Birmingham City Health and Economic Impact Assessment study

For: UK:100

By: David Dajnak, Heather Walton and James David Smith

Final Report

Address: Environmental Research Group, School of Analytical, Environmental and Forensic Sciences , King's College London, Franklin-Wilkins Building, 150 Stamford Street, London, SE1 9NH, United Kingdom.
Tel: +44 207 848 4009, **email:** heather.walton@kcl.ac.uk
Web: https://www.kcl.ac.uk/lsm/research/divisions/aes/research/ERG/index.aspx
London monitoring: http://www.londonair.org.uk/LondonAir/Default.aspx

Table of Contents

1.0 Executive Summary and Key results

UK100 commissioned Kings College London (King's) to produce a health and economic impact assessment associated with current[1] and future pollution levels in Birmingham City. In this study, King's combined the relationships between Defra's Air Quality modelling concentrations and health outcomes for each parliamentary constituency in Birmingham. King's has previously carried out similar mortality burden calculations for London and Greater Manchester but to our knowledge this is the first time that the new burden recommendations (COMEAP, 2018a)[2] that include a combined $PM_{2.5}$ and NO_2 approach have been applied in practice in a large city area[3]. The calculations relate to deaths or loss of life expectancy from all causes rather than separately for specific causes or for cases of specific illnesses.

Mortality impact (long –term exposure)

The population in Birmingham would gain around 440,000 life years over a lifetime to 2134[4] if air pollution concentrations improved as projected from 2011 to 2030[5], compared with remaining at 2011 concentrations. The average life expectancy of a child born in Birmingham in 2011 would improve by around 2.5 to 4 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 after these air pollution changes in Birmingham (a life year is one person living for one year). Put another way, children born in 2011 are still estimated to die 2-7 months early[6] on average, if exposed over their lifetimes to the projected future air pollution concentrations in Birmingham. Males are more affected than females. This is due to the fact that men have higher death rates and die earlier than women

The report provides figures for both $PM_{2.5}$ and NO_2 separately but then uses one or the other as the best indicator pollutant rather than adding results together to avoid large overestimation (details in the report below). The 'best indicator' approach may result in a small underestimate.

Economic costs

[1] Birmingham air quality annual status report (2018) shows that Birmingham has been in breach of both the national air quality objective for NO_2 and the World Health Organization guideline for $PM_{2.5}$.
https://www.birmingham.gov.uk/downloads/file/11938/air_quality_annual_status_report_2018_containing_data_for_2017

[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.

[3] Mortality burden calculations for the UK, England, Wales, Scotland and Northern Ireland can be found in the COMEAP (2018) report itself.

[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.

[5] 2011 and 2015 concentrations representing current reference years and any future years up to 2030 have been estimated from the 2015 baseline. Note that the government data projections to 2030 were produced before the Birmingham Clean Air Zone was proposed

[6] The range is according to whether indicator pollutant is taken as $PM_{2.5}$ or NO_2, whether or not there is a cut-off concentration below which no effects are assumed and gender (Table 4 in report).

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. 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.

The monetized benefits over a lifetime[7] of improvements to future anthropogenic $PM_{2.5}$ and NO_2 concentrations, compared with 2011 concentrations remaining unchanged, has been estimated to be up to £240 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 Birmingham over a lifetime are still between £190 - £470 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. 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 (for avoiding 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 analyzing 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 Birmingham the equivalent of[8] between 570 to 709 deaths are estimated to be attributable to air pollution (anthropogenic $PM_{2.5}$ and NO_2). These deaths occur mostly at older ages, as is typical for deaths in the general population.

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

The results for both life years lost after pollution improvements and attributable deaths from 2011 are smaller than the results for Greater Manchester from a 2018 report, primarily due to the smaller population in the smaller area of Birmingham city (around 1 million compared with 2.7 million for Greater Manchester). But they are not as much smaller as the population would predict due to higher pollution concentrations in Birmingham City. This also shows in the fact that the loss of life

[7] From 2030, so the total time period was 2011-2134.

[8] 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.

expectancy (which is independent of population) is greater in Birmingham than in Manchester. Gains in life years are smaller in Birmingham City than in Greater Manchester, again mainly due to population and the similar proportional 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 Birmingham city area. Reductions in emissions will also have benefits for air pollution concentrations in the wider region (the West Midlands and beyond). For example, reductions in NO_x emissions will reduce nitrate concentrations and thus $PM_{2.5}$ 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 city itself.

There will be further impacts from ozone concentrations. 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 NO_2 and $PM_{2.5}$.

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.

2.0 Introduction

UK100 has asked King's College London (King's) to help produce an Health Impact assessment (HIA) and economic assessment of Birmingham City (Birmingham) formed of ten parliamentary constituencies (constituencies) (Edgbaston, Erdington, Hall Green, Hodge Hill, Ladywood, Northfield, Perry Barr, Selly Oak, Yardley and Sutton Coldfield). To do this, King's first downloaded the air quality data in Birmingham, 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 constituency.

3.0 Method

3.1 Air Quality data

From 1kmx1km grid data to ward concentration

To create maps of annual average air quality ($PM_{2.5}$ and NO_2) for Birmingham, King's downloaded air quality data from the DEFRA Local Air Quality Management webpages (https://uk-air.defra.gov.uk/data/laqm-background-maps). Specifically, we downloaded $PM_{2.5}$ and NO_2 data for the regions of 'Midlands' for the year 2011, and for the years 2015 to 2030. The 2011 data were downloaded from the 2011 model predictions, and the 2015 to 2030 data were downloaded from the 2015 model predictions. Using these data of regular 1km by 1km pollutant points we then created a raster layer (for every year and pollutant) in 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 constituency 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 constituency and then divided by the constituency population. The constituency population-weighted means were then used directly in the health impact calculations across all constituencies. (This process allows one health calculation per constituency rather than calculations in each separate ward). A map of Birmingham parliamentary constituencies can be found in Figure 1.

3.2 Health assessment

It is now well established that adverse health effects, including mortality, are statistically associated with outdoor ambient concentrations of air pollutants. Moreover, toxicological studies of potential mechanisms of damage have added to the evidence such that many organisations (e.g. US Environmental Protection Agency; 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 10, Table 11 and Table 12 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 $PM_{2.5}$ (COMEAP, 2010). The new COMEAP report considers whether there is an additional burden or impact from nitrogen dioxide or other pollutants with which it is closely correlated.

Results are given with and without a cut-off[9] of 5 $\mu g\ m^{-3}$ for NO_2 and 7 $\mu g\ m^{-3}$ for $PM_{2.5}$.

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.

3.3 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 King's College London on the health impacts of air pollution in London (Walton et al., 2015) and in King's latest NIHR report (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[10], 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.[11] 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.

[9] 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.
[10] Defra (2019) Impact Pathways Approach Guidance for Air Quality Appraisal
[11] HM Treasury (2018) The Green Book

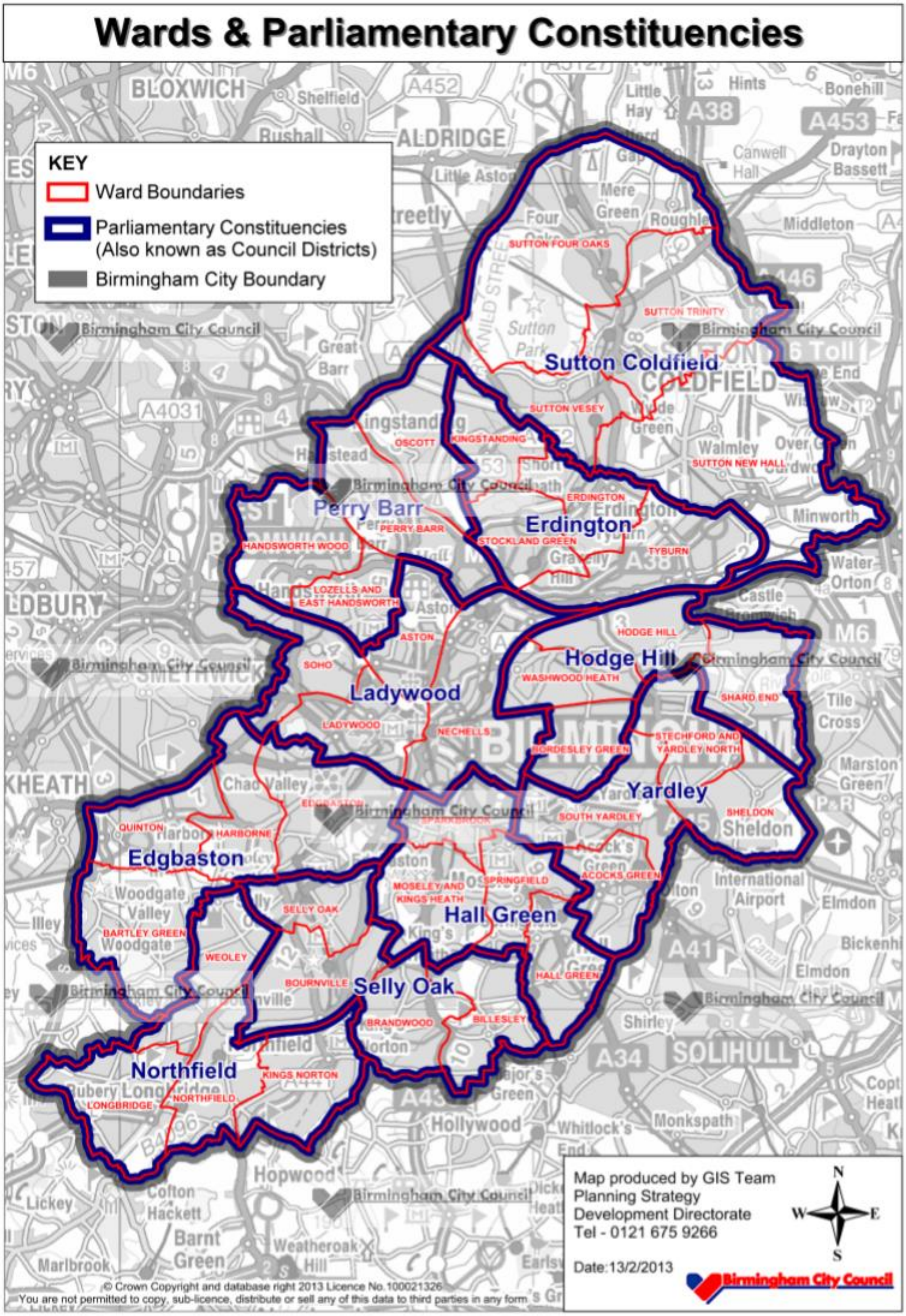

Figure 1 Map of Birmingham's parliamentary constituencies[12]

[12] https://www.birmingham.gov.uk/downloads/file/4604/map_birmingham_constituencies

4.0 Air Quality modelling

2011 and 2015 concentrations representing current reference years and any future years up to 2030 have been estimated from the 2015 baseline[13]. Birmingham air quality annual status report (2018) shows that Birmingham has been in breach of both the national air quality objective for NO2 and the World Health Organization guideline for $PM_{2.5}$ (https://www.birmingham.gov.uk/downloads/file/11938/air_quality_annual_status_report_2018_containing_data_for_2017). 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 source of pollution and on how pollutant concentrations change over time.
A summary of the population-weighted average concentration (PWAC) between 2011 and 2030 in each constituency is shown in Table 1 and Table 2 for anthropogenic $PM_{2.5}$ and NO_2, respectively.

Table 1 Anthropogenic $PM_{2.5}$ PWAC (in µg m^{-3}) (annual) by constituency

Local authority	2011	2015	2020	2025	2030
Edgbaston	12.21	9.35	8.79	8.61	8.56
Erdington	13.58	10.38	9.75	9.55	9.52
Hall Green	12.57	9.61	9.02	8.83	8.79
Hodge Hill	13.41	10.11	9.49	9.31	9.27
Ladywood	14.24	11.02	10.29	10.10	10.08
Northfield	11.60	8.96	8.43	8.25	8.21
Perry Barr	13.58	10.52	9.88	9.69	9.67
Selly Oak	12.00	9.15	8.60	8.42	8.38
Yardley	12.91	9.73	9.13	8.95	8.91
Sutton Coldfield	12.08	9.24	8.70	8.52	8.48

Table 2 NO_2 PWAC (in µg m^{-3}) (annual) by constituency

Local authority	2011	2015	2020	2025	2030
Edgbaston	23.34	18.69	15.46	12.66	11.14
Erdington	29.66	23.89	19.67	16.22	14.35
Hall Green	24.87	20.88	17.33	14.49	12.92
Hodge Hill	28.63	23.99	20.04	16.98	15.26
Ladywood	32.54	28.03	23.29	19.60	17.54
Northfield	20.89	16.38	13.59	11.24	9.95
Perry Barr	29.55	23.45	19.11	15.75	13.95
Selly Oak	22.62	18.19	15.16	12.69	11.35
Yardley	26.42	22.00	18.46	15.76	14.21
Sutton Coldfield	22.63	17.82	14.72	12.14	10.71

Maps of $PM_{2.5}$ and NO_2 annual mean concentration by wards are shown in Figure 2 and Figure 3, respectively.

[13] Note that the government data projections to 2030 were produced before the Birmingham Clean Air Zone was proposed

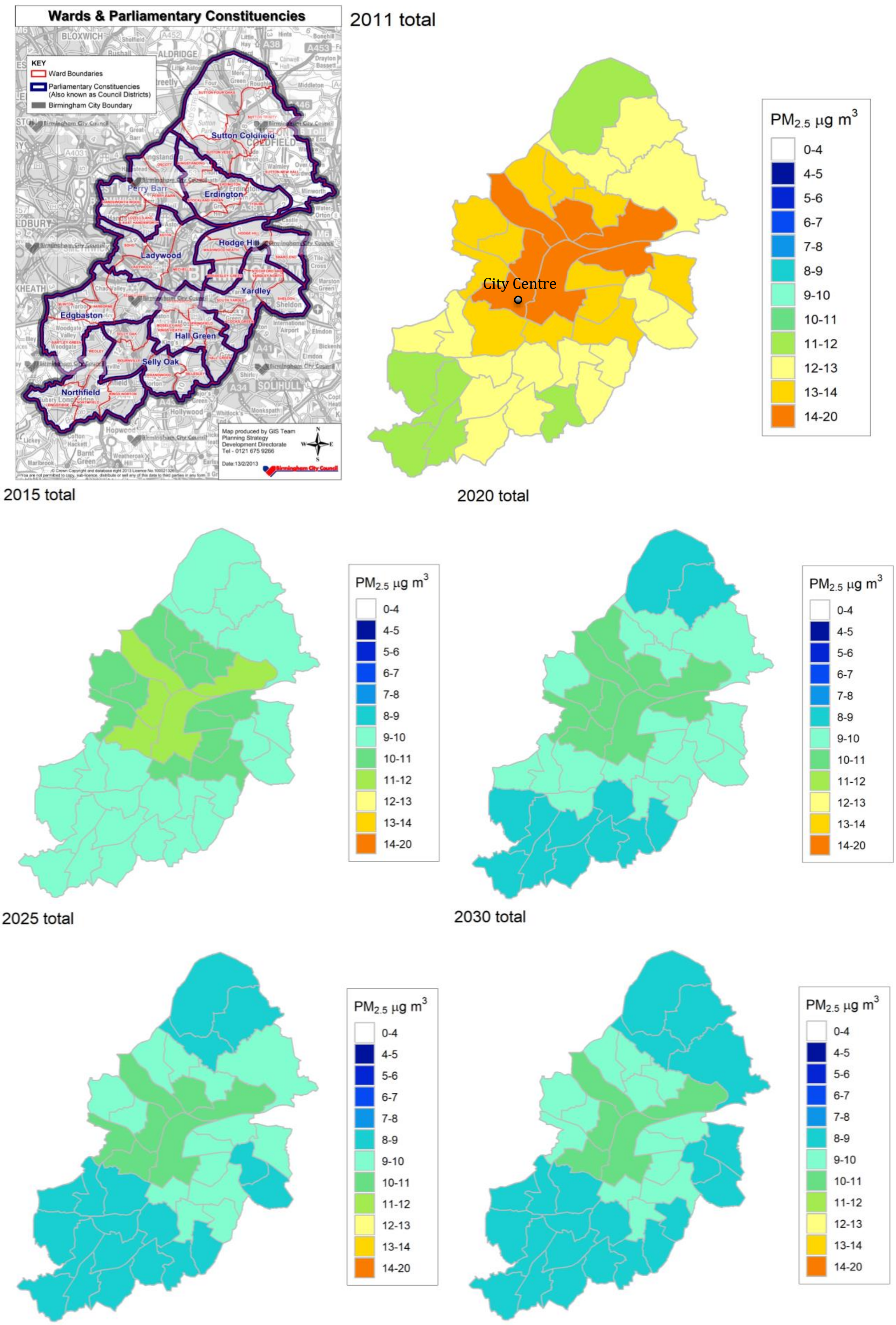

Figure 2 Annual mean $PM_{2.5}$ concentrations (in µg m^{-3}) by wards between 2011 and 2030

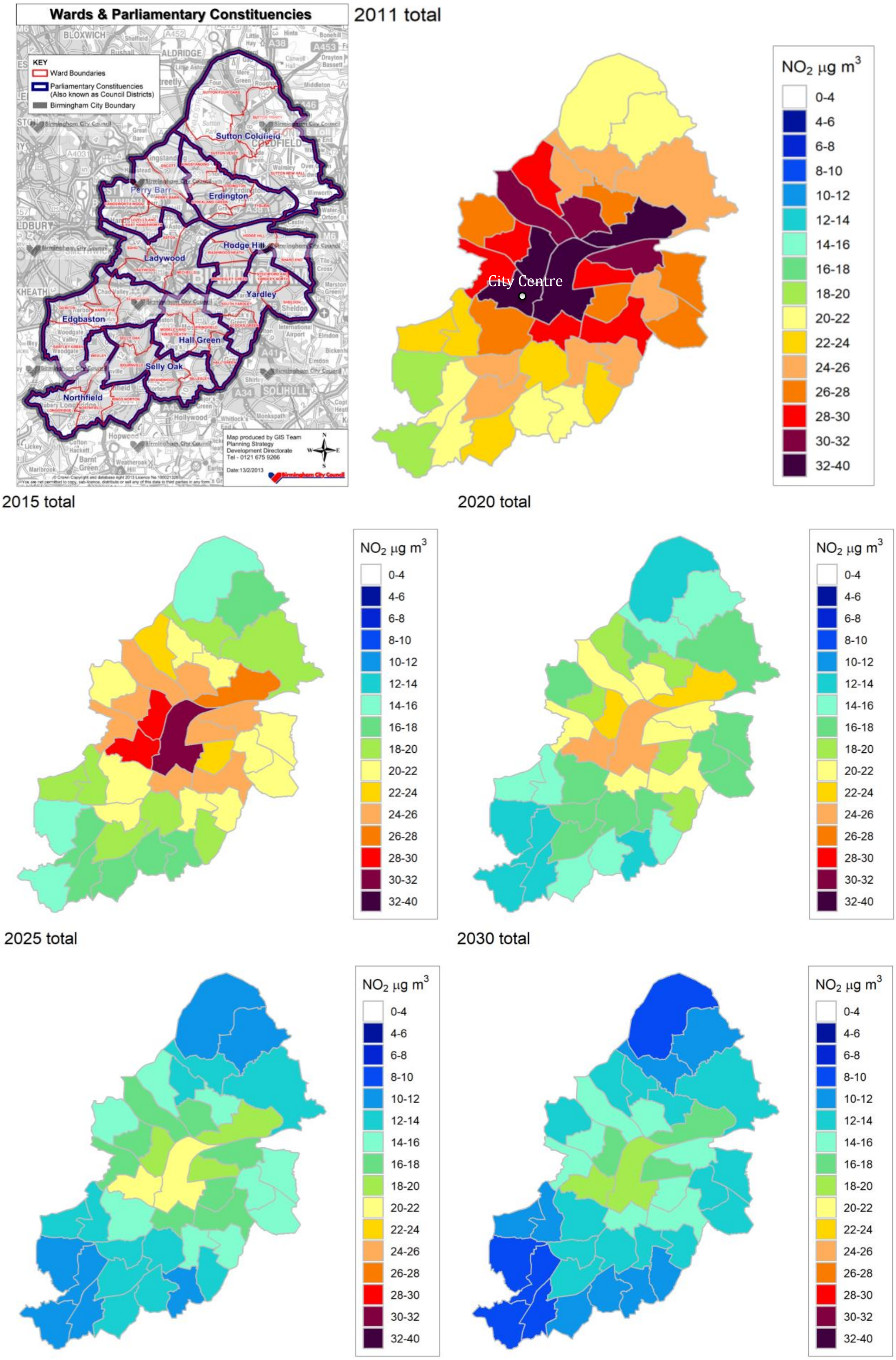

Figure 3 Annual mean NO_2 concentrations (in µg m^{-3}) by wards between 2011 and 2030

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

5.1 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 $PM_{2.5}$ and NO_2 separately. Because air pollutants are correlated with each other, the air pollutant concentrations in the health studies represent both the pollutants themselves but also other air pollutants closely correlated with them. Health impacts from changes in NO_2 and $PM_{2.5}$ 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, 2015, 2020, 2025 and 2030 but also interpolated for the intervening years) are shown in Table 3, for anthropogenic $PM_{2.5}$ and NO_2. Results for each constituency can be found in the Appendix in Table 13 and Table 17 (life table calculations for anthropogenic $PM_{2.5}$ with and without a cut-off), in Table 14 and Table 18 (life table calculations for NO_2 with and without a cut-off) and Table 15 and Table 16 (central and lower/upper CI estimates of annualised economic impact for anthropogenic $PM_{2.5}$ and NO_2 without a cut-off) and Table 19 (central CI estimates of annualised economic impact for anthropogenic $PM_{2.5}$ and NO_2 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 Birmingham over 124 years. For context, the total life years lived with baseline mortality rates is around 198 million, so these losses of life years involve about 0.5% of total life years lived.

If 2011 concentrations of anthropogenic $PM_{2.5}$ remained unchanged for 124 years, around 0.6 – 1.2 million life years would be lost across Birmingham's population over that period. This improves to around 0.2 – 0.8 million life years lost with the predicted concentration between 2011 and 2030 changes 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 NO_2. If 2011 concentrations of NO_2 remained unchanged for 124 years, around 0.8 – 0.9 million life years would be lost across Birmingham's population over that period. This improves to around 0.3 – 0.5 million life years lost with the predicted concentration between 2011 and 2030 changes 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 in the case of each calculation. Note that this means that the indicator pollutant changes in different circumstances. In the case above, for no cut-off, this is the result for $PM_{2.5}$ (0.8 vs 0.5 million life years lost for NO_2). However, for the cut-off, this is the result for NO_2 (0.3 vs 0.2 million life years lost for $PM_{2.5}$). This is one of the first times these recommendations have been applied in practice, so 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 Birmingham over 124 years.

Table 3 Total life years lost across the Birmingham population for anthropogenic $PM_{2.5}$ and NO_2 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 $PM_{2.5}$ (representing the regional air pollution mixture and some of the local mixture)	Concentration does not reduce from 2011 levels	1,169,520 562,960	£653,424,492 £313,958,210
	Predicted concentration between 2011 and 2030	**831,708** 213,344	**£467,766,599** £121,993,163
NO_2 (representing the local mixture and the rural air pollution mixture)	Concentration does not reduce from 2011 levels	942,827 767,457	£525,828,421 £427,680,084
	Predicted concentration between 2011 and 2030	505,434 **328,491**	£289,339,663 **£190,370,755**

For anthropogenic $PM_{2.5}$ 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 $PM_{2.5}$ without cut-off and with 7 µg m^{-3} cut-off[14], with lags from the USEPA.
For NO_2 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 NO_2 without cut-off and with 5 µg m^{-3} cut-off, with lags from the USEPA.
(Results with cut-offs do not extrapolate beyond the original data, results with no cut-off represent the possibility that there are effects below the cut-off value (it is unknown whether or not this is the case).)
Figures in bold are the larger of the alternative estimates using $PM_{2.5}$ or NO_2, as summarized in the headline results.

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

[14] 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. 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.

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 $PM_{2.5}$ remained unchanged for 124 years, the annualised economic cost would be around £310 – 650 million. This improves to around £120 – 470 million with the projected baseline concentration changes examined here.

If 2011 concentrations of NO_2 remained unchanged for 124 years, the annualised economic cost would be around £430 – 530 million. This improves to around £190 – 290 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 £190 to 470 million.

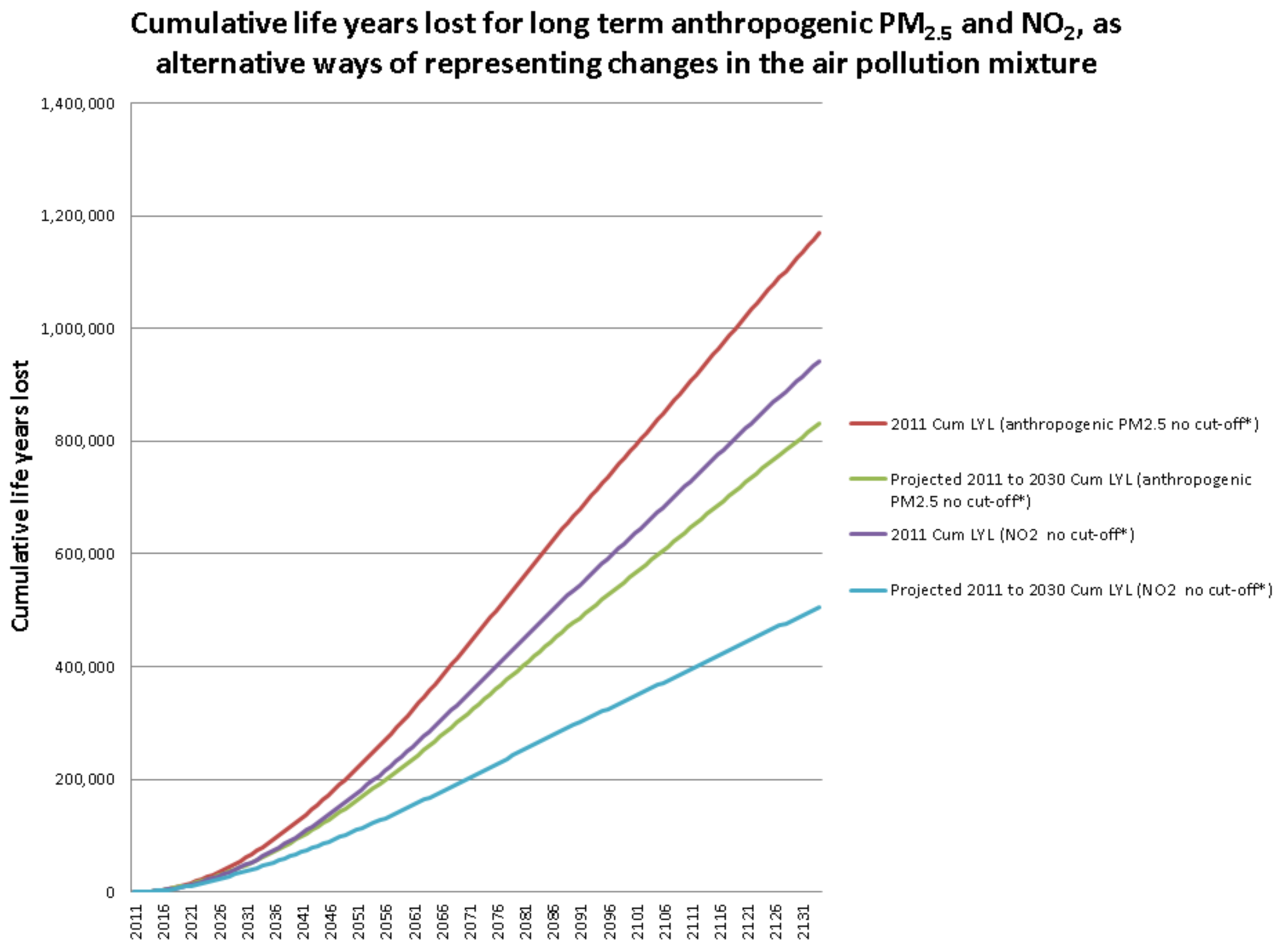

Figure 4 Cumulative life years lost for anthropogenic $PM_{2.5}$ and NO_2 if 2011 concentrations remained unchanged and the baseline (current policies 2011-2030) across the Birmingham population (no migration), with projected new births, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) 2011-2134. RR 1.06 per 10 µg m^{-3} for anthropogenic $PM_{2.5}$ and RR 1.023 per 10 µg m^{-3} for NO_2, 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 $PM_{2.5}$ and NO_2 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 NO_2 concentration constant at 2011 levels. Using $PM_{2.5}$ as an indicator of the regional pollution and some of the local pollution mixture gives an estimate of 340,000 to 350,000 life years gained as a result of the predicted concentration between 2011 and 2030. Using NO_2 as an indicator of mostly the local pollution mixture and the rural pollution gives a larger estimate of 440,000 life years gained. This makes sense because the concentration projected (2011 to 2030) suggests more continuous declines in NO_2 concentrations (likely to be mostly due to the improvement in NO_X emissions of large parts of the road transport sector) than for $PM_{2.5}$, reflecting the fact that PM reduction from traffic is not larger due to the increasing contribution from non-exhaust emissions and also that the declines in regional $PM_{2.5}$ are relatively small.

Thus, using NO_2 rather than $PM_{2.5}$, as the indicator of <u>changes</u> in the traffic pollution mixture seems more appropriate for future changes as presented here. This is a different indicator compared with the <u>overall</u> impact in terms of life years lost[15]. Regional pollution is a greater contributor to absolute total concentrations than to future changes so there is also some sense in $PM_{2.5}$ being the indicator in this case.

The <u>overall summary</u> would be that taking into account predicted air pollution concentration changes between 2011 and 2030, the population in Birmingham would <u>gain around 440,000 life years</u> over a lifetime.

[15] This was not the case for the cut-off, where NO_2 rather than $PM_{2.5}$ gives the larger result. But this may be mostly to do with the value of the cut-off.

Table 4 Life years <u>saved</u> (and associated monetised benefits) across Birmingham population of the predicted concentration between 2011 and 2030 compared with 2011 anthropogenic $PM_{2.5}$ concentrations and NO_2 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 $PM_{2.5}$ (representing the regional air pollution mixture and some of the local mixture)	Predicted concentration between 2011 and 2030	337,812 349,616	£185,657,893 £191,965,047
NO_2 (representing the local mixture and the rural air pollution mixture)	Predicted concentration between 2011 and 2030	**437,393** **438,966**	**£236,488,758** **£237,309,329**

Figures in bold are the larger of the alternative estimates using $PM_{2.5}$ or NO_2, as summarized in the headline results.

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 <u>annualised monetary benefit</u> of anthropogenic $PM_{2.5}$ and NO_2 improvements has been estimated to be up to <u>£240 million</u> (at 2014 prices).

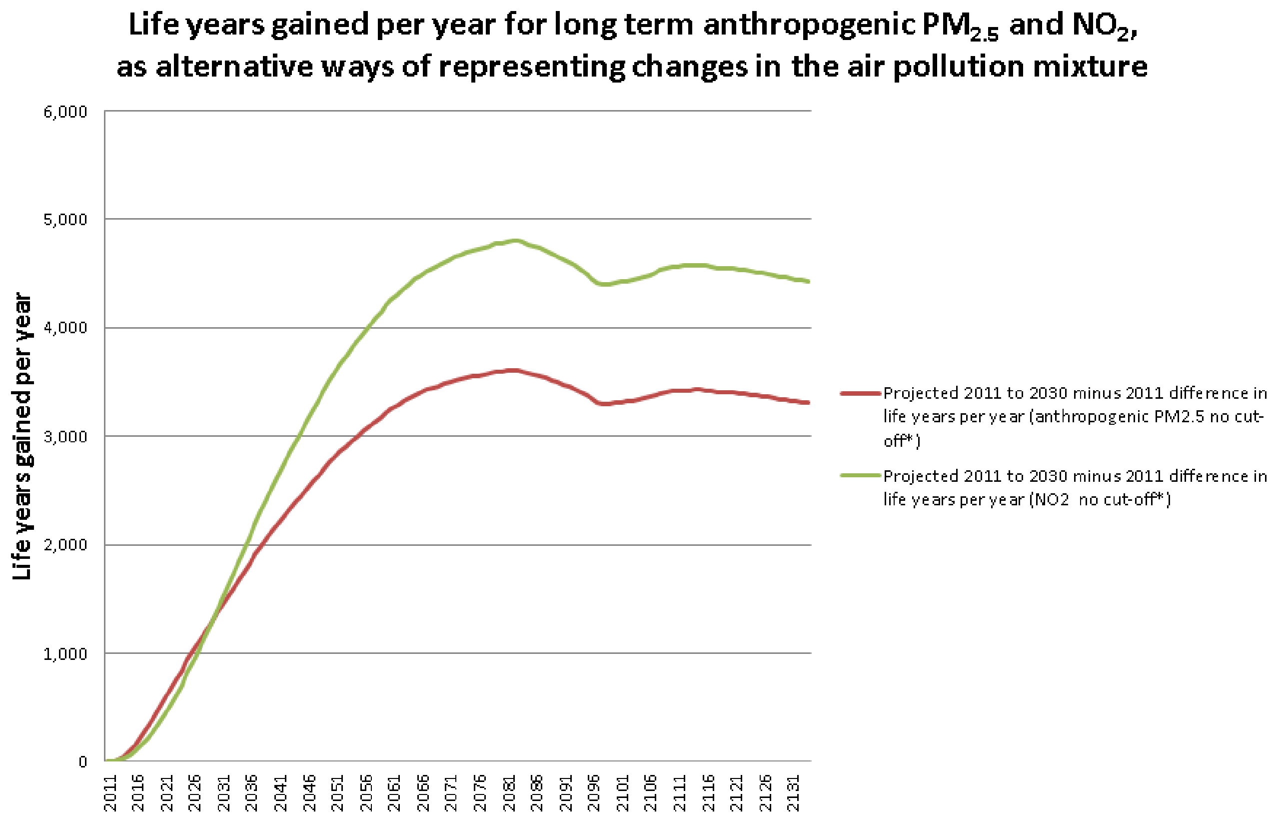

Figure 5 Life years gained per year from long-term exposure to the improvements in pollution from 2011 to 2030 of anthropogenic $PM_{2.5}$ and NO_2 relative to 2011 concentrations remaining unchanged

* Cut-off results not shown

Figure 5 shows the effect of the decrease in $PM_{2.5}$ and NO_2 concentration from 2011 to 2030 (as seen in Table 1 and Table 2).

5.2 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 constituency can be found in the Appendix in Table 20 and Table 21 (Loss of life expectancy for anthropogenic $PM_{2.5}$ and NO_2 with and without a cut-off).

This shows that the average loss of life expectancy from birth in Birmingham would be about 20 – 41 weeks for male and 17 – 35 weeks for female if 2011 $PM_{2.5}$ concentrations were unchanged but improves to 7 – 29 weeks for male and 6 – 25 weeks for female for the predicted concentration between 2011 and 2030 (an improvement by about 10-13 weeks).
Using NO_2, the average loss of life expectancy from birth in Birmingham would be about 27 – 33 weeks for male and 23 – 28 weeks for female if NO_2 concentrations were unchanged from 2011 but

improves by about 13-16 weeks to 11 – 17 weeks for male and 9 – 15 weeks for female 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 2.5 – 4 months (11 – 17 weeks) but an average loss of life expectancy from birth in 2011 of around 2 to 7 months (9 – 29 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.

Table 5 Loss of life expectancy by gender across Birmingham from birth in 2011 (followed for 105 years) for anthropogenic $PM_{2.5}$ and NO_2

Pollutant	Scenario	Loss of life expectancy from birth compared with baseline mortality rates, 2011 birth cohort (in weeks) (without cut-off with cut-off)	
		Male	Female
Anthropogenic $PM_{2.5}$	Concentration does not reduce from 2011 levels	40.9 19.8	34.9 17.0
	Predicted concentration between 2011 and 2030	**28.8** 7.2	**24.6** 6.2
NO_2	Concentration does not reduce from 2011 levels	33.2 27.1	28.4 23.2
	Predicted concentration between 2011 and 2030	17.0 **10.9**	14.5 **9.3**

Figures in bold are the larger of the alternative estimates using $PM_{2.5}$ or NO_2, as summarized in the headline results.

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 $PM_{2.5}$ and NO_2 are available upon request to the authors.

6.0 Health Estimates of the mortality burden of air pollution

6.1 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. They are included here as a comparison with similar calculations presented elsewhere (COMEAP, 2010; Walton et al., 2015; Dajnak et al., 2018). 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. 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. 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[16] 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 are done as intermediate stages towards the overall results.

[Burden calculations would normally include accompanying estimates of the burden life years lost[17]. 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.

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

Using the exploratory new combined method (COMEAP, 2018a) gives an estimate for the 2011 mortality burden in Birmingham of 2011 levels of air pollution (represented by NO_2 and anthropogenic $PM_{2.5}$) to be equivalent to <u>570 to 709 attributable deaths</u> at typical ages, or a result

---

[16] 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.

[17] 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.

equivalent to 400 to 430 deaths when cut-offs for each pollutant were implemented. Estimates for individual constituencies are provided in Table 6. The results varied by constituency with highest in Erdington and lowest in Hall Green. The ranking by constituency did not fully follow the ranking in pollutant concentrations (see Table 1 and Table 2). This is because the results are also influenced by variations in death rates by constituency (highest in Erdington, lowest in Ladywood), which in turn are driven in part by the proportion of elderly in the population (highest in Sutton Coldfield, lowest in Ladywood) and the level of deprivation (similar across most constituencies, but better in Sutton Coldfield). Details are given in Table 23 in the Appendix.

These results use recommendations from COMEAP, 2018a. For each of the four individual cohort studies that included multi-pollutant model results[18], the burden results were estimated separately using mutually adjusted summary coefficients for $PM_{2.5}$ and NO_2 and then the adjusted $PM_{2.5}$ and NO_2 results were summed to give an estimated burden of the air pollution mixture. Example of the calculations for each study for individual constituencies and Birmingham of 2011 levels of NO_2 and $PM_{2.5}$ can be found the appendix in Table 24 and Table 25. 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 $PM_{2.5}$ and NO_2 (with and without cut-off)

Zone	Anthropogenic $PM_{2.5}$ and NO2 (without cut-off)	Anthropogenic $PM_{2.5}$ 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*)
Edgbaston	47 - 59	32 - 34
Erdington	75 - 91	55 - 59
Hall Green	46 - 57	32 - 35
Hodge Hill	69 - 85	50 - 53
Ladywood	50 - 60	38 - 40
Northfield	49 - 64	32 - 34
Perry Barr	56 - 69	42 - 44
Selly Oak	56 - 72	37 - 41
Yardley	65 - 81	46 - 49
Sutton Coldfield	56 - 72	37 - 41
Birmingham	570 -709	400 - 430

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

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

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

6.3 Single pollutant model estimates

The previous mortality burden method using single pollutant model estimates would have estimated that Birmingham's 2011 levels of anthropogenic $PM_{2.5}$ would lead to effects equivalent to 554 (range[19] 378 to 724) attributable deaths at typical ages, or results equivalent to 266 (range 180 to 350) deaths when the cut-off was implemented. Estimates for individual constituencies are provided in Table 7. This represents the regional pollution mixture and partial 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 $PM_{2.5}$ alone to the sum of the $PM_{2.5}$ and NO_2 results, but the uncertainty of the latter was emphasized. Since then it has become clearer that the overlap is likely to be substantial (COMEAP, 2015). COMEAP (2018a) concluded that the combined adjusted coefficients were similar to, or slightly larger than, the single-pollutant association reported with either pollutant alone.

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 22 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 $PM_{2.5}$ (with and without cut-off)

Zone	Anthropogenic $PM_{2.5}$ (without cut-off)			Anthropogenic $PM_{2.5}$ (with cut-off)		
	Attributable deaths			Attributable deaths		
	Central estimate	Lower estimate	Upper estimate	Central estimate	Lower estimate	Upper estimate
Edgbaston	48	32	62	22	15	28
Erdington	70	47	91	36	24	47
Hall Green	45	31	59	21	14	28
Hodge Hill	65	45	85	33	22	43
Ladywood	45	31	58	24	16	31
Northfield	51	35	67	22	15	29
Perry Barr	53	36	69	27	18	35
Selly Oak	57	39	75	26	17	34
Yardley	63	43	83	31	21	40
Sutton Coldfield	57	39	74	26	17	34
Birmingham	554	378	724	266	180	350

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

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

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

for NO_2 (this may represent the burden of traffic pollution more clearly than that of $PM_{2.5}$). The results give estimates that Birmingham's 2011 levels of NO_2 lead to effects equivalent to 442 (range[20] 158 to 694) attributable deaths at typical ages, or results equivalent to 359 (range 128 to 565) deaths when the cut-off was implemented. Estimates for individual constituencies 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 NO_2 (with and without cut-off)

Zone	NO_2 (without cut-off) Attributable deaths			NO_2 (with cut-off) Attributable deaths		
	Central estimate	Lower estimate	Upper estimate	Central estimate	Lower estimate	Upper estimate
Edgbaston	36	13	56	28	10	44
Erdington	59	21	93	50	18	78
Hall Green	35	13	55	28	10	45
Hodge Hill	54	19	85	45	16	71
Ladywood	40	14	63	34	12	54
Northfield	37	13	58	28	10	44
Perry Barr	45	16	70	37	13	59
Selly Oak	43	15	67	33	12	53
Yardley	51	18	80	41	15	65
Sutton Coldfield	42	15	66	33	12	52
Birmingham	442	158	694	359	128	565

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

6.4 Summary of burden results

Results without the cut-off give a range of 570-709 attributable deaths using the approach derived from multi-pollutant model results. This compares with around 554 attributable deaths[21] using the single-pollutant model estimate for $PM_{2.5}$ (the previous method) and around 442 attributable deaths using the single-pollutant model estimate for NO_2 (a good indicator of traffic pollution). As expected, the estimate combining effects of NO_2 and $PM_{2.5}$ is slightly larger than for either pollutant alone but not by much, reflecting the substantial overlap between the single pollutant model estimates for $PM_{2.5}$ and NO_2. Nonetheless, there are substantial ranges of uncertainty around these estimates so it is not clear cut that there is an additional effect over and above estimates using the previous method.

The message from the results with a cut-off is similar with a range of 400-430 attributable deaths using the approach derived from multi-pollutant model results compared with 266 ($PM_{2.5}$ single-pollutant model) and 359 (NO_2 single-pollutant model). In this case, the result for NO_2 is larger than that for $PM_{2.5}$ - probably a reflection of the different cut-offs for NO_2 and $PM_{2.5}$.

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

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

[21] More fully 'results equivalent to xx attributable deaths at typical ages'.

be 266 attributable deaths (long-established method for $PM_{2.5}$, avoids the complexities of interpreting multi-pollutant model results) and the 'exploratory, more up to date, extrapolate beyond the data' results would be 570-709 attributable deaths (combined NO_2 and $PM_{2.5}$; no cut-off). For messages incorporating most of the uncertainties, the message would be 'somewhere between about 150 and 700 attributable deaths'.

7.0 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.

Ozone

Study from Williams et al. (2018a and 2018b) shows that ozone concentrations in 2035 and 2050 are projected to increase in winter because the NOx removal process is reduced through reductions in NOx emissions. So-called summer smog ozone concentrations are projected to decrease because of the reductions in emissions of ozone precursors. 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 NO_2, is potentially of some concern because ozone has a higher redox potential than does NO_2, and so could possibly increase the hazard from oxidative stress, although it is too early to be confident about this theory.

Comparison with results for Greater Manchester

The current authors performed a similar analysis for Greater Manchester in 2018 (Dajnak et al., 2018). This analysis was similar 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 and 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 both Birmingham and Greater Manchester was for $PM_{2.5}$ with no cut-off. The result was larger for Greater Manchester

(1.6 million life years lost) with the result for 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 larger area and has a larger population (2,682,727 people) with the population for Birmingham city being about a third of that (1,073,188). However, there is a higher concentration of $PM_{2.5}$ in Birmingham than in Manchester (Table 9) which will increase the life years lost in Birmingham relative to Manchester. This probably contributes to the fact that the Birmingham results is only half of that in Manchester rather than a third of it as would (loosely) be predicted by the differences in population. The equivalent results for NO_2 with no cut-off is 1 million life years lost in Greater Manchester and 0.5 million life years lost in Birmingham city. This is again around half the life years lost in Birmingham compared with Manchester, with the explanations being similar.

The comparison of the results with a cut-off give different messages for NO_2 and $PM_{2.5}$. The comparison for NO_2 with a cut-off is similar to the no cut-off results (the result for Birmingham, 0.3 million life years lost, about half that for Manchester, 0.6 million life years lost). For $PM_{2.5}$, however, the result for Birmingham (0.21 million life years lost) is more similar and, in fact, more than that for Greater Manchester (0.18 million life years lost). This is because the $PM_{2.5}$ concentrations in Greater Manchester are much closer to the 7 µg m^{-3} cut-off (and are probably below it in some areas). It is therefore assumed that the particulate pollution has no effect on life-years lost in those areas, reducing the total overall.

Table 9 Anthropogenic $PM_{2.5}$ PWAC (in µg m^{-3}) (annual) and NO_2 PWAC (in µg m^{-3}) (annual) for Birmingham City and Greater Manchester

Pollutant	Location	2011	2015	2020	2025	2030
Anthropogenic $PM_{2.5}$ PWAC*	Birmingham City	12.82	9.81	9.21	9.02	8.99
	Greater Manchester	11.39	8.09	7.62	7.47	7.44
NO_2 PWAC*	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 Birmingham City: average of the PWAC by constituency from Table 1 and Table 2, above. For Greater Manchester, average of the PWAC by local authority from Table 1 and Table 2 (Dajnak et al., 2018).

Loss of life expectancy still remaining after pollution improvements: The influence of the difference in pollution concentrations between 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 $PM_{2.5}$ as an indicator without a cut-off was 21/24 weeks (Female/Male) in Greater Manchester and 25/29 weeks (F/M) in Birmingham City, close but somewhat higher in Birmingham as with the concentrations. The comparison was similarly close but higher in Birmingham for life expectancy using NO_2 without a cut-off as an indicator (12 – 14 weeks compared with 15-17 weeks in Birmingham). As with the previous discussions of total life years lost, the difference between Greater Manchester and Birmingham City is more marked for $PM_{2.5}$ with a cut-off than for NO_2 with a cut-off because the cut-off of 7 µg m^{-3} is closer to the general concentrations in Manchester.

Gains in life years from pollution improvements: Similar factors influence the comparative results for life years gained between the two cities. As with the life years lost after the pollution improvements, the results for NO_2 in Birmingham are about half those in Manchester, driven mainly by the lower population but also partially cancelled out by the higher pollution levels. There are

NO_2 reductions in both cities (Table 9), which also influence the answer but proportionately the reductions are quite similar. For $PM_{2.5}$, there is proportionally a slightly greater reduction in Manchester and this shows in the fact that the gains from $PM_{2.5}$ in Birmingham are a bit less than half those in Manchester.

Mortality burden: The mortality burden in Birmingham city is again smaller in Birmingham city than in Greater Manchester but not by as much as predicted by the smaller population, given the higher pollution levels.

In all the cases discussed above, other factors may also be having an influence such as the mortality rates (see discussion of differences across constituencies 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 $PM_{2.5}$. This was 52,630 life-years lost, equivalent to 3,537 deaths at typical ages for 2010 compared with 554 attributable deaths for Birmingham for 2011. (Due to the short duration of the Birmingham project life years lost was not calculated for mortality burden). Again, this difference is primarily driven by the larger population in London (8 million vs 1 million).

In summary, this report shows the gains in life years from the projected pollution improvements but also that adverse health impacts will still remain i.e. there is still justification for further pollution improvements beyond those already made.

8.0 Appendix

8.1 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 $PM_{2.5}$ and NO_2 are available upon request to the authors.

Table 10 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
$PM_{2.5}$	Annual average	1.06	1.04-1.08 1.01-1.12*	Zero Or 7 µg m^{-3}	Age 30+, Anthropogenic $PM_{2.5}$ (Hazard ratio COMEAP (2010) and COMEAP (2017)) Age 30+, total $PM_{2.5}$ (cut-off reference COMEAP (2010))
NO_2	Annual average	1.023	1.008 – 1.037	Zero or 5 µg m^{-3}	Age 30+ (Hazard ratio COMEAP (2017), cutoff COMEAP (2016)

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

Table 11 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
$PM_{2.5}$	Annual average	1.029 (Jerrett) 1.033 (Fischer) 1.053 (Beelen) 1.019 (Crouse)	Zero Or 7 µg m^{-3}	Age 30+, Anthropogenic $PM_{2.5}$ (Hazard ratio COMEAP (2010) and COMEAP (2017)) Age 30+, total $PM_{2.5}$ (cut-off reference COMEAP (2010))
NO_2	Annual average	1.019 (Jerrett) 1.016 (Fischer) 1.011 (Beelen) 1.020 (Crouse)	Zero or 5 µg m^{-3}	Age 30+ (Hazard ratio COMEAP (2017), cutoff COMEAP (2016)

*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 12 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 parliamentary constituency	Constituency	Sum of constituency results

8.2 Additional tables - impact

Table 13 Life years lost by gender across the parliamentary constituencies and Birmingham population for anthropogenic $PM_{2.5}$ (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
Edgbaston	Female	41,817	28,270	54,993	29,872	20,169	39,336
Edgbaston	Male	47,845	32,303	63,000	34,045	22,965	44,871
Erdington	Female	56,758	38,352	74,675	40,409	27,272	53,229
Erdington	Male	60,739	41,008	79,977	43,186	29,130	56,919
Hall Green	Female	53,596	36,236	70,475	38,004	25,660	50,042
Hall Green	Male	68,977	46,621	90,729	48,931	33,031	64,444
Hodge Hill	Female	73,997	50,018	97,324	51,807	34,972	68,230
Hodge Hill	Male	87,589	59,168	115,272	61,301	41,363	80,769
Ladywood	Female	77,966	52,704	102,537	55,768	37,650	73,437
Ladywood	Male	99,111	67,042	130,260	70,987	47,947	93,437
Northfield	Female	44,448	30,043	58,463	32,002	21,604	42,145
Northfield	Male	51,005	34,464	67,110	36,709	24,776	48,355
Perry Barr	Female	55,567	37,574	73,059	40,121	27,093	52,822
Perry Barr	Male	65,961	44,570	86,786	47,612	32,135	62,714
Selly Oak	Female	45,213	30,515	59,555	32,035	21,603	42,233
Selly Oak	Male	50,440	34,060	66,408	35,745	24,114	47,107
Yardley	Female	55,329	37,384	72,802	38,813	26,193	51,132
Yardley	Male	63,099	42,626	83,040	44,231	29,846	58,276
Sutton Coldfield	Female	34,402	23,232	45,289	24,650	16,630	32,483
Sutton Coldfield	Male	35,663	24,054	47,006	25,480	17,175	33,605
Birmingham	Female	539,092	364,328	709,172	383,480	258,845	505,089
Birmingham	Male	630,428	425,916	829,588	448,228	302,482	590,498
Birmingham	Total	1,169,520	790,244	1,538,761	831,708	561,327	1,095,587

Table 14 Life years lost by gender across the parliamentary constituencies and Birmingham population for NO_2 (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
Edgbaston	Female	31,231	11,014	49,603	15,991	5,622	25,473
Edgbaston	Male	35,874	12,627	57,076	18,297	6,427	29,170
Erdington	Female	48,435	17,082	76,913	25,056	8,808	39,913
Erdington	Male	51,839	18,258	82,424	26,717	9,387	42,581
Hall Green	Female	41,505	14,642	65,896	22,617	7,954	36,015
Hall Green	Male	53,461	18,851	84,915	29,214	10,272	46,529
Hodge Hill	Female	61,732	21,781	97,992	34,266	12,052	54,558
Hodge Hill	Male	73,135	25,778	116,204	40,583	14,266	64,649
Ladywood	Female	69,588	24,568	110,396	38,838	13,666	61,812
Ladywood	Male	88,585	31,311	140,379	49,940	17,584	79,434
Northfield	Female	31,356	11,051	49,830	16,067	5,646	25,602
Northfield	Male	35,959	12,667	57,169	18,396	6,463	29,320
Perry Barr	Female	47,294	16,699	75,021	23,685	8,331	37,711
Perry Barr	Male	56,133	19,796	89,142	28,156	9,898	44,850
Selly Oak	Female	33,317	11,720	53,038	17,715	6,220	28,249
Selly Oak	Male	37,200	13,095	59,179	19,803	6,957	31,567
Yardley	Female	44,291	15,613	70,371	25,075	8,816	39,942
Yardley	Male	50,530	17,807	80,303	28,576	10,045	45,522
Sutton Coldfield	Female	25,229	8,882	40,132	13,052	4,584	20,807
Sutton Coldfield	Male	26,131	9,183	41,636	13,389	4,699	21,359
Birmingham	Female	433,979	153,051	689,191	232,362	81,699	370,082
Birmingham	Male	508,848	179,374	808,429	273,072	95,998	434,982
Birmingham	Total	942,827	332,425	1,497,620	505,434	177,697	805,064

Table 15 Central Annualised economic impact estimate (in 2014 prices) across the parliamentary constituencies and Birmingham population for anthropogenic $PM_{2.5}$ and NO_2 (without cut-off)

Zone	Anthropogenic $PM_{2.5}$		NO_2	
	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
Edgbaston	£51,375,485	£36,887,202	£38,446,958	£20,290,037
Erdington	£66,406,816	£47,595,352	£56,668,413	£30,229,656
Hall Green	£67,609,835	£48,241,268	£52,377,027	£29,303,571
Hodge Hill	£86,585,316	£60,962,701	£72,263,115	£40,997,725
Ladywood	£95,542,313	£68,701,219	£85,342,521	£48,816,024
Northfield	£54,880,838	£39,801,589	£38,695,791	£20,486,583
Perry Barr	£67,720,755	£49,183,873	£57,629,795	£29,752,759
Selly Oak	£54,654,167	£39,009,105	£40,289,947	£22,062,293
Yardley	£66,258,293	£46,798,522	£53,044,830	£30,799,172
Sutton Coldfield	£42,390,673	£30,585,767	£31,070,025	£16,601,844
Birmingham	£653,424,492	£467,766,599	£525,828,421	£289,339,663

Table 16 Lower and upper Annualised economic impact estimate (in 2014 prices) across the parliamentary constituencies and Birmingham population for anthropogenic $PM_{2.5}$ and NO_2 (without cut-off)

Zone	Anthropogenic $PM_{2.5}$		NO_2	
	Predicted concentration between 2011 and 2030		Predicted concentration between 2011 and 2030	
	Lower estimate	Upper estimate	Lower estimate	Upper estimate
Edgbaston	£24,891,249	£48,599,024	£7,130,009	£32,333,244
Erdington	£32,110,056	£62,719,962	£10,624,270	£48,165,659
Hall Green	£32,565,183	£63,534,358	£10,304,365	£46,667,294
Hodge Hill	£41,139,787	£80,313,255	£14,415,399	£65,294,631
Ladywood	£46,394,151	£90,445,925	£17,185,511	£77,657,261
Northfield	£26,862,529	£52,429,746	£7,198,587	£32,648,513
Perry Barr	£33,201,158	£64,776,119	£10,462,671	£47,381,022
Selly Oak	£26,310,392	£51,419,078	£7,749,165	£35,172,582
Yardley	£31,576,843	£61,661,858	£10,826,995	£49,062,531
Sutton Coldfield	£20,623,913	£40,325,956	£5,829,480	£26,474,681
Birmingham	£315,675,261	£616,225,282	£101,726,453	£460,857,417

Table 17 Life years lost by gender across the parliamentary constituencies and Birmingham for $PM_{2.5}$ (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
Edgbaston	Female	18,760	12,651	24,731	6,366	4,288	8,403
Edgbaston	Male	21,510	14,498	28,373	7,259	4,888	9,583
Erdington	Female	28,732	19,376	37,878	11,822	7,964	15,603
Erdington	Male	30,720	20,709	40,514	12,612	8,495	16,648
Hall Green	Female	24,977	16,846	32,924	8,795	5,924	11,608
Hall Green	Male	32,148	21,680	42,382	11,367	7,656	15,004
Hodge Hill	Female	36,997	24,954	48,767	14,032	9,452	18,519
Hodge Hill	Male	43,774	29,516	57,717	16,622	11,196	21,940
Ladywood	Female	41,253	27,829	54,367	18,310	12,337	24,161
Ladywood	Male	52,465	35,404	69,121	23,345	15,731	30,800
Northfield	Female	18,711	12,616	24,672	5,766	3,883	7,612
Northfield	Male	21,455	14,464	28,293	6,602	4,446	8,715
Perry Barr	Female	28,141	18,985	37,086	12,123	8,168	15,997
Perry Barr	Male	33,363	22,499	43,982	14,377	9,685	18,974
Selly Oak	Female	19,840	13,370	26,175	6,239	4,201	8,237
Selly Oak	Male	22,171	14,944	29,244	6,979	4,700	9,214
Yardley	Female	26,543	17,898	34,997	9,462	6,373	12,489
Yardley	Male	30,287	20,421	39,936	10,785	7,264	14,237
Sutton Coldfield	Female	15,291	10,307	20,168	5,176	3,486	6,834
Sutton Coldfield	Male	15,820	10,658	20,877	5,303	3,571	7,002
Birmingham	Female	259,247	174,832	341,766	98,091	66,074	129,463
Birmingham	Male	303,713	204,791	400,441	115,252	77,632	152,118
Birmingham	Total	562,960	379,623	742,207	213,344	143,706	281,581

Table 18 Life years lost by gender across the parliamentary constituencies and Birmingham population for NO_2 (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
Edgbaston	Female	24,564	8,650	39,065	9,258	3,250	14,765
Edgbaston	Male	28,263	9,938	45,009	10,633	3,732	16,966
Erdington	Female	40,334	14,209	64,120	16,873	5,926	26,904
Erdington	Male	43,161	15,188	68,686	17,971	6,309	28,663
Hall Green	Female	33,226	11,705	52,820	14,256	5,007	22,729
Hall Green	Male	42,807	15,075	68,076	18,464	6,484	29,440
Hodge Hill	Female	51,036	17,985	81,110	23,464	8,243	37,401
Hodge Hill	Male	60,469	21,291	96,177	27,811	9,767	44,344
Ladywood	Female	58,996	20,804	93,701	28,135	9,889	44,825
Ladywood	Male	75,133	26,520	119,219	36,324	12,773	57,846
Northfield	Female	23,902	8,412	38,035	8,546	3,000	13,635
Northfield	Male	27,402	9,641	43,619	9,768	3,428	15,585
Perry Barr	Female	39,370	13,883	62,531	15,664	5,503	24,968
Perry Barr	Male	46,713	16,456	74,263	18,640	6,546	29,720
Selly Oak	Female	25,982	9,132	41,396	10,337	3,627	16,497
Selly Oak	Male	29,026	10,207	46,222	11,574	4,062	18,466
Yardley	Female	35,966	12,663	57,206	16,680	5,858	26,597
Yardley	Male	41,040	14,447	65,290	19,011	6,676	30,315
Sutton Coldfield	Female	19,687	6,924	31,348	7,469	2,621	11,918
Sutton Coldfield	Male	20,380	7,157	32,492	7,612	2,670	12,150
Birmingham	Female	353,062	124,367	561,331	150,682	52,923	240,237
Birmingham	Male	414,394	145,920	659,054	177,808	62,447	283,495
Birmingham	Total	767,457	270,287	1,220,386	328,491	115,370	523,732

Table 19 Annualised economic impact (in 2014 prices) across the parliamentary constituencies and Birmingham population for $PM_{2.5}$ and NO_2 (with 7 µg m^{-3} and 5 µg m^{-3} cut-off for $PM_{2.5}$ and NO_2, respectively)

Zone	Anthropogenic $PM_{2.5}$		NO_2	
	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
Edgbaston	£23,069,783	£8,088,749	£30,264,686	£12,043,928
Erdington	£33,592,790	£14,183,538	£47,182,867	£20,666,070
Hall Green	£31,502,362	£11,432,109	£41,931,729	£18,766,104
Hodge Hill	£43,272,635	£16,804,911	£59,741,837	£28,369,599
Ladywood	£50,564,437	£22,806,055	£72,368,899	£35,697,933
Northfield	£23,084,994	£7,432,709	£29,488,817	£11,206,998
Perry Barr	£34,265,161	£15,084,249	£47,962,747	£19,984,928
Selly Oak	£24,001,756	£7,853,300	£31,427,705	£13,147,583
Yardley	£31,786,720	£11,689,665	£43,074,754	£20,755,045
Sutton Coldfield	£18,817,573	£6,617,878	£24,236,043	£9,732,568
Birmingham	£313,958,210	£121,993,163	£427,680,084	£190,370,755

Table 20 Loss of life expectancy by gender across the parliamentary constituencies and Birmingham from birth in 2011 for anthropogenic $PM_{2.5}$ (without cut-off) and NO_2 (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 $PM_{2.5}$ (without cut-off)		NO_2 (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
Edgbaston	Female	31.1	22.0	23.3	11.2
Edgbaston	Male	36.7	25.8	27.5	13.2
Erdington	Female	39.7	27.9	33.9	16.5
Erdington	Male	44.5	31.3	38.0	18.5
Hall Green	Female	31.0	21.8	24.0	12.6
Hall Green	Male	38.3	26.9	29.7	15.5
Hodge Hill	Female	37.5	26.0	31.3	16.8
Hodge Hill	Male	44.8	31.1	37.4	20.0
Ladywood	Female	40.7	28.9	36.3	19.7
Ladywood	Male	48.1	34.2	43.0	23.4
Northfield	Female	30.3	21.5	21.4	10.3
Northfield	Male	35.9	25.5	25.3	12.1
Perry Barr	Female	34.9	25.0	29.7	14.1
Perry Barr	Male	42.1	30.1	35.8	17.0
Selly Oak	Female	32.4	22.7	23.9	12.1
Selly Oak	Male	37.0	26.0	27.3	13.8
Yardley	Female	35.5	24.6	28.4	15.4
Yardley	Male	39.8	27.6	31.9	17.3
Sutton Coldfield	Female	28.4	20.0	20.8	9.9
Sutton Coldfield	Male	31.8	22.4	23.4	11.1
Birmingham	Female	34.9	24.6	28.4	14.5
Birmingham	Male	40.9	28.8	33.2	17.0

Table 21 Loss of life expectancy by gender across the parliamentary constituencies and Birmingham from birth in 2011 for anthropogenic $PM_{2.5}$ (with 7 μg m^{-3} cut-off) and NO_2 (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 $PM_{2.5}$ (with 7 μg m^{-3} cut-off)		NO_2 (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
Edgbaston	Female	14.0	4.4	18.3	6.1
Edgbaston	Male	16.5	5.2	21.7	7.3
Erdington	Female	20.1	7.9	28.2	10.8
Erdington	Male	22.5	8.9	31.6	12.0
Hall Green	Female	14.5	4.9	19.2	7.7
Hall Green	Male	17.9	6.0	23.8	9.6
Hodge Hill	Female	18.8	6.9	25.9	11.3
Hodge Hill	Male	22.4	8.2	30.9	13.5
Ladywood	Female	21.5	9.4	30.8	14.1
Ladywood	Male	25.5	11.1	36.5	16.8
Northfield	Female	12.8	3.6	16.3	5.1
Northfield	Male	15.1	4.3	19.3	6.1
Perry Barr	Female	17.7	7.4	24.8	9.1
Perry Barr	Male	21.3	8.9	29.8	10.9
Selly Oak	Female	14.3	4.2	18.7	6.8
Selly Oak	Male	16.3	4.8	21.4	7.7
Yardley	Female	17.0	5.8	23.1	10.0
Yardley	Male	19.1	6.5	25.9	11.2
Sutton Coldfield	Female	12.7	3.9	16.3	5.3
Sutton Coldfield	Male	14.2	4.4	18.2	5.9
Birmingham	Female	17.0	6.2	23.2	9.3
Birmingham	Male	19.8	7.2	27.1	10.9

8.3 Additional tables – burden

Table 22 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 $PM_{2.5}$ (with and without cut-off)

Zone	Anthropogenic $PM_{2.5}$ (without cut-off)			Anthropogenic $PM_{2.5}$ (with cut-off)		
	Attributable deaths			Attributable deaths		
	Central estimate	Lower estimate	Upper estimate	Central estimate	Lower estimate	Upper estimate
Edgbaston	48	8	90	22	4	41
Erdington	70	12	130	36	6	68
Hall Green	45	8	86	21	4	41
Hodge Hill	65	12	123	33	6	63
Ladywood	45	8	84	24	4	46
Northfield	51	9	97	22	4	42
Perry Barr	53	9	99	27	5	51
Selly Oak	57	10	108	26	4	49
Yardley	63	11	119	31	5	59
Sutton Coldfield	57	10	107	26	4	49
Birmingham	554	98	1,041	266	46	510

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

Table 23 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 $PM_{2.5}$ and NO_2 (with cut-off), total population in each constituency in 2011, mortality rate (total death age 30 plus divided by total population age 30 plus) in each constituency, ratio of the population age 65 and above over the total population in each constituency and deprivation index Carstairs quintiles[22]

Zone	Anthropogenic $PM_{2.5}$ 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*)				
Edgbaston	47 - 59	96,579	1.29%	14%	4.5
Erdington	75 - 91	97,791	1.62%	14%	5
Hall Green	46 - 57	115,921	1.07%	11%	4.5
Hodge Hill	69 - 85	121,700	1.49%	10%	5
Ladywood	50 - 60	126,713	1.03%	7%	5
Northfield	49 - 64	101,434	1.29%	15%	5
Perry Barr	56 - 69	107,105	1.20%	12%	4.75
Selly Oak	56 - 72	104,078	1.51%	14%	4.5
Yardley	65 - 81	95,115	1.45%	14%	5
Sutton Coldfield	56 - 72	106,753	1.31%	20%	2.25

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

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

22 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

Table 24 Estimated burden (from multi pollutant study) of effects on annual mortality in 2011 of 2011 levels of anthropogenic $PM_{2.5}$ and NO_2 (without cut-off)

Zone	Anthropogenic $PM_{2.5}$ (without cut-off) (not to be used separately)				NO_2 (without cut-off) (not to be used separately)				Anthropogenic $PM_{2.5}$ and 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
Edgbaston	24	27	42	16	30	25	17	31	54	52	59	47
Erdington	35	39	62	23	49	42	29	52	84	81	91	75
Hall Green	23	26	40	15	29	25	17	31	52	51	57	46
Hodge Hill	33	37	58	22	45	38	27	47	78	75	85	69
Ladywood	22	25	40	15	33	28	20	35	55	53	60	50
Northfield	26	29	46	17	31	26	18	32	57	55	64	49
Perry Barr	26	30	47	17	37	32	22	39	63	62	69	56
Selly Oak	29	32	51	19	35	30	21	37	64	62	72	56
Yardley	32	36	56	21	42	36	25	44	74	72	81	65
Sutton Coldfield	28	32	51	19	35	30	21	37	63	62	72	56
Birmingham	277	314	493	184	368	311	216	386	645	625	709	570

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

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

Table 25 Estimated burden (from multi pollutant study) of effects on annual mortality in 2011 of 2011 levels of anthropogenic $PM_{2.5}$ and NO_2 (with cut-off)

Zone	Anthropogenic $PM_{2.5}$ (with cut-off) (not to be used separately)				NO_2 (with cut-off) (not to be used separately)				Anthropogenic $PM_{2.5}$ and NO2 (with cut-off)			
	Attributable deaths				Attributable deaths				Attributable deaths			
	Jerrett	Fischer	Beelen	Crouse	Jerrett	Fischer	Beelen	Crouse	Jerrett	Fischer	Beelen	Crouse
Edgbaston	11	12	19	7	23	20	14	25	34	32	33	32
Erdington	18	20	32	12	41	35	24	43	59	55	56	55
Hall Green	11	12	19	7	24	20	14	25	35	32	33	32
Hodge Hill	16	18	29	11	37	32	22	39	53	50	51	50
Ladywood	12	14	21	8	28	24	17	30	40	38	38	38
Northfield	11	12	20	7	23	20	14	25	34	32	34	32
Perry Barr	13	15	24	9	31	26	18	33	44	41	42	42
Selly Oak	13	14	23	8	28	23	16	29	41	37	39	37
Yardley	15	17	27	10	34	29	20	36	49	46	47	46
Sutton Coldfield	13	14	23	8	28	23	16	29	41	37	39	37
Birmingham	132	150	237	87	298	252	175	313	430	402	412	400

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

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

8.4 Additional Health and economic assessment methods

Anthropogenic $PM_{2.5}$: Non-anthropogenic $PM_{2.5}$ was derived by subtracting the modelled contribution from natural sources – here sea-salt - from the total $PM_{2.5}$ modelled as above to give anthropogenic $PM_{2.5}$.

Population data in Birmingham: 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 Birmingham: 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 constituency level.

<u>Mortality Burden</u>

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

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

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

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

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

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 constituency. This allows different death rates in different wards and constituency to influence the results.

The process was repeated for the lower and upper confidence intervals around the relative risks, and for a cut-off of 7 µg m^{-3} $PM_{2.5}$.

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

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

The method using multi-pollutant model results is also based on the same method for scaling the relevant relative risks (see Table 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 NO_2 and $PM_{2.5}$ results within each study are summed and then the final result expressed as the range for the sums across the 4 studies. This can be illustrated by examining Table 24 and Table 25 (with and without the cut-offs). It can be seen for Edgbaston, for example, that the sum of column 2 (24 attributable deaths) and column 6 (30 attributable deaths) leads to the result in column 10 (54 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.

Changes in births over time by constituency – births in each local authority as above was weighted by the 2011 birth data in each constituency aggregated from the population data in Birmingham by ward using 2011 census data (as above).

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 NO_2. HRAPIE (WHO, 2013) recommended that, in the absence of information on likely lags between long-term exposure to NO_2 and mortality, calculations should follow whatever lags are chosen for $PM_{2.5}$.

Calculations

The relative risk (RR) per 10 µg m^{-3} was scaled to a new relative risk for the appropriate population-weighted mean for each gender in each parliamentary constituency 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, 2015, 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 NO_2, ward concentrations were interpolated between 2011, 2015, 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[23] 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-

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

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 parliamentary constituency were then summed to Birmingham level. We also used the life tables to calculate changes in life expectancy.

Economic valuation[24]

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:

---

[24] Much of this section is sourced from text written by Mike Holland in Williams et al (2018b).

WTP to avoid lost utility (being well, and enjoying the opportunities that good health offers)
The costs of health care
Costs to the marketed economy through lost productivity
Costs have been defined for a variety of endpoints of relevance to air pollution in analysis for UK government and also for other bodies, such as the European Commission (Holland, 2014a and 2014b).

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 26) is so slight this will still make little difference.

Table 26 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).

9.0 References

Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z. J., Weinmayr, G., Hoffmann, B., Wolf, K., Samoli, E., Fischer, P., Nieuwenhuijsen, M., Vineis, P., Xun, W. W., Katsouyanni, K., Dimakopoulou, K., Oudin, A., Forsberg, B., Modig, L., Havulinna, A. S., Lanki, T., Turunen, A., Oftedal, B., Nystad, W., Nafstad, P., De Faire, U., Pedersen, N. L., Ostenson, C. G., Fratiglioni, L., Penell, J., Korek, M., Pershagen, G., Eriksen, K. T., Overvad, K., Ellermann, T., Eeftens, M., Peeters, P. H., Meliefste, K., Wang, M., Bueno-De-Mesquita, B., Sugiri, D., Kramer, U., Heinrich, J., De Hoogh, K., Key, T., Peters, A., Hampel, R., Concin, H., Nagel, G., Ineichen, A., Schaffner, E., ProbstHensch, N., Kunzli, N., Schindler, C., Schikowski, T., Adam, M., Phuleria, H., Vilier, A., Clavel-Chapelon, F., Declercq, C., Grioni, S., Krogh, V., Tsai, M. Y., Ricceri, F., Sacerdote, C., Galassi, C., Migliore, E., Ranzi, A., Cesaroni, G., Badaloni, C., Forastiere, F., Tamayo, I., Amiano, P., Dorronsoro, M., Katsoulis, M., Trichopoulou, A., Brunekreef, B. & Hoek, G. 2014. Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. The Lancet, 383, 785-95.

Chilton S, Covey J, Jones-Lee M, Loomes G and Metcalf H (2004) Valuation of health benefits associated with reductions in air pollution. Department for Environment, Food and Rural Affairs, London. Available at: randd.defra.gov.uk/Document.aspx?Document=EP01006_4723_FRP.pdf

COMEAP (Committee on the Medical Effects of Air Pollutants), 2010, The mortality effects of long-term exposure to particulate matter air pollution in the UK, London, UK. Available at http://comeap.org.uk/documents/reports/128-the-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-uk.html. (Accessed 7 June 2019).

COMEAP (2015) Interim Statement on Quantifying the Association of Long-Term Average Concentrations of Nