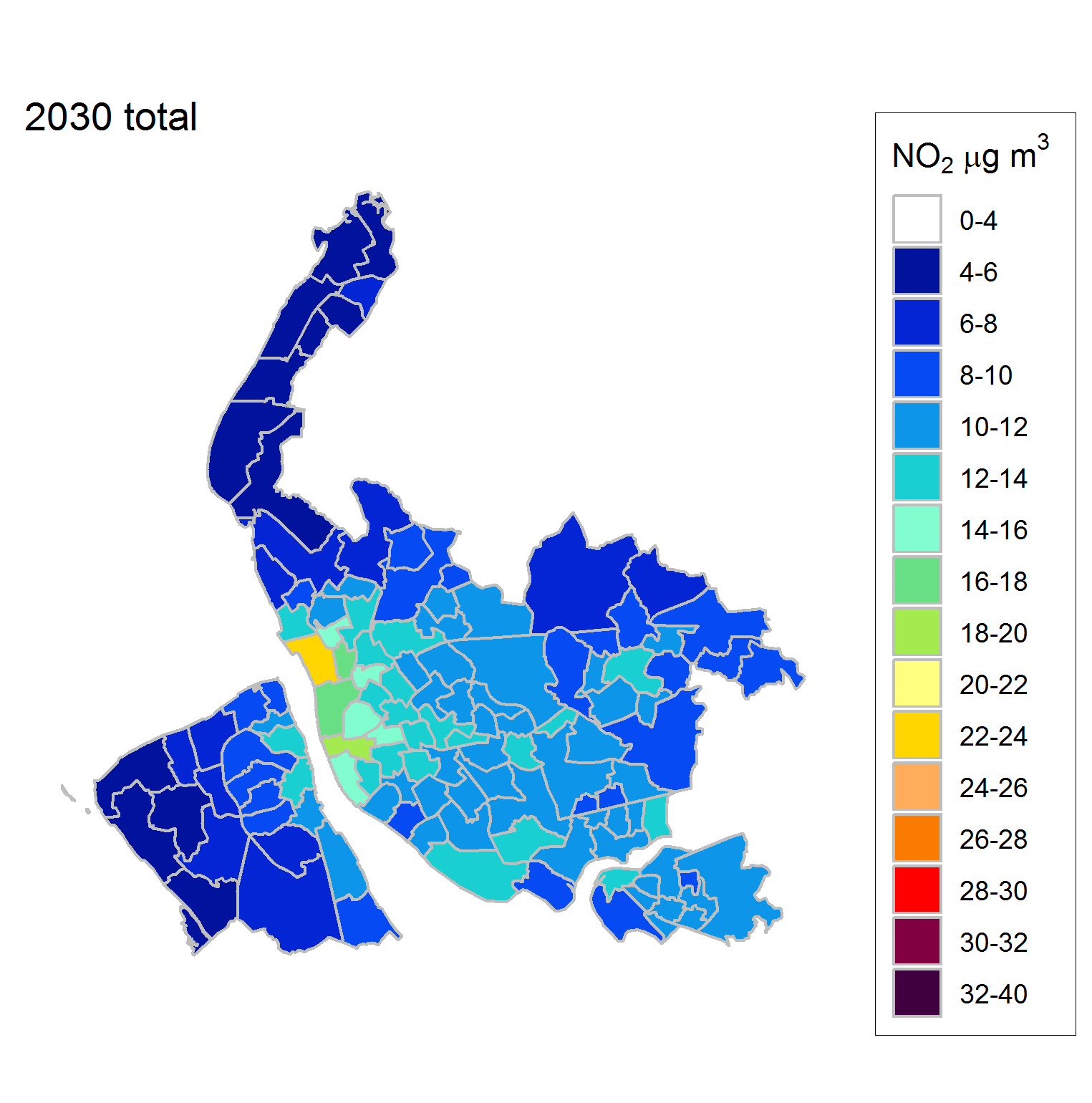
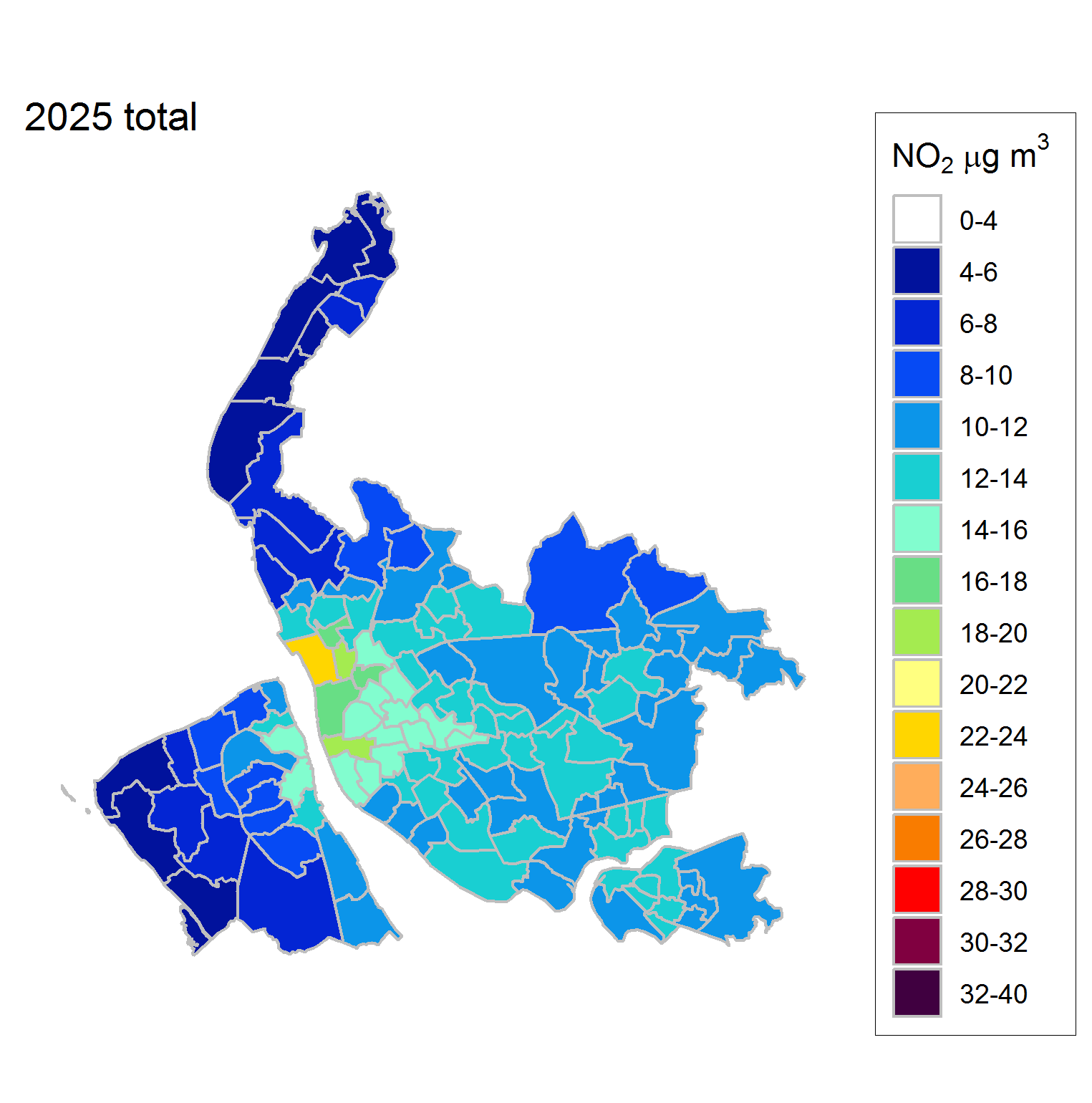


Figure 3 Annual mean NO2 concentrations (in μg m-3) by wards between 2011 and 2030

# Health Estimates of the mortality impact of air pollution and its economic valuation

## Mortality impact

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

Calculations are first given for PM2.5 and NO2 separately. Because air pollutants are correlated with each other, the air pollutant concentrations in the health studies represent both the pollutants themselves but also other air pollutants closely correlated with them. Health impacts from changes in PM2.5 and NO2 represent the health impacts of changes in the air pollution mixture in slightly different ways that overlap i.e. they should not be added. This is discussed further at the end of this section.

The results from the life table calculations assuming that the concentration does not reduce from 2011 levels and assuming the predicted concentration between 2011 and 2030 (concentrations were modelled at 2011, 2017, 2020, 2025 and 2030 but also interpolated for the intervening years) are shown in Table 3, for anthropogenic PM2.5 and NO2. Results for each local authority can be found in the Appendix in Table 16 and Table 20 (life table calculations for anthropogenic PM2.5 with and for PM2.5 without a cut-off), in Table 17 and Table 21 (life table calculations for NO2 with and without a cut-off) and Table 18 and Table 19 (central and lower/upper CI estimates of annualised economic impact for anthropogenic PM2.5 and NO2 without a cut-off) and Table 22 (central estimates of annualised economic impact for PM2.5 and NO2 with a cut-off).

The life years lost gives a large number because the life years (one person living for one year) is summed over the whole population in the Liverpool City Region combined authority over 124 years. For context, the total life years lived with baseline mortality rates is around 205 million, so these losses of life years involve about 0.5% of total life years lived.

If 2011 concentrations of anthropogenic PM2.5 remained unchanged for 124 years, around 0.4 – 1.2 million life years would be lost across Liverpool City Region’s population over that period. This improves to around 0.1 – 0.8 million life years lost with the predicted concentration changes between 2011 and 2030 examined here.

Another way of representing the health impacts if air pollution concentrations remained unchanged (in 2011) compared with the projected future changes (2011 to 2030) is provided by the results for NO2. If 2011 concentrations of NO2 remained unchanged for 124 years, around 0.6 – 0.8 million life years would be lost across LCR’s population over that period. This improves to around 0.3 – 0.5 million life years lost with the predicted concentration changes between 2011 and 2030 examined here.

Summarising these results is not easy. The results should not be added as there is considerable overlap. On the other hand, either result is an underestimate to some extent as it is missing the impacts that are better picked up in the calculations using the other pollutant. COMEAP (2017, 2018a) suggested taking the larger of the two alternatives in the calculation of benefits. We have interpreted this as the larger of the two alternatives (PM2.5 or NO2) in the case of each calculation. Note that this means that the indicator pollutant changes in different circumstances. In the case above, for no cut-off, this is the result for PM2.5 (0.8 vs 0.5 million life years lost for NO2). However, for the cut-off, this is the result for NO2 (0.3 vs 0.1 million life years lost for PM2.5). Other interpretations e.g. keeping the same indicator pollutant with and without a cut-off, are possible. All the relevant data are in the tables to enable creation of summaries in a different form.

So, the **overall summary** for the projected future changes in air pollution concentrations from 2011 to 2030 would be around **0.3 to 0.8 million life years lost** for the population of Liverpool City Region over 124 years.

Table 3 Total life years lost across the Liverpool City Region population for anthropogenic PM2.5 and NO2 and the associated annualised economic impact (central estimate)

|  |  |  |  |
| --- | --- | --- | --- |
| Pollutant | Scenario | Life years lost  Central estimate (without cut-off  with cut-off) | Annualised economic impact (in 2014 prices)  (without cut-off  with cut-off) |
| Anthropogenic PM2.5 (representing the regional air pollution mixture and some of the local mixture) | Concentration does not reduce from 2011 levels | 1,164,593  403,924 | £688,756,919  £238,435,359 |
| Predicted concentration between 2011 and 2030 | **798,521**  61,107 | **£477,603,949**  £40,773,443 |
| NO2 (representing the local mixture and the rural air pollution mixture) | Concentration does not reduce from 2011 levels | 845,138  624,376 | £498,974,404  £368,284,161 |
| Predicted concentration between 2011 and 2030 | 493,408  **272,258** | £300,081,973  **£169,191,136** |

For anthropogenic PM2.5 assuming no net migration, with projected new births, 2011-2134, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.06 per 10 μg m-3 of anthropogenic PM2.5 without cut-off and with 7 μg m-3 cut-off[[24]](#footnote-25), with lags from the USEPA.

For NO2 assuming no net migration, with projected new births, 2011-2134, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.023 per 10 μg m-3 of NO2 without cut-off and with 5 μg m-3 cut-off, with lags from the USEPA.

(Results with cut-offs do not extrapolate beyond the original data, results with no cut-off represent the possibility that there are effects below the cut-off value (it is unknown whether or not this is the case).)

Figures in bold are the larger of the alternative estimates using PM2.5 or NO2, as summarized in the headline results. Note that the comparison for which is largest for the predicted concentration changes is across the results either without a cut-off (first row in each cell; 798,521 vs 493,408) or with a cut-off (second row in each cell; 272,258 vs 61,107) using Life year lost of predicted concentration between 2011 and 2030 results as an example.

Table 3 also gives the economic impacts (economic costs). Note that these are derived from applying monetary valuation to the health impacts. The monetary values are derived from surveys of what people are willing to pay to avoid the risk of the relevant health impact. They do not represent the costs of the policies or the costs to the NHS.

If 2011 concentrations of anthropogenic PM2.5 remained unchanged for 124 years, the annualised economic cost would be around £240 – 690 million. This improves to around £40 – 480 million with the projected baseline concentration changes examined here.

If 2011 concentrations of NO2 remained unchanged for 124 years, the annualised economic cost would be around £370 – 500 million. This improves to around £170 – 300 million with the predicted concentration between 2011 and 2030 changes examined here.

The **overall summary** for the projected baseline would be annualised economic costs of around **£170 to 480 million**.

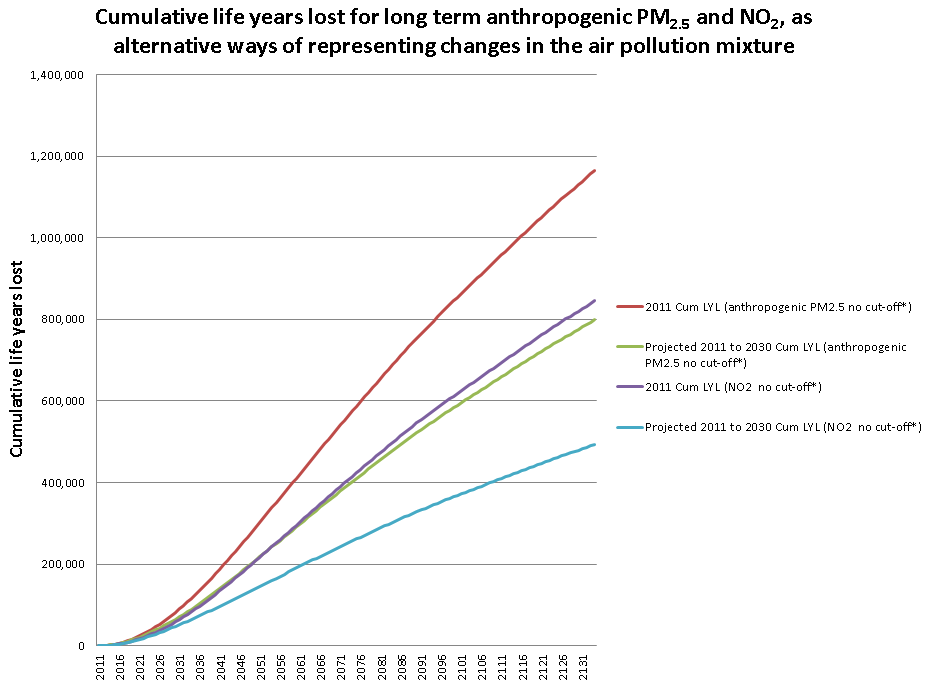


Figure 4 Cumulative life years lost for anthropogenic PM2.5 and NO2 if 2011 concentrations remained unchanged and the baseline (current policies 2011-2030) across the LCR population (no migration), with projected new births, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) 2011-2134. RR 1.06 per 10 μg m-3 for anthropogenic PM2.5 and RR 1.023 per 10 μg m-3 for NO2, EPA lag

\* Cut-off results not shown

Figure 4 shows that the cumulative life years lost for the predicted concentration between 2011 and 2030 accumulates more slowly than the constant 2011 concentration results for both anthropogenic PM2.5 and NO2 as a result of the reduced concentrations from 2011 to 2030. It is worth remembering that there is a delay before the full benefits of concentration reductions are achieved. This is not just due to a lag between exposure and effect, but also because the greatest gains occur when mortality rates are highest i.e. in the elderly.

Table 4 shows the differences between the predicted concentrations between 2011 and 2030 and both particulate levels and NO2 concentration constant at 2011 levels. Using PM2.5 as an indicator of the regional pollution and some of the local pollution mixture gives an estimate of 340,000 to 370,000 life years gained as a result of the predicted concentration between 2011 and 2030. Using NO2 as an indicator of mostly the local pollution mixture and the rural pollution gives a similar estimate of 350,000 life years gained, although the PM2.5 concentration response function (see Table 13) is much stronger than for NO2 (RR 1.06 per 10 μg m-3 for anthropogenic PM2.5 and RR 1.023 per 10 μg m-3 for NO2). This makes sense because the concentration projected (2011 to 2030) suggests more continuous declines in NO2 concentrations (likely to be mostly due to the improvement in NOX emissions of large parts of the road transport sector) than for PM2.5, reflecting the fact that PM reduction from traffic is not larger due to the increasing contribution from non-exhaust emissions[[25]](#footnote-26) and also that the declines in regional PM2.5 are relatively small.

The **overall summary** would be that taking into account predicted air pollution concentration changes between 2011 and 2030, the population in LCR would **gain around 350,000 to 370,000 life years** over a lifetime.

Table 4 Life years saved (and associated monetised benefits) across LCR population of the predicted concentration between 2011 and 2030 compared with 2011 anthropogenic PM2.5 concentrations and NO2 remaining unchanged

|  |  |  |  |
| --- | --- | --- | --- |
| Pollutant | Scenario | Total life years **saved** compared with 2011 concentrations maintained  (without cut-off  with cut-off) | Monetised benefits compared with 2011 concentrations maintained  (without cut-off  with cut-off) |
| Anthropogenic PM2.5 (representing the regional air pollution mixture and some of the local mixture) | Predicted concentration between 2011 and 2030 | **366,072**  342,817 | **£211,152,970**  £197,661,916 |
|
| NO2 (representing the local mixture and the rural air pollution mixture) | Predicted concentration between 2011 and 2030 | 351,730  **352,118** | £198,892,431  **£199,093,025** |
|

Figures in bold are the larger of the alternative estimates using PM2.5 or NO2, as summarized in the headline results. Note that the comparison for which is largest for the predicted concentration changes is across the results either without a cut-off (first row in each cell; 366,072 vs 351,730) or with a cut-off (second row in each cell; 352,118 vs 342,817) using total life years saved compared with 2011 concentrations maintained results as an example.

Table 4 also provides an estimate of the economic impact as a result of the improvements in pollution from 2011 to 2030 versus 2011 pollution remaining unchanged. The **annualised monetary benefit** of anthropogenic PM2.5 and NO2 improvements has been estimated to be **£200 to 210 million** (at 2014 prices).

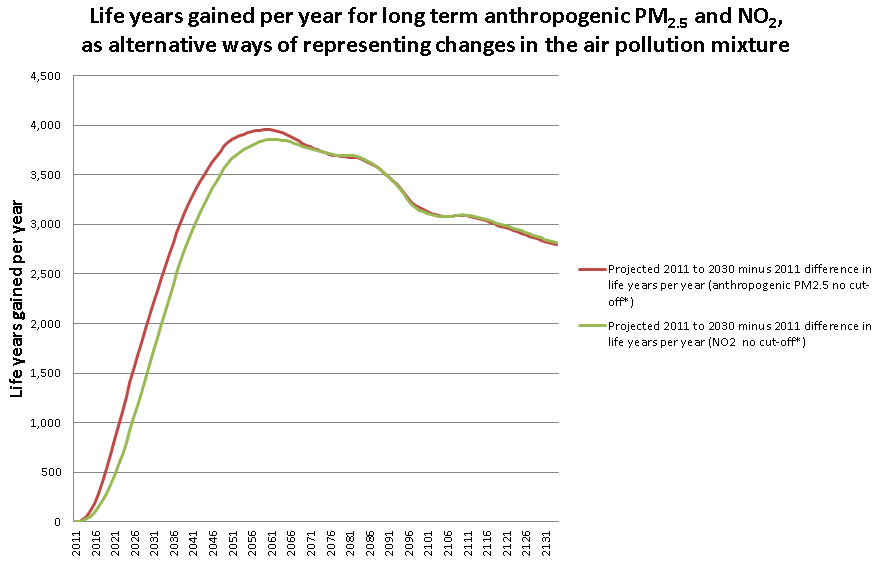


Figure 5 Life years gained per year from long-term exposure to the improvements in pollution from 2011 to 2030 of anthropogenic PM2.5 and NO2 relative to 2011 concentrations remaining unchanged

\* Cut-off results not shown

Figure 5 shows the effect of the decrease in PM2.5 and NO2 concentration from 2011 to 2030 (as seen in Table 1 and Table 2).

## Life-expectancy from birth in 2011

Total life years across the population is the most appropriate metric for cost-benefit analysis of policies as it captures effects in the entire population. However, it is a difficult type of metric to communicate as it is difficult to judge what is a ‘small’ answer or a ‘large’ answer. Life-expectancy from birth is a more familiar concept for the general public, although it only captures effects on those born on a particular date. Results for life expectancy from birth are shown in Table 5. Results for each local authority can be found in the Appendix in Table 23 and Table 24 (Loss of life expectancy for anthropogenic PM2.5 and NO2 with and without a cut-off).

This shows that the average loss of life expectancy from birth in LCR would be about 11 – 33 weeks for males and 10 – 29 weeks for females if 2011 PM2.5 concentrations were unchanged but improves to 1 – 22 weeks for males and 1 – 19 weeks for females for the predicted concentration changes between 2011 and 2030 (an improvement by about 9-11 weeks).

Using NO2, the average loss of life expectancy from birth in LCR would be about 18 – 24 weeks for males and 16 – 21 weeks for females if NO2 concentrations were unchanged from 2011 but improves by about 9-11 weeks to 7 – 13 weeks for males and 6 – 12 weeks for females with projected future changes between 2011 and 2030 included.

The **overall summary** would be that the projected future changes provide an improvement in average life expectancy from birth in 2011 of around 2 – 2.5 months (9 – 11 weeks) but an average loss of life expectancy from birth in 2011 of around 1.5 to 5 months (6 – 22 weeks) remains even with the reduced concentrations. Males are more affected than females – this is mainly due to the higher mortality rates in men compared with women rather than differences in air pollution exposure. The concentration-response function is implemented as a percentage change in baseline mortality rates. If the baseline mortality rates are higher then the absolute impact is higher even though the percentage change is the same.

Table 5 Loss of life expectancy by gender across LCR from birth in 2011 (followed for 105 years) for anthropogenic PM2.5 and NO2

|  |  |  |  |
| --- | --- | --- | --- |
| Pollutant | Scenario | Loss of life expectancy from birth compared with baseline mortality rates, 2011 birth cohort (in weeks)  (without cut-off  with cut-off) | |
| Male | Female |
| Anthropogenic PM2.5 | Concentration does not reduce from 2011 levels | 32.7  11.4 | 28.8  10.1 |
| Predicted concentration between 2011 and 2030 | **22.0**  1.3 | **19.4**  1.2 |
| NO2 | Concentration does not reduce from 2011 levels | 23.8  17.6 | 21.0  15.5 |
| Predicted concentration between 2011 and 2030 | 13.1  **6.9** | 11.5  **6.0** |

Figures in bold are the larger of the alternative estimates using PM2.5 or NO2, as summarized in the headline results. Note that the comparison for which is largest for the predicted concentration changes is across the results either without a cut-off (first row in each cell; 22 vs 13.1) or with a cut-off (second row in each cell; 6.9 vs 1.3) using Male results as an example.

Additional data such as the loss of life expectancy lower and upper estimate and the full range of confidence intervals with and without the counterfactual for both PM2.5 and NO2 are available upon request to the authors.

# Health Estimates of the mortality burden of air pollution

## Burden background

Burden calculations are a snapshot of the burden in one year, assuming that concentrations had been the same for many years beforehand. They are intended as a simpler calculation than the more detailed assessments that are given above (in the mortality impact section). They are not suitable for calculation is several successive years as they do not have a mechanism for allowing the number of deaths the year before to influence the age and population size the following year as the lifetables used in impact calculations do.

The burden calculations are included here as a comparison with similar calculations presented elsewhere (COMEAP, 2010; Walton et al., 2015; Dajnak et al., 2018; Dajnak et al., 2019). The concentration-response functions used for these calculations are evolving over time. Previous recommendations favoured methods similar to the single pollutant model approach presented below. The latest COMEAP (2018a) report shows that a majority of the committee supported a new approach using information from multi pollutant model results but COMEAP (2018a) also recommended using a range to reflect the uncertainty.

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

The report goes on to explain that multi-pollutant models aim to disentangle the effects of separate pollutants but this is difficult to do. Despite the best attempts, it may still be the case that some of the effect of one pollutant ‘attaches’ to the effects ascribed to another pollutant, leading to an underestimation of the effects of one pollutant and an overestimation of the effects of another. In this situation, the combined effect across the two pollutants should give a more reliable answer[[26]](#footnote-27) than the answers for the individual pollutants that may be over- or under-estimated. This was the basis for the approach described below, including adding results derived from information within each of 4 separate studies first, before combining them as a range. The intention is not to present the individual pollutant results separately as final results, although the calculations for individual pollutants are done as intermediate stages towards the overall results.

[Burden calculations would normally include accompanying estimates of the burden of life years lost[[27]](#footnote-28). This would require inputting average loss of life expectancy by age and gender for calculations in each ward. For this small project, it was not possible to do this.]

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

## Combined estimate for PM2.5 and NO2 using multi pollutant model results

Using the exploratory new combined method (COMEAP, 2018a) gives an estimate for the 2011 mortality burden in Liverpool City Region of 2011 levels of air pollution (represented by anthropogenic PM2.5 and NO2) to be equivalent to 800 to 1,040 attributable deaths at typical ages, or a result equivalent to 470 to 510 deaths when cut-offs for each pollutant were implemented. Estimates for individual local authorities are provided in Table 6. The results varied by local authority with the highest in Liverpool and the lowest in Halton. The ranking by local authority did not fully follow the ranking in pollutant concentrations (see Table 1 and Table 2). This is because the results are also influenced by the size of the population and variations in death rates by local authority (highest in Sefton, lowest in Halton), which in turn are driven in part by the proportion of elderly in the population (highest in Sefton, lowest in Halton and Liverpool) and the level of deprivation (highest in Knowsley and Liverpool, lowest in Sefton and Wirral). Details are given in Table 26 in the Appendix.

These results use recommendations from COMEAP, 2018a. For each of the four individual cohort studies that included multi-pollutant model results[[28]](#footnote-29), the burden results were estimated separately using mutually adjusted summary coefficients for PM2.5 and NO2 and then the adjusted PM2.5 and NO2 results were summed to give an estimated burden of the air pollution mixture. Example of the calculations for each study for individual local authority and LCR of 2011 levels of NO2 and PM2.5 can be found in the appendix in Table 27 and Table 28. The uncertainty of each separate study was not quantified (COMEAP, 2018a) but it is worth noting that each of the individual results also has uncertainty associated with it.

Table 6 Estimated burden (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (with and without cut-off)

|  |  |  |
| --- | --- | --- |
| Zone | Anthropogenic PM2.5 and NO2  (without cut-off) | Anthropogenic PM2.5 and NO2  (with cut-off) |
| Attributable deaths (using coefficients derived from information in 4 studies below\*) | Attributable deaths (using coefficients derived from information in 4 studies below\*) |
| Halton | 66 - 85 | 42 - 45 |
| Knowsley | 82 - 105 | 53 - 56 |
| Liverpool | 260 - 322 | 160 - 177 |
| St. Helens | 95 - 126 | 58 - 63 |
| Sefton | 138 - 188 | 71 - 77 |
| Wirral | 161 - 214 | 85 - 93 |
| Liverpool City Region | 803 -1,040 | 472 - 511 |

\*Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

\*Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

## Single pollutant model estimates

The previous mortality burden method using single pollutant model estimates would have estimated that Liverpool City Region’s 2011 levels of anthropogenic PM2.5 would lead to effects equivalent to 840 (range[[29]](#footnote-30) 570 to 1,100) attributable deaths at typical ages, or results equivalent to 290 (range 200 to 380) deaths when the cut-off was implemented. Estimates for individual local authorities are provided in Table 7. This represents the regional pollution mixture and partially represents the contribution from traffic pollution.

These results use recommendations from COMEAP, 2010. Walton et al. (2015) used both COMEAP (2010) recommendations and WHO (2013) recommendations that included recommendations for nitrogen dioxide to provide estimates for London. The results were presented as a range from PM2.5 alone to the sum of the PM2.5 and NO2 results, but the uncertainty of the latter was emphasized. Since then it has become clearer that the overlap is likely to be substantial (COMEAP, 2015a). COMEAP (2018a) concluded that the combined adjusted coefficients were similar to, or slightly larger than, the single-pollutant association reported with either pollutant alone.

The lower and upper estimates in Table 7 are based on the 95% confidence intervals (1.04 – 1.08) around the pooled summary estimate (1.06) for the increase in risk from Hoek et al (2013). COMEAP recently agreed to use this range (COMEAP, 2018b) rather than the wider ones of 1.01 – 1.12 in the original COMEAP (2010) report. Nonetheless, the wider ones remain reflective of the fact that the uncertainties are wider than just the statistical uncertainty represented by the confidence intervals. We have included results for this wider range of uncertainty in Table 25 of the Appendix but as a rough guide the range goes from around a sixth to around double the central estimate in Table 7.

Table 7 Estimated burden (from single-pollutant model summary estimate) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 (with and without cut-off)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5  (without cut-off) | | | Anthropogenic PM2.5  (with cut-off) | | |
| Attributable deaths | | | Attributable deaths | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Halton | 67 | 46 | 88 | 26 | 18 | 35 |
| Knowsley | 83 | 57 | 109 | 33 | 22 | 43 |
| Liverpool | 251 | 170 | 328 | 94 | 64 | 124 |
| St. Helens | 103 | 70 | 135 | 41 | 27 | 53 |
| Sefton | 158 | 107 | 206 | 44 | 30 | 58 |
| Wirral | 177 | 120 | 232 | 52 | 35 | 68 |
| Liverpool City Region | 839 | 570 | 1,098 | 290 | 196 | 382 |

Using COMEAP’s recommended concentration-response coefficient of 1.06 per 10 μg m-3 of anthropogenic PM2.5 for the central estimate (lower estimate RR of 1.04 and upper estimate RR 1.08)

In addition to the combined multi-pollutant model derived estimates in the section above, the COMEAP (2018a) report suggests also calculating the burden using the single pollutant model result for NO2 (this may represent the burden of traffic pollution more clearly than that of PM2.5). The results give estimates that Liverpool City Region’s 2011 levels of NO2 lead to effects equivalent to 600 (range[[30]](#footnote-31) 220 to 950) attributable deaths at typical ages, or results equivalent to 440 (range 160 to 700) deaths when the cut-off was implemented. Estimates for individual local authorities are provided in Table 8.

Table 8 Estimated burden (from single pollutant model summary estimate) of effects on annual mortality in 2011 of 2011 levels of NO2 (with and without cut-off)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Zone | NO2 (without cut-off) | | | NO2 (with cut-off) | | |
| Attributable deaths | | | Attributable deaths | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Halton | 51 | 18 | 80 | 39 | 14 | 61 |
| Knowsley | 63 | 23 | 100 | 49 | 17 | 77 |
| Liverpool | 203 | 72 | 320 | 158 | 56 | 249 |
| St. Helens | 70 | 25 | 111 | 52 | 18 | 82 |
| Sefton | 99 | 35 | 156 | 66 | 23 | 104 |
| Wirral | 118 | 42 | 186 | 81 | 29 | 128 |
| Liverpool City Region | 604 | 215 | 952 | 444 | 157 | 702 |

Using COMEAP’s recommended concentration-response coefficient of 1.023 per 10 μg m-3 of NO2 for the central estimate (lower estimate RR of 1.008 and upper estimate RR 1.037)

## Summary of burden results

Results without the cut-off give a range of 800-1,040 attributable deaths using the approach derived from multi-pollutant model results. This compares with around 840 attributable deaths[[31]](#footnote-32) using the single-pollutant model estimate for PM2.5 (the previous method) and around 600 attributable deaths using the single-pollutant model estimate for NO2 (a good indicator of traffic pollution). As expected, the estimate combining effects of NO2 and PM2.5 is slightly larger than for either pollutant alone but not by much, reflecting the substantial overlap between the single pollutant model estimates for PM2.5 and NO2. Nonetheless, there are substantial ranges of uncertainty around these estimates so it is not clear cut that there is an additional effect over and above estimates using the previous method.

The message from the results with a cut-off is similar with a range of 470-510 attributable deaths using the approach derived from multi-pollutant model results compared with 290 (PM2.5 single-pollutant model) and 440 (NO2 single-pollutant model). In this case, the result for NO2 is larger than that for PM2.5 - probably a reflection of the different cut-offs for NO2 and PM2.5.

In developing policy in the face of uncertainty, it is useful to have guidance on the result using the most conservative assumptions and that using approaches using recent trends in evidence and methods that may also be more uncertain. In this case, the ‘conservative assumptions’ result would be 290 attributable deaths (long-established method for PM2.5, avoids the complexities of interpreting multi-pollutant model results) and the ‘exploratory, more up to date, extrapolate beyond the data’ results would be 800-1,040 attributable deaths (combined NO2 and PM2.5; no cut-off). For messages incorporating most of the uncertainties, the message would be ‘somewhere between about 200 and 1,000 attributable deaths’.

# Discussion

This study addressed the effect of air pollution on deaths and loss of life-expectancy. This included all causes of death grouped together so covers, for example, respiratory, lung cancer and cardiovascular deaths for which there is good evidence for an effect of air pollution. It does not, however, cover the effect of air pollution on health where this does not result in death. So well established effects (such as respiratory and cardiovascular hospital admissions, effects on asthma, low birth weight etc) and other outcomes more recently potentially linked with air pollution (such as dementia) are not included. Their inclusion would increase the benefit of policies to further reduce air pollution.

## Impact of Air Pollution on Inequalities within LCR

The HIA results’ variation and ranking by local authority did not fully follow the ranking in pollutant concentrations. As already discussed in section 6.2, this is because the results are also influenced by the size of the population and variations in death rates, the proportion of elderly in the population and the level of deprivation by local authority as seen in Table 26 in the Appendix.

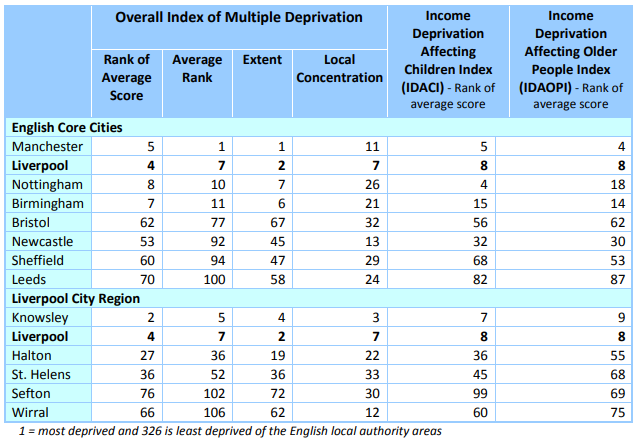
Individuals of lower social classes may experience increased susceptibility to the negative air pollution-related health effects particularly in urban areas, where they are possibly more affected than individuals of higher social class (discussed in Williams et al., 2018b). As a result, higher levels of pollution exposure and socioeconomic deprivation may lead to impaired health.

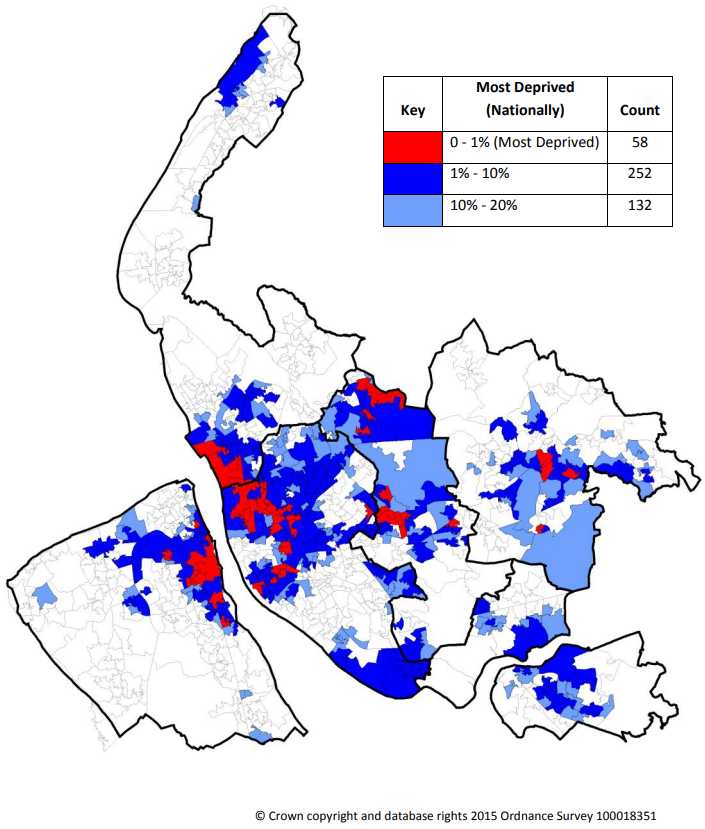
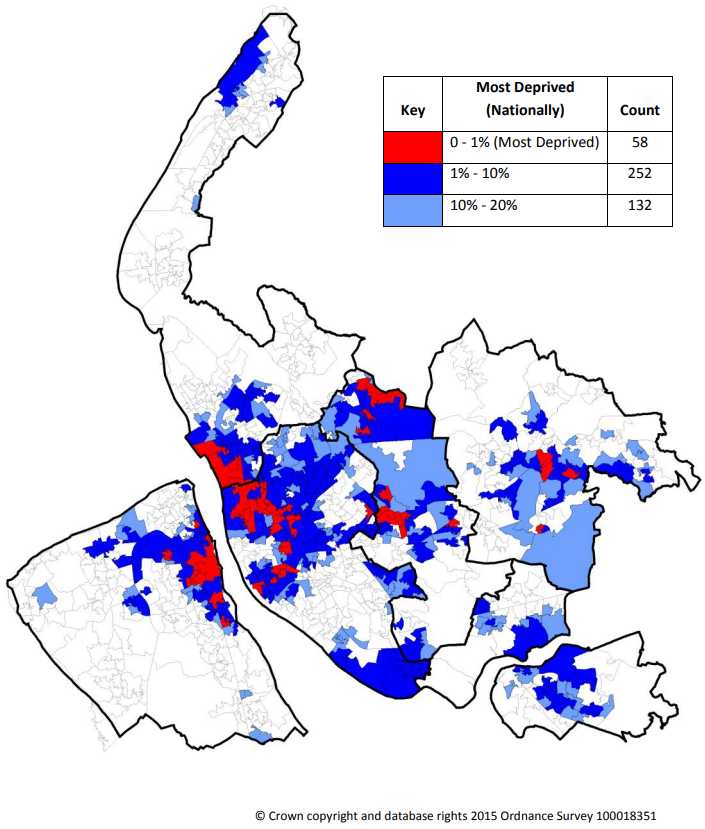
Within the Liverpool City Region, Sefton and Wirral have the lowest level of deprivation (see Table 9) and also the lowest PM2.5 and NO2 air pollution levels (see Table 1 and Table 2).

The Liverpool City Region map of multiple deprivation can be linked to the highest concentrations of PM2.5 and NO2 air pollution maps (Figure 6) showing environmental inequality (in which socioeconomically disadvantaged populations are among the most exposed). The most vulnerable individuals within Liverpool City Region are more likely to be exposed to higher levels of air pollution and would benefit the most from a reduction of air pollution. The main cluster of areas associated with both the most deprived and highest levels of air pollution are located in a ring around Liverpool city centre (i.e. Bootle (A[[32]](#footnote-33)) in the north, through north Liverpool (B), Kensington (C) and Princes Park (D) and across the river through much of Birkenhead (E)). Other significant clusters of deprivation linked to high levels of air pollution include areas centred upon Widnes (F) and Runcorn (G) in Halton, central (Huyton, H) and northern (Kirkby, I) Knowsley, Speke Garston (J) and Halewood (K) (areas of Liverpool and Knowsley) and within the central area of St Helens (L).

Furthermore, Liverpool has the highest population, highest level of deprivation and highest attributable death out of the six local authorities forming the LCR and would benefit most significantly from a reduction in air pollution concentrations.

Table 9 Indices of Multiple Deprivation (IMD)[[33]](#footnote-34) 2015: Local Authority Rankings[[34]](#footnote-35)





**L**

**K**

**J**

**H**

**I**

**B**

**G**

**F**

**E**

**C**

**D**

**A**

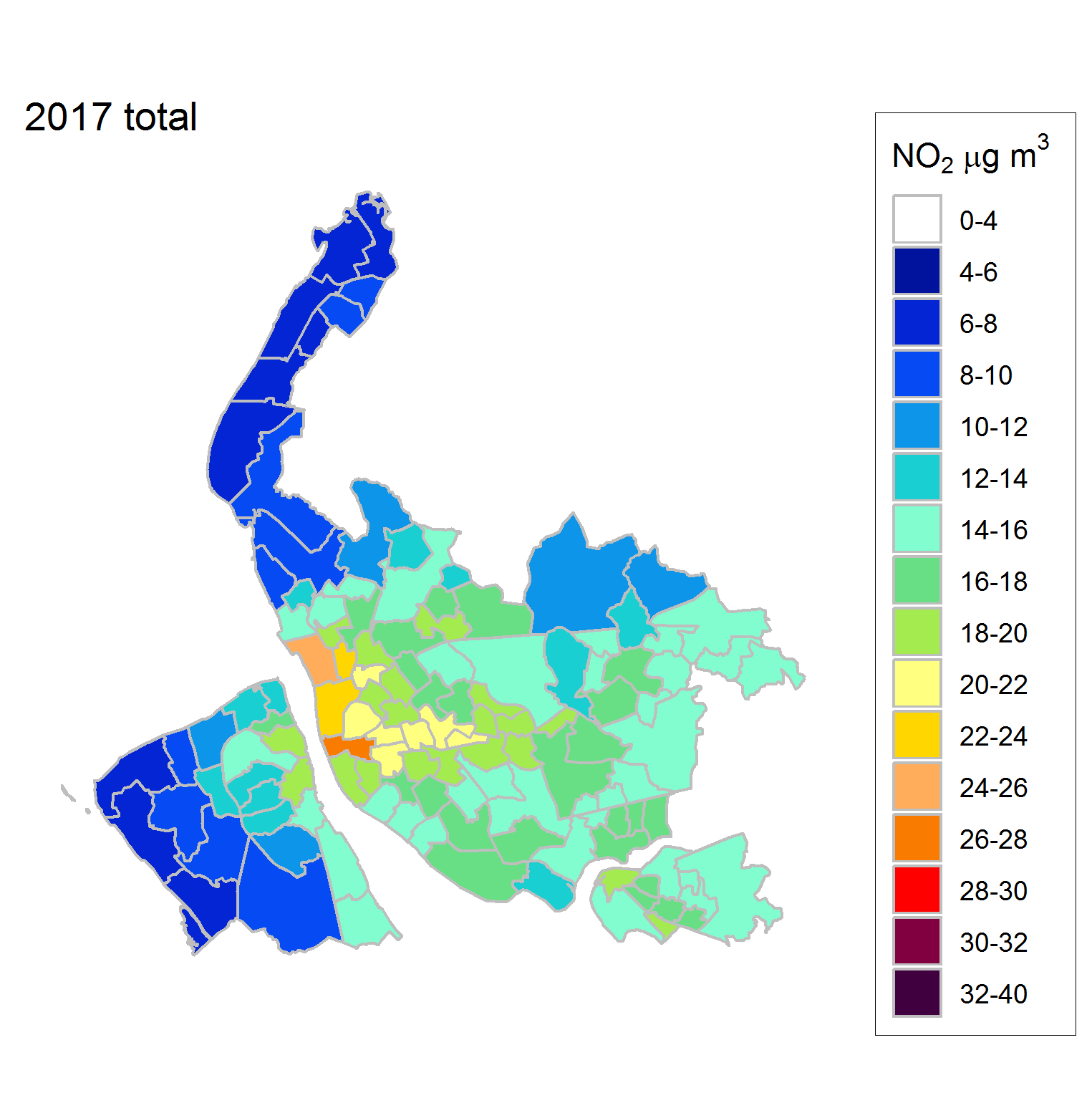
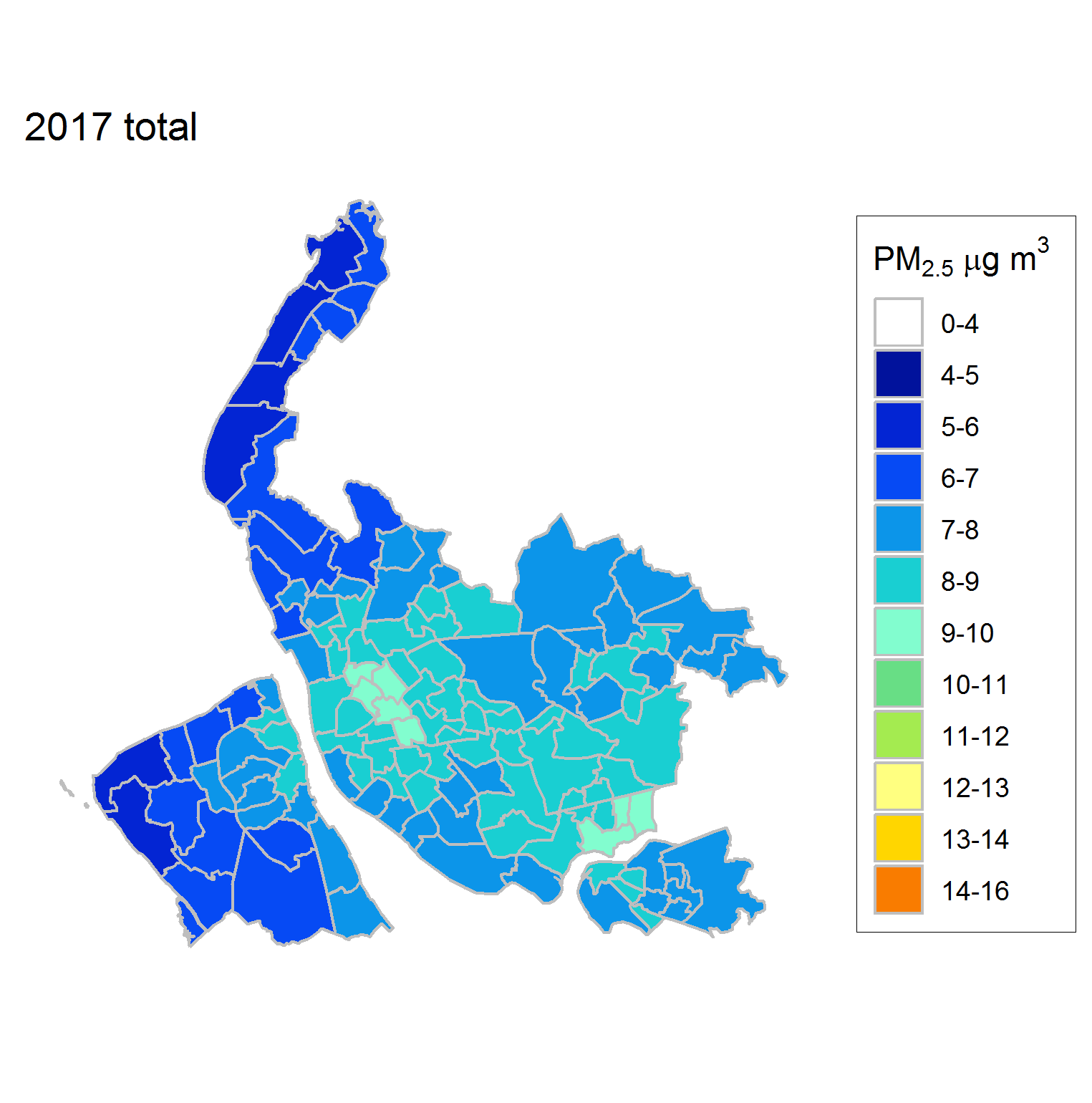


Figure 6 Map of Index of Multiple Deprivation 2015 in the Liverpool City Region (top)[[35]](#footnote-36) and annual mean PM2.5 and NO2 concentrations (in μg m-3) by wards in 2017 (bottom left and right, respectively). Letters in top map defined in text: Bootle (A), north Liverpool (B), Kensington (C), Princes Park (D), Birkenhead (E), Widnes (F), Runcorn (G), Huyton (H), Kirkby (I), Speke Garston (J), Halewood (K) and central area of St Helens (L)

## Comparison with results for Greater Manchester (GM), Birmingham City and London

The current authors performed a similar analysis for Greater Manchester in 2018 (Dajnak et al., 2018) and more recently for Birmingham in 2019 (Dajnak et al., 2019). This analysis was similar to the one for Birmingham City and Greater Manchester for the impact calculations although the Greater Manchester report predated the multi-pollutant model aspects of the new burden methodology published in COMEAP (2018). Even with the same methodology, comparisons for the impact calculations are complex because the results are driven by multiple factors changing over time (not only the pollutant concentrations but also the mortality rates, new births and the changes in population age distribution and size as a result of the pollutant changes). Nonetheless, some approximate comparisons can be made.

*Life years lost still remaining after pollution improvements:* The largest result in the Liverpool City Region, Birmingham City and Greater Manchester was for PM2.5 with no cut-off. The result was largest for Greater Manchester (1.6 million life years lost) with the result for both Liverpool City Region and Birmingham city being about half of that at 0.8 million life years lost. The primary driver of this difference is probably the difference in population – the area of Greater Manchester is a larger area and has a larger population (2.7 million) with the population for Liverpool City Region being about half of that (1.5 million) and the population in Birmingham city being above a third at 1 million. The LCR death rate (Table 12) is higher than in Birmingham city and Greater Manchester (Table 11) which will result in higher life years lost relative to both Birmingham city and Greater Manchester. On the other hand, the LCR PM2.5 and NO2 concentration is lower than in Birmingham city and Greater Manchester (Table 11) which will result in lower life years lost relative to both Birmingham city and Greater Manchester. This probably contributes to the fact that the LCR results are similar to those for Birmingham city despite the population and death rate being higher.

The equivalent result for NO2 with no cut-off is 1 million life years lost in Greater Manchester and 0.5 million life years lost in both Liverpool City Region and Birmingham city. This is again around half the life years lost in Liverpool City Region and Birmingham City compared with Greater Manchester, with the explanations being similar.

The comparison of the results with a cut-off give different messages for NO2 and PM2.5. The comparison for NO2 with a cut-off is similar to the no cut-off results (the result for Liverpool City Region and Birmingham, 0.3 million life years lost, about half that for Manchester, 0.6 million life years lost). For PM2.5, however, the result for Liverpool City Region (0.06 million life years lost) is much smaller than for Birmingham City (0.21 million life years lost) and Greater Manchester (0.18 million life years lost). This is because the PM2.5 concentrations in the LCR are much lower in some areas than the 7 μg m-3 cut-off. It is therefore assumed that the particulate pollution has no effect on life-years lost in those areas, reducing the total overall. (Strictly, the definition of a cut-off means it is unknown whether or not there are effects. In addition, this cut-off is based on Pope *et al* (2002) which in turn used particulate concentrations from many years earlier. As concentrations reduce and newer studies are completed, it is often found that the health effects at lower concentrations become clearer as there are more data points available for analysis at these lower concentrations.)

Table 10 Total life years lost across the Liverpool City Region, Birmingham City and Greater Manchester population for anthropogenic PM2.5 and NO2 and the associated annualised economic impact (central estimate)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pollutant | Scenario | Location | Life years lost  Central estimate (without cut-off  with cut-off) | Annualised economic impact (in 2014 prices)  (without cut-off  with cut-off) |
| Anthropogenic PM2.5 | Predicted concentration between 2011 and 2030 | Liverpool City Region | **798,521**  61,107 | **£477,603,949**  £40,773,443 |
| Birmingham City | **831,708**  213,344 | **£467,766,599**  £121,993,163 |
| Greater Manchester | **1,638,043**  175,471 | **£954,495,447**  £109,582,547 |
| NO2 | Predicted concentration between 2011 and 2030 | Liverpool City Region | 493,408  **272,258** | £300,081,973  **£169,191,136** |
| Birmingham City | 505,434  **328,491** | £289,339,663  **£190,370,755** |
| Greater Manchester | 981,519  **561,169** | £586,562,264  **£343,719,554** |

Table 11 Anthropogenic PM2.5 PWAC (in μg m-3) (annual) and NO2 PWAC (in μg m-3) (annual) for Liverpool City Region (LCR), Birmingham City and Greater Manchester (GM)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Pollutant | Location | 2011 | 2015 for Birmingham/GM  2017 for LCR | 2020 | 2025 | 2030 |
| Anthropogenic PM2.5 PWAC\* | Liverpool City Region | 10.39 | 7.52 | 7.21 | 6.93 | 6.89 |
| Birmingham City | 12.82 | 9.81 | 9.21 | 9.02 | 8.99 |
| Greater Manchester | 11.39 | 8.09 | 7.62 | 7.47 | 7.44 |
| NO2 PWAC\* | Liverpool City Region | 18.97 | 15.11 | 13.38 | 11.31 | 10.22 |
| Birmingham City | 26.12 | 21.33 | 17.68 | 14.75 | 13.14 |
| Greater Manchester | 22.39 | 18.78 | 14.94 | 12.08 | 10.65 |

\*For Liverpool City Region: average of the PWAC by local authority from Table 1 and Table 2, above. For Birmingham City: average of the PWAC by constituency from Table 1 and Table 2 (Dajnak et al., 2019). For Greater Manchester, average of the PWAC by local authority from Table 1 and Table 2 (Dajnak et al., 2018).

Table 12 Total population in 2011 and mortality rate (total death age 30 plus divided by total population age 30 plus) in Liverpool City Region, Birmingham City and Greater Manchester

|  |  |  |
| --- | --- | --- |
| Location | Total population | Mortality rate  (age group 30 plus) |
|
| Liverpool City Region | 1,507,032 | 1.49% |
| Birmingham City | 1,073,188 | 1.33% |
| Greater Manchester | 2,682,727 | 1.36% |

*Loss of life expectancy still remaining after pollution improvements:* The influence of the difference in pollution concentrations and death rate between Liverpool City Region, Greater Manchester and Birmingham City can be seen more clearly in the results for loss of life expectancy from birth. This is because it comes from the total life years lost in those exposed for a lifetime divided by the size of that population. So, the difference in population has already been taken into account. The loss of life expectancy using PM2.5 as an indicator without a cut-off was 19/22 weeks (Female/Male) in Liverpool City Region, 21/24 weeks (Female/Male) in Greater Manchester and 25/29 weeks (F/M) in Birmingham City, close but somewhat higher in Greater Manchester and even higher in Birmingham City as with the concentrations (Table 11). The comparison was similarly close for life expectancy using NO2 without a cut-off as an indicator (12 – 13 weeks (LCR) compared with 12 – 14 weeks (GM) and 15-17 weeks in Birmingham). As with the previous discussions of total life years lost, the difference between Liverpool City Region, Greater Manchester and Birmingham City is more marked for PM2.5 with a cut-off than for NO2 with a cut-off because the cut-off of 7 µg m-3 is closer to the general concentrations in Liverpool City Region and Greater Manchester.

*Gains in life years from pollution improvements:* Similar factors influence the comparative results for life years gained between the three cities. As with the life years lost after the pollution improvements, the results for NO2 in Liverpool City Region and Birmingham City are about a third and half, respectively, of those in Greater Manchester, driven mainly by the LCR and Birmingham’s lower population but also furthermore by the lower pollution levels in LCR and by the NO2 and PM2.5 reductions in all three cities (Table 11), which also influence the answer. For PM2.5, the gains from PM2.5 reductions in the Liverpool City Region and Birmingham City are a bit less than half those in Greater Manchester.

*Mortality burden:* The mortality burden in Liverpool City Region (800-1,040 and 840 attributable deaths from multi-pollutant and single-pollutant model, respectively) is between that in Birmingham City (570-709 and 554 attributable deaths from multi-pollutant and single-pollutant model, respectively) and Greater Manchester (1,459 attributable deaths from single-pollutant model [[36]](#footnote-37)) and can be explained by the population, death rate (Table 12) and pollution level differences as above.

In all the cases discussed above, other factors may also be having an influence (see discussion of differences across local authorities in section 6.2).

Comparisons are more difficult with an earlier report in London (Walton *et al* 2015) as the methodology has changed to a greater extent and the time periods of the pollution changes are also different. The mortality burden result for the single pollutant model for PM2.5 was 3,537 deaths at typical ages for 2010 compared with 840 attributable deaths for Liverpool City Region for 2011. Again, this difference is primarily driven by the larger population in London (8 million vs 1.5 million, London vs LCR respectively).

In summary, this report shows the gains in life years from the projected pollution improvements but also that adverse health impacts will still remain. There is still justification for further pollution improvements beyond those already made, especially to tackle environmental inequality (in which socioeconomically disadvantaged populations are still among the most exposed).

## Ozone

The study from Williams et al. (2018a and 2018b) shows that ozone concentrations in 2035 and 2050 are projected to increase in winter because the removal of ozone by reaction with NO occurs to a lesser extent due to reductions in NOx emissions. So-called summer smog ozone concentrations are projected to decrease because of the reductions in emissions of ozone precursors. The Williams (2018a and 2018b) study found that the long-term ozone exposure metric recommended by WHO (2013) is projected to decrease over time compared with 2011. This outcome is a relatively small change compared with that for the other pollutants, due to the WHO threshold of 35 parts per billion and the effect being on respiratory mortality, not all cause mortality. Williams et al. (2018a and 2018b) also warned that the increased proportion of ozone in the mixture of oxidant gases, including NO2, is potentially of some concern because ozone has a higher redox potential than does NO2, and so could possibly increase the hazard from oxidative stress, although it is too early to be confident about this theory.

# Appendix

## Additional tables- method

Additional data such as the annualised economic impact and the loss of life expectancy lower and upper estimate and the full range of confidence interval with and without counterfactual for both PM2.5 and NO2 are available upon request to the authors.

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) and for the single-pollutant model aspect of burden calculations).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Pollutant | Averaging time | Hazard ratio per 10 μg m-3 | Confidence interval | Counterfactual | Comment/Source |
| PM2.5 | Annual average | 1.06 | 1.04-1.08  1.01-1.12\* | Zero  Or 7 μg m-3 | Age 30+, Anthropogenic PM2.5 (Hazard ratio COMEAP (2010) and COMEAP (2018))  Age 30+, total PM2.5 (cut-off reference COMEAP (2010)) |
| NO2 | Annual average | 1.023 | 1.008 – 1.037 | Zero  or 5 μg m-3 | Age 30+ (Hazard ratio COMEAP (2017), cutoff COMEAP (2018) |

\*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 long-term exposures and 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 |
| PM2.5 | Annual average | 1.029 (Jerrett)  1.033 (Fischer)  1.053 (Beelen)  1.019 (Crouse) | Zero  Or 7 μg m-3 | Age 30+, Anthropogenic PM2.5 (Hazard ratio COMEAP (2010) and COMEAP (2018))  Age 30+, total PM2.5 (cut-off reference COMEAP (2010)) |
| NO2 | 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 (2018) |

\*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 of health impact calculations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Concentrations | Concentration output for health impacts | Population by gender and age group | Population-weighting | Mortality data | Impact calculations |
| 1km | Ward | Ward | Ward to LA | Local authority | Sum of LA results |

## Additional tables - impact

Table 16 Life years lost by gender across the local authorities and Liverpool City Region population for anthropogenic PM2.5 (without cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Halton | Female | 52,031 | 35,122 | 68,527 | 35,803 | 24,145 | 47,199 |
| Halton | Male | 50,722 | 34,190 | 66,897 | 34,793 | 23,443 | 45,909 |
| Knowsley | Female | 60,263 | 40,663 | 79,399 | 41,910 | 28,257 | 55,262 |
| Knowsley | Male | 65,081 | 43,905 | 85,765 | 45,223 | 30,486 | 59,638 |
| Liverpool | Female | 189,113 | 127,598 | 249,180 | 135,443 | 91,321 | 178,593 |
| Liverpool | Male | 217,862 | 146,999 | 287,053 | 155,824 | 105,064 | 205,462 |
| St. Helens | Female | 67,298 | 45,404 | 88,678 | 44,356 | 29,901 | 58,498 |
| St. Helens | Male | 70,343 | 47,429 | 92,748 | 46,254 | 31,169 | 61,023 |
| Sefton | Female | 84,504 | 57,013 | 111,351 | 55,313 | 37,287 | 72,949 |
| Sefton | Male | 93,205 | 62,846 | 122,890 | 60,814 | 40,980 | 80,233 |
| Wirral | Female | 100,873 | 68,039 | 132,954 | 67,230 | 45,314 | 88,678 |
| Wirral | Male | 113,298 | 76,424 | 149,323 | 75,556 | 50,928 | 99,655 |
| Liverpool City Region | Female | 554,082 | 373,840 | 730,089 | 380,056 | 256,225 | 501,178 |
| Liverpool City Region | Male | 610,511 | 411,794 | 804,676 | 418,464 | 282,070 | 551,920 |
| Liverpool City Region | Total | 1,164,593 | 785,633 | 1,534,764 | 798,521 | 538,296 | 1,053,098 |

Table 17 Life years lost by gender across the local authorities and Liverpool City Region population for NO2 (without cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Halton | Female | 38,714 | 13,622 | 61,614 | 21,517 | 7,557 | 34,306 |
| Halton | Male | 37,702 | 13,239 | 60,119 | 20,833 | 7,310 | 33,244 |
| Knowsley | Female | 45,440 | 15,980 | 72,354 | 26,025 | 9,139 | 41,501 |
| Knowsley | Male | 49,002 | 17,228 | 78,048 | 28,016 | 9,836 | 44,681 |
| Liverpool | Female | 152,389 | 53,601 | 242,609 | 91,335 | 32,078 | 145,620 |
| Liverpool | Male | 176,279 | 62,007 | 280,628 | 106,021 | 37,238 | 169,026 |
| St. Helens | Female | 45,379 | 15,950 | 72,294 | 25,311 | 8,885 | 40,376 |
| St. Helens | Male | 47,420 | 16,654 | 75,604 | 26,352 | 9,247 | 42,050 |
| Sefton | Female | 53,064 | 18,648 | 84,555 | 32,522 | 11,416 | 51,878 |
| Sefton | Male | 58,752 | 20,631 | 93,683 | 35,906 | 12,598 | 57,297 |
| Wirral | Female | 66,291 | 23,291 | 105,651 | 37,393 | 13,123 | 59,661 |
| Wirral | Male | 74,708 | 26,251 | 119,056 | 42,176 | 14,803 | 67,288 |
| Liverpool City Region | Female | 401,276 | 141,091 | 639,077 | 234,104 | 82,197 | 373,342 |
| Liverpool City Region | Male | 443,862 | 156,009 | 707,137 | 259,303 | 91,031 | 413,585 |
| Liverpool City Region | Total | 845,138 | 297,100 | 1,346,214 | 493,408 | 173,228 | 786,928 |

Table 18 Central annualised economic impact estimate (in 2014 prices) across the local authorities and Liverpool City Region population for anthropogenic PM2.5 and NO2 (without cut-off)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 | | NO2 | |
| Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Central estimate | Central estimate | Central estimate | Central estimate |
| Halton | £60,639,406 | £42,141,079 | £45,094,744 | £25,787,169 |
| Knowsley | £73,518,783 | £51,663,304 | £55,388,988 | £32,736,848 |
| Liverpool | £236,248,303 | £170,709,549 | £190,782,123 | £117,714,285 |
| St. Helens | £81,910,856 | £54,626,160 | £55,218,777 | £31,778,737 |
| Sefton | £107,932,769 | £71,597,638 | £67,900,439 | £42,708,007 |
| Wirral | £128,506,802 | £86,866,219 | £84,589,333 | £49,356,927 |
| Liverpool City Region | £688,756,919 | £477,603,949 | £498,974,404 | £300,081,973 |

Table 19 Lower and upper annualised economic impact estimate (in 2014 prices) across the local authorities and Liverpool City Region population for anthropogenic PM2.5 and NO2 (without cut-off)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 | | NO2 | |
| Predicted concentration between 2011 and 2030 | | Predicted concentration between 2011 and 2030 | |
| Lower estimate | Upper estimate | Lower estimate | Upper estimate |
| Halton | £28,407,140 | £55,577,860 | £9,053,644 | £41,127,125 |
| Knowsley | £34,828,913 | £68,130,502 | £11,495,178 | £52,204,095 |
| Liverpool | £115,097,442 | £225,096,094 | £41,346,390 | £187,661,413 |
| St. Helens | £36,816,243 | £72,057,368 | £11,153,483 | £50,698,663 |
| Sefton | £48,253,096 | £94,447,428 | £14,988,113 | £68,140,201 |
| Wirral | £58,547,529 | £114,580,670 | £17,322,271 | £78,745,383 |
| Liverpool City Region | £321,950,363 | £629,889,922 | £105,359,079 | £478,576,880 |

Table 20 Life years lost by gender across the local authorities and Liverpool City Region for PM2.5 (with 7 μg m-3 cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Halton | Female | 20,045 | 13,506 | 26,447 | 3,292 | 2,217 | 4,347 |
| Halton | Male | 19,498 | 13,131 | 25,740 | 3,146 | 2,118 | 4,154 |
| Knowsley | Female | 23,596 | 15,897 | 31,136 | 4,719 | 3,177 | 6,231 |
| Knowsley | Male | 25,468 | 17,157 | 33,610 | 5,060 | 3,407 | 6,681 |
| Liverpool | Female | 69,767 | 47,000 | 92,070 | 14,790 | 9,958 | 19,529 |
| Liverpool | Male | 80,543 | 54,260 | 106,290 | 16,994 | 11,441 | 22,439 |
| St. Helens | Female | 26,074 | 17,566 | 34,408 | 2,793 | 1,881 | 3,688 |
| St. Helens | Male | 27,255 | 18,357 | 35,976 | 2,868 | 1,931 | 3,786 |
| Sefton | Female | 23,753 | 15,999 | 31,354 | 1,831 | 1,232 | 2,417 |
| Sefton | Male | 26,296 | 17,708 | 34,715 | 1,951 | 1,313 | 2,576 |
| Wirral | Female | 28,966 | 19,508 | 38,236 | 1,711 | 1,152 | 2,259 |
| Wirral | Male | 32,662 | 21,998 | 43,115 | 1,954 | 1,315 | 2,580 |
| Liverpool City Region | Female | 192,201 | 129,476 | 253,652 | 29,135 | 19,616 | 38,471 |
| Liverpool City Region | Male | 211,723 | 142,612 | 279,445 | 31,972 | 21,526 | 42,216 |
| Liverpool City Region | Total | 403,924 | 272,088 | 533,097 | 61,107 | 41,143 | 80,687 |

Table 21 Life years lost by gender across the local authorities and Liverpool City Region population for NO2 (with 5 μg m-3 cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Halton | Female | 29,402 | 10,335 | 46,840 | 12,151 | 4,264 | 19,389 |
| Halton | Male | 28,616 | 10,043 | 45,653 | 11,721 | 4,111 | 18,712 |
| Knowsley | Female | 34,834 | 12,240 | 55,512 | 15,367 | 5,392 | 24,523 |
| Knowsley | Male | 37,544 | 13,189 | 59,845 | 16,507 | 5,792 | 26,344 |
| Liverpool | Female | 117,805 | 41,400 | 187,710 | 56,584 | 19,857 | 90,284 |
| Liverpool | Male | 136,478 | 47,964 | 217,454 | 66,027 | 23,172 | 105,346 |
| St. Helens | Female | 33,464 | 11,752 | 53,355 | 13,345 | 4,681 | 21,302 |
| St. Helens | Male | 34,972 | 12,275 | 55,790 | 13,866 | 4,863 | 22,136 |
| Sefton | Female | 35,456 | 12,448 | 56,549 | 15,081 | 5,289 | 24,076 |
| Sefton | Male | 39,368 | 13,815 | 62,817 | 16,724 | 5,864 | 26,703 |
| Wirral | Female | 45,285 | 15,897 | 72,232 | 16,330 | 5,727 | 26,074 |
| Wirral | Male | 51,153 | 17,958 | 81,587 | 18,555 | 6,507 | 29,623 |
| Liverpool City Region | Female | 296,245 | 104,071 | 472,198 | 128,857 | 45,209 | 205,647 |
| Liverpool City Region | Male | 328,131 | 115,243 | 523,147 | 143,400 | 50,309 | 228,864 |
| Liverpool City Region | Total | 624,376 | 219,315 | 995,345 | 272,258 | 95,517 | 434,511 |

Table 22 Annualised economic impact (in 2014 prices) across the local authorities and Liverpool City Region population for PM2.5 and NO2 (with 7 μg m-3 and 5 μg m-3 cut-off for PM2.5 and NO2, respectively)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | PM2.5 | | NO2 | |
| Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Central estimate | Central estimate | Central estimate | Central estimate |
| Halton | £23,334,602 | £4,304,646 | £34,236,908 | £14,885,830 |
| Knowsley | £28,771,786 | £6,324,271 | £42,446,371 | £19,739,880 |
| Liverpool | £87,243,649 | £20,140,102 | £147,598,252 | £74,337,087 |
| St. Helens | £31,729,935 | £4,088,187 | £40,719,630 | £17,232,596 |
| Sefton | £30,388,493 | £2,941,600 | £45,432,329 | £20,442,921 |
| Wirral | £36,966,894 | £2,974,636 | £57,850,671 | £22,552,822 |
| Liverpool City Region | £238,435,359 | £40,773,443 | £368,284,161 | £169,191,136 |

Table 23 Loss of life expectancy by gender across the local authorities and Liverpool City Region from birth in 2011 for anthropogenic PM2.5 (without cut-off) and NO2 (without cut-off)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Zone | Gender | Loss of life expectancy from birth compared with baseline mortality rates, 2011 birth cohort followed for 105 years (weeks) | | | |
|  |  | Anthropogenic PM2.5 (without cut-off) | | NO2 (without cut-off) | |
|  |  | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Halton | Female | 31.7 | 21.4 | 23.6 | 12.3 |
| Halton | Male | 33.0 | 22.2 | 24.6 | 12.8 |
| Knowsley | Female | 31.1 | 21.2 | 23.5 | 12.6 |
| Knowsley | Male | 35.8 | 24.4 | 27.0 | 14.5 |
| Liverpool | Female | 31.0 | 21.9 | 25.0 | 14.2 |
| Liverpool | Male | 35.4 | 24.9 | 28.7 | 16.3 |
| St. Helens | Female | 30.4 | 19.6 | 20.6 | 10.7 |
| St. Helens | Male | 33.0 | 21.2 | 22.2 | 11.6 |
| Sefton | Female | 24.7 | 15.7 | 15.6 | 9.0 |
| Sefton | Male | 29.4 | 18.7 | 18.6 | 10.7 |
| Wirral | Female | 24.9 | 16.2 | 16.4 | 8.6 |
| Wirral | Male | 29.4 | 19.1 | 19.4 | 10.2 |
| Liverpool City Region | Female | 28.8 | 19.4 | 21.0 | 11.5 |
| Liverpool City Region | Male | 32.7 | 22.0 | 23.8 | 13.1 |

Table 24 Loss of life expectancy by gender across the local authorities and Liverpool City Region from birth in 2011 for anthropogenic PM2.5 (with 7 μg m-3 cut-off) and NO2 (with 5 μg m-3 cut-off)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Zone | Gender | Loss of life expectancy from birth compared with baseline mortality rates, 2011 birth cohort followed for 105 years (weeks) | | | |
|  |  | Anthropogenic PM2.5 (with 7 μg m-3 cut-off) | | NO2 (with 5 μg m-3 cut-off) | |
|  |  | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Halton | Female | 12.2 | 1.5 | 17.9 | 6.6 |
| Halton | Male | 12.7 | 1.6 | 18.7 | 6.8 |
| Knowsley | Female | 12.2 | 2.0 | 18.0 | 7.1 |
| Knowsley | Male | 14.0 | 2.3 | 20.7 | 8.1 |
| Liverpool | Female | 11.5 | 2.0 | 19.4 | 8.5 |
| Liverpool | Male | 13.1 | 2.3 | 22.2 | 9.8 |
| St. Helens | Female | 11.8 | 0.8 | 15.2 | 5.3 |
| St. Helens | Male | 12.8 | 0.8 | 16.4 | 5.7 |
| Sefton | Female | 7.0 | 0.2 | 10.4 | 3.9 |
| Sefton | Male | 8.3 | 0.3 | 12.4 | 4.7 |
| Wirral | Female | 7.2 | 0.1 | 11.2 | 3.4 |
| Wirral | Male | 8.5 | 0.2 | 13.3 | 4.1 |
| Liverpool City Region | Female | 10.1 | 1.2 | 15.5 | 6.0 |
| Liverpool City Region | Male | 11.4 | 1.3 | 17.6 | 6.9 |

## Additional tables – burden

Table 25 Estimated burden (from single-pollutant model summary estimate with wider estimates of uncertainty) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 (with and without cut-off)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 (without cut-off) | | | Anthropogenic PM2.5 (with cut-off) | | |
| Attributable deaths | | | Attributable deaths | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Halton | 67 | 12 | 127 | 26 | 5 | 51 |
| Knowsley | 83 | 15 | 157 | 33 | 6 | 64 |
| Liverpool | 251 | 44 | 474 | 94 | 16 | 181 |
| St. Helens | 103 | 18 | 195 | 41 | 7 | 78 |
| Sefton | 158 | 28 | 299 | 44 | 8 | 85 |
| Wirral | 177 | 31 | 336 | 52 | 9 | 100 |
| Liverpool City Region | 839 | 147 | 1,587 | 290 | 50 | 558 |

Using COMEAP’s recommended concentration-response coefficient of 1.06 per 10 μg m-3 of anthropogenic PM2.5 for the central estimate (lower estimate RR of 1.01 and upper estimate RR 1.12)

Table 26 Estimated burden (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (with cut-off), total population in each local authority in 2011, mortality rate (total death age 30 plus divided by total population age 30 plus) in each local authority, ratio of the population age 65 and above over the total population in each local authority and deprivation index Carstairs quintiles[[37]](#footnote-38)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 and NO2  (without cut-off) | Total population | Mortality rate  (age group 30 plus) | Ratio Population above 65 when compared with total population | Carstairs quintile |
| Attributable deaths (using coefficients derived from information in 4 studies below\*) |
| Halton | 66 - 85 | 125,769 | 1.35% | 15% | 3.9 |
| Knowsley | 82 - 105 | 145,909 | 1.43% | 16% | 4.5 |
| Liverpool | 260 - 322 | 466,440 | 1.50% | 14% | 4.6 |
| St. Helens | 95 - 126 | 175,315 | 1.41% | 18% | 3.9 |
| Sefton | 138 - 188 | 273,799 | 1.58% | 21% | 3.7 |
| Wirral | 161 - 214 | 319,800 | 1.53% | 19% | 3.6 |

\*Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

\*Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Table 27 Estimated burden (from multi pollutant study) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (without cut-off)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5  (without cut-off)  (not to be used separately) | | | | NO2  (without cut-off)  (not to be used separately) | | | | Anthropogenic PM2.5 and NO2  (without cut-off)  (combined estimate has less uncertainty) | | | |
| Attributable deaths | | | | Attributable deaths | | | | Attributable deaths | | | |
| Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse |
| Halton | 34 | 38 | 60 | 22 | 42 | 36 | 25 | 44 | 76 | 74 | 85 | 66 |
| Knowsley | 41 | 47 | 74 | 27 | 53 | 44 | 31 | 55 | 94 | 91 | 105 | 82 |
| Liverpool | 125 | 142 | 223 | 83 | 169 | 143 | 99 | 177 | 294 | 285 | 322 | 260 |
| St. Helens | 51 | 58 | 92 | 34 | 58 | 49 | 34 | 61 | 109 | 107 | 126 | 95 |
| Sefton | 78 | 89 | 140 | 52 | 82 | 69 | 48 | 86 | 160 | 158 | 188 | 138 |
| Wirral | 88 | 100 | 157 | 58 | 98 | 83 | 57 | 103 | 186 | 183 | 214 | 161 |
| Liverpool City Region | 418 | 474 | 746 | 276 | 502 | 424 | 294 | 527 | 920 | 898 | 1040 | 803 |

Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Table 28 Estimated burden (from multi pollutant study) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (with cut-off)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5  (with cut-off)  (not to be used separately) | | | | NO2  (with cut-off)  (not to be used separately) | | | | Anthropogenic PM2.5 and NO2  (with cut-off) | | | |
| Attributable deaths | | | | Attributable deaths | | | | Attributable deaths | | | |
| Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse |
| Halton | 13 | 15 | 23 | 9 | 32 | 27 | 19 | 34 | 45 | 42 | 42 | 43 |
| Knowsley | 16 | 19 | 29 | 11 | 40 | 34 | 24 | 43 | 56 | 53 | 53 | 54 |
| Liverpool | 46 | 53 | 83 | 31 | 131 | 111 | 77 | 138 | 177 | 164 | 160 | 169 |
| St. Helens | 20 | 23 | 36 | 13 | 43 | 36 | 25 | 45 | 63 | 59 | 61 | 58 |
| Sefton | 22 | 25 | 39 | 14 | 55 | 46 | 32 | 57 | 77 | 71 | 71 | 71 |
| Wirral | 26 | 29 | 46 | 17 | 67 | 57 | 39 | 71 | 93 | 86 | 85 | 88 |
| Liverpool City Region | 143 | 162 | 257 | 94 | 368 | 311 | 215 | 387 | 511 | 473 | 472 | 481 |

Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

## Additional Health and economic assessment methods

*Anthropogenic PM2.5*: Non-anthropogenic PM2.5 was derived by subtracting the modelled contribution from natural sources – here sea-salt - from the total PM2.5 modelled as above to give anthropogenic PM2.5.

*Population data in LCR:* 2011 census data by ward by 5 year age group and gender (ONS, 2012) was split into 1 year age groups using the age ratios from single year of age and gender population data, by LSOA, for mid-2012 (ONS, 2016a).

*Deaths data in LCR*: Deaths data by gender and 5 year age group by ward for 2011 was obtained on request from ONS (ONS, 2016b). It was scaled to 1 year age groups using age group ratios from data by LSOA by single year of age and gender for mid-2014 (ONS, 2016c). Ward data was then aggregated up to local authority level.

Mortality Burden

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

Using the COMEAP (2010)/Gowers *et* al (2014) methodology as the first example, the relative risk (RR) per 10 μg m-3 was scaled to a new relative risk for the relevant anthropogenic PM2.5 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.

The attributable fraction was then multiplied by the number of deaths in the relevant gender and 5-year age group aged 30+ 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 each ward.

The calculations above were done at ward level and the results for deaths summed to give a total for each local authority. This allows different death rates in different wards and local authority 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 PM2.5.

The COMEAP (2018a) methodology uses the above method for PM2.5 but also calculates a result using a single-pollutant model relative risk for NO2 and a result combining multi-pollutant model estimates for NO2 and PM2.5.

The method for the single-pollutant model calculation for NO2 is exactly analogous to that above for PM2.5 except that the relative risk used is 1.023 (1.008 – 1.037) and the cut-off where used is 5 μg m-3 NO2.

The method using multi-pollutant model results is also based on the same method for scaling the relevant relative risks (see Table 10) according to the relevant pollution concentration. In this case though, there are more calculations (16) because calculations are done separately for each pollutant for relative risks derived from each of 4 studies, both with and without the relevant cut-off for each pollutant. There is also an additional step in that the NO2 and PM2.5 results within each study are summed and then the final result expressed as the range for the sums across the 4 studies. This can be illustrated by examining Table 26 and Table 27 (with and without the cut-offs). It can be seen for Halton, for example, that the sum of column 2 (34 attributable deaths) and column 6 (42 attributable deaths) leads to the result in column 10 (76 attributable deaths). In this example, the results in columns 2 and 6 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.

Mortality Impact

*Projections for the baseline life tables before applying concentration changes*

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

Changes in births over time – actual data on numbers of births in each local authority was used from 2011-2015(ONS, 2016d), birth projections by local authority were used from 2016 to 2033 (ONS, 2016e) and the ratio of birth projections to 2039 births for England obtained from national populations projections (ONS, 2015a) was used to scale 2039 births in local authorities to local authority births for 2040 to 2114. No projections were available after 2114 so births were left constant for 2115 to 2134.

Mortality rate improvements were applied to the 2011 all-cause hazard rates according to the projected % improvements per year provided by ONS. Percentage improvements for different example ages are provided in Office for National Statistics (ONS, 2015b); we requested the full set of percentage improvements from ONS.

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

*Lags*: The approach allowed for a delay between exposure and effect using the recommended distribution of lags from COMEAP (COMEAP, 2010) i.e. 30% of the effect in the first year, 12.5% in each of years 2-5 and 20% spread over years 5-20. An analogous approach was used for the effects of long-term exposure to NO2. HRAPIE (WHO, 2013) recommended that, in the absence of information on likely lags between long-term exposure to NO2 and mortality, calculations should follow whatever lags are chosen for PM2.5.

*Calculations*

The relative risk (RR) per 10 μg m-3 was scaled to a new relative risk for the appropriate population-weighted mean for each gender in each local authority for each scenario and year. The equation used (for the example coefficient of 1.06) was: RR(x) = 1.06x/10 where x is the concentration of interest (with a negative sign for a reduction). Concentrations were assumed to reduce linearly between the years in which modelled concentrations were available (2011, 2017, 2020, 2025, 2030). The scaled RR was then used to adjust the all-cause hazard rates in the life table calculations.

For the 5 μg m-3 cut-off for NO2, ward concentrations were interpolated between 2011, 2017, 2020, 2025 and 2030 and 5 μg m-3 was then subtracted from the ward concentrations in each year. Any resulting negative concentrations were then set to zero before all the ward concentrations were population-weighted to local authority level as normal.

Life table calculations were programmed in SQL based on the methods used in the standard IOMLIFET spreadsheets 132 with the following amendments:

* Extension to 2134 (105 years after 2030)
* Adjustment of the baseline hazard rates over time according to projected mortality rate improvements
* Inclusion of changes in numbers of births over time
* IOMLIFET excludes neonatal deaths. We included neonatal deaths and followed the South East Public Health Observatory life-expectancy calculator[[38]](#footnote-39) and Gowers et al. (2014) in taking into account the uneven distribution of deaths over the course of the first year when calculating the survival probability. (The survival probability (the ratio of the number alive at the end of the year to the number alive at the beginning) is derived by the equivalent of adding half the deaths back onto the mid-year population to give the starting population and subtracting half the deaths from the mid-year population to give the end population, assuming deaths are distributed evenly across the year. This is not the case in the first year where a weighting factor based on 90% of the deaths occurring in the first half of the year and 10% in the second half is used instead. After rearrangement the actual formula is (1- 0.1 x hazard rate)/(1+ 0.9 x hazard rate) rather than the (1- 0.5 x hazard rate)/(1+ 0.5 x hazard rate) used in other years.)

Results for total and annual life years lost by local authority were then summed to LCR level. We also used the life tables to calculate changes in life expectancy.

Economic valuation[[39]](#footnote-40)

The approach taken here is based on the discipline of environmental economics (ExternE, 2005). Environmental economics was developed partly in response to recognition of the externalities, or external costs, posed by various human activities. ‘Externalities’ are unforeseen effects that arise from action that benefits one party generally to the detriment of others, when those effects are external, or not considered, in the decision-making process. Notable examples include the loss of utility from effects of air pollution arising from power generation or transport. The question faced by the economist in this situation is not how to allocate a defined amount of resource (the health service budget), but how much should be spent to mitigate externalities. This requires that health impacts are monetised in order that the benefits of action can be compared directly with the costs in a benefit-cost analysis.

Several approaches have been taken to value mortality impacts (the impacts that dominate the assessment made in this report), though all seek to quantify public preference, demonstrating consistency in objective with the health economics work in deriving QALYs for various conditions. The methods used for valuing a death fall into three categories:

Wage-risk studies, which consider the additional wage demanded of people working in risky occupations, providing an estimate of willingness to accept (WTA) risk.

Consumer market studies, that consider the willingness of individuals to pay (WTP) for equipment that will reduce their risk of death. Several studies were carried out on car safety equipment (air bags, etc.) before they were made mandatory.

Contingent valuation (CV) surveys, where individuals are asked for their WTP for treatments that will reduce the risk of a health impact of some kind, or of dying within X years.

Early work in this field was affected by various biases. Considerable effort has been taken over the last three decades to identify these biases and refine CV approaches to reduce them, with some success.

In the context of health valuation, the underlying calculations are similar whichever of the three methods just mentioned is used. In the case of the wage risk studies, for example, it may be observed that construction workers operating at height will accept an additional risk of death annually of 1 in 1,000 (0.001), for an additional wage of £1000. The value of statistical life (VSL) calculated from these figures would be £1000/0.001 - £1,000,000. A review by OECD gives an averaged VSL for EU Member States of €3million. UK Government, via the Department for Transport, adopts a value that is lower by about 40% of £1.56 million (DfT, 2017).

Opinion is divided as to whether valuation of mortality should concern ‘deaths’ or ‘life years lost’. The OECD is firmly committed to use of the VSL (OECD, 2012). UK government, through the Interdepartmental Group on Costs and Benefits, however, values mortality in terms of the loss of life expectancy expressed as the ‘Value of a Life Year’ (VOLY), taking a value of £36,379 in 2014 prices. The basic approach to quantification, however, is the same, with values elicited against a change in the risk of a health outcome, in this case, the loss of a life year. The large difference between the unit values for VSL and VOLY is partly mitigated in subsequent analysis by the number of life years lost being about 10 times higher than the number of deaths. However, the UK government position generates estimates of air pollution damage that are significantly lower than estimates made using the OECD position. Given that the UK government position is followed here, results should be considered to be at the conservative end of plausible ranges.

Similar calculations can be made to assess the WTP to avoid ill health more generally, such as development of respiratory or cardiovascular disease. The total impact for morbidity has a number of elements:

WTP to avoid lost utility (being well, and enjoying the opportunities that good health offers)

Adopted values, discounting and uplift

The values of most relevance concern acute and chronic mortality, as these have been shown by numerous studies to dominate the CBA. The value of a lost year of life to chronic exposure as applied in the current analysis is £36,379, assuming that it reflects the loss of a year of life in ‘normal health’ taken from the guidance issued by Defra (2019).

It is important to factor the time at which impacts occur into the analysis for two reasons. The first is that values should be uplifted for future years to capture the likely effect of (anticipated) growth in incomes on WTP for health protection. The second, opposing effect, concerns the need to discount future values on the basis that money or goods are more valuable now than at some point in the future. There are several reasons for this. One is that resource available now can be used to increase the availability of resource in the future. An obvious example concerns investment in infrastructure projects that facilitate economic development. Along similar lines, investment in health research may lead to the development of cures or treatments for illnesses in the future. Further information can be found in Guidance from Her Majesty’s Treasury in the ‘Green Book’ (HMT, 2018).

The Green Book recommends the use of declining discount rates for effects quantified over prolonged periods. However, the impact of using declining discount rates in line with the HMT recommendation, rather than constant discount rates, will be minimal as they apply only after 30 years have passed, by which time values are reduced by two thirds. The impact of the declining rates will clearly increase over time, though the rate of decline (see Table 29) is so slight this will still make little difference.

Table 29 Schedule of declining long-term discount rates from HMT, 2018

|  |  |
| --- | --- |
| Period of years | Discount rate |
| 0 – 30 | 3.5% |
| 31 – 75 | 3.0% |
| 76 – 125 | 2.5% |
| 126 – 200 | 2.0% |
| 201 – 300 | 1.5% |
| 301+ | 1.0% |

The government guidance (HMT, 2019) recommends that future values should be uplifted at 2% per annum given that “It is expected that as people’s incomes rise, so too does their willingness to pay to reduce health risks such as those associated with air pollution.” However, it is unclear whether the uplift of 2% is still appropriate. It is notable that it was first developed before the economic crash of 2008, and so does not account for any change in growth since that time. However, the present analysis is based on a long time-frame, so short-term perturbations to growth seem likely to be factored out in the longer term.

Inequality is not factored explicitly into the economic analysis, beyond the acceptance of a national average estimate for mortality valuation (in other words, the values of disadvantaged groups are not down rated to reflect a likely lower WTP linked to reduced ability to pay).

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1. Air quality annual status and air quality plan reports show that some parts of Liverpool City Region have been in breach of both the national air quality objective for NO2 and the World Health Organisation guideline for PM2.5. [↑](#footnote-ref-2)
2. COMEAP – the Committee on the Medical Effects of Air Pollutants is a national expert Committee advising Government on the health effects of air pollution. Their recommendations for quantification are usually used in Government cost-benefit analysis of policies to reduce air pollution. [↑](#footnote-ref-3)
3. <https://uk-air.defra.gov.uk/data/laqm-background-maps> [↑](#footnote-ref-4)
4. It is not possible to calculate the full result for gains in life expectancy until everyone in the initial population has died (105 years from 2030), necessitating follow-up for a life-time even if the pollution changes are only for the next decade or so. [↑](#footnote-ref-5)
5. 2011 and 2017 concentrations representing current reference years and any future years up to 2030 have been estimated from the 2017 baseline. [↑](#footnote-ref-6)
6. The range is according to whether indicator pollutant is taken as PM2.5 or NO2, whether or not there is a cut-off concentration below which no effects are assumed and gender. [↑](#footnote-ref-7)
7. From 2030, so the total time period was 2011-2134. [↑](#footnote-ref-8)
8. The monetary value comes from a survey asking 170 members of the public how much they would be willing to pay to reduce their risk of experiencing a loss of one month of life (in good health) due to air pollution. NHS costs and loss of productivity are not included. [↑](#footnote-ref-9)
9. The original studies were analysed in terms of ‘time to death’ aggregated across the population. Strictly, it is unknown whether this total change in life years was from a smaller number of deaths fully attributable to air pollution or a larger number of deaths to which air pollution partially contributed. The former is used with the phrase ‘equivalent’ to address this issue. See COMEAP (2010) for a fuller discussion. [↑](#footnote-ref-10)
10. See Table 11 for details of Anthropogenic PM2.5 PWAC (in μg m-3) (annual) and NO2 PWAC (in μg m-3) (annual) for Liverpool City Region (LCR), Birmingham City and Greater Manchester (GM) [↑](#footnote-ref-11)
11. Cut-off is a term used for the concentration below which it is unclear whether or not epidemiological evidence supports the existence of an effect. This does not mean there is no effect below the cut-off, just that the numbers of data points are too small to be sure one way or the other. In addition, this cut-off is based on Pope et al (2002) which in turn used particulate concentrations from many years earlier. As concentrations reduce and newer studies are completed, it is often found that the health effects at lower concentrations become clearer as there are more data points available for analysis at these lower concentrations. [↑](#footnote-ref-12)
12. Defra (2019) Impact Pathways Approach Guidance for Air Quality Appraisal [↑](#footnote-ref-13)
13. HM Treasury (2018) The Green Book [↑](#footnote-ref-14)
14. <https://recycleformerseyside.com/in-your-area/> [↑](#footnote-ref-15)
15. <https://www3.halton.gov.uk/Pages/planning/pdf/airquality/AirQualityReview2018.pdf> [↑](#footnote-ref-16)
16. <https://www.knowsley.gov.uk/knowsleycouncil/media/Documents/2018-Annual-Status-Report.pdf> [↑](#footnote-ref-17)
17. <https://liverpool.gov.uk/council/strategies-plans-and-policies/environment-and-planning/liverpools-clean-air-plan/> [↑](#footnote-ref-18)
18. <https://www.sthelens.gov.uk/media/10448/asr_2018-final-signed.pdf> [↑](#footnote-ref-19)
19. <https://uk-air.defra.gov.uk/assets/documents/no2ten/2017-zone-plans/AQplans_UK0006.pdf> [↑](#footnote-ref-20)
20. <https://www.wirral.gov.uk/sites/default/files/all/environmental%20problems/Pollution/Wirral%20ASR%202018.pdf> [↑](#footnote-ref-21)
21. Total air pollution concentration instead of subset air pollution data such as secondary, residual concentrations… [↑](#footnote-ref-22)
22. Population-weighting average concentration (PWAC): The ward concentrations were multiplied by the population aged 30 plus and the resulting product summed across all wards in each local authority then divided by the local authority population. [↑](#footnote-ref-23)
23. [https://en.wikipedia.org/wiki/Liverpool\_City\_Region#/media/File:Liverpool\_city\_region.png](https://recycleformerseyside.com/in-your-area/) [↑](#footnote-ref-24)
24. It is possible that this cut-off will be defined at a value lower than 7 μg m-3 in the future as this is based on a 2002 study by Pope et al (2002) which in turn used particulate concentrations from many years earlier. As concentrations reduce and newer studies are completed, it is often found that the health effects at lower concentrations become clearer as there are more data points available for analysis at these lower concentrations. The concentration-response function and its confidence intervals have been updated using a 2013 meta-analysis (the central estimate happened to remain the same). The cut-off has not so far been updated to reflect the range of the data in the meta-analysis. [↑](#footnote-ref-25)
25. Particle traps/DPF already reduced most PM exhaust emissions form Traffic [↑](#footnote-ref-26)
26. This is certainly true for estimates based on the interquartile range within an individual study. However, application to situations where the ratio between the interquartile ranges for the two pollutants differs from that in the original study may exaggerate the contribution of one pollutant over another. The views of COMEAP members differed on how important this issue might be in practice, with the majority considering that a recommended approach on the basis of combined multi-pollutant model estimates could still be made provided caveats were given. [↑](#footnote-ref-27)
27. 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 as presented in the next section. [↑](#footnote-ref-28)
28. Some further cohort studies were omitted because of high correlations between pollutants (see COMEAP (2018a) [↑](#footnote-ref-29)
29. From the 95% confidence interval around the coefficient. [↑](#footnote-ref-30)
30. From the 95% confidence interval around the coefficient. [↑](#footnote-ref-31)
31. More fully ‘results equivalent to xx attributable deaths at typical ages’. [↑](#footnote-ref-32)
32. Note the letters defined location can be found in top map of Figure 6. [↑](#footnote-ref-33)
33. Note that IMD has seven thematic domains: income deprivation, employment deprivation, education skills and training deprivation, health deprivation and disability, crime, barriers to housing and services and living environment deprivation(LED). LEV falls into two sub-domains: indoor environment and outdoor environment containing measures of air quality and road traffic accidents. The IMD for LCR local authorities follows a similar order compared with the deprivation index Carstairs quintiles (which does not include air quality) compiled for LCR local authorities in Table 26. [↑](#footnote-ref-34)
34. <https://liverpool.gov.uk/media/10001/1-imd-2015-executive-summary.pdf> [↑](#footnote-ref-35)
35. The red areas show the LSOAs within the most deprived one per cent nationally, the areas of dark blue show the LSOAs within the most deprived ten per cent nationally and the areas of light blue show the LSOAs within the most deprived ten to twenty per cent nationally. <https://liverpool.gov.uk/media/10001/1-imd-2015-executive-summary.pdf> [↑](#footnote-ref-36)
36. Multi-pollutant model results not available for Greater Manchester [↑](#footnote-ref-37)
37. Acknowledgement to Dr Daniela Fecht (Imperial College London) for formatting Carstair Quintiles data by Wards

    <https://www.researchgate.net/publication/6817786_Measuring_deprivation_in_England_and_Wales_using_2001_Carstairs_scores> [↑](#footnote-ref-38)
38. <https://webarchive.nationalarchives.gov.uk/20130329125326/http://www.lho.org.uk/viewResource.aspx?id=8943&sUri=http%3a%2f%2fwww.sepho.org.uk%2f> [↑](#footnote-ref-39)
39. Much of this section is sourced from text written by Mike Holland in Williams et al (2018b). [↑](#footnote-ref-40)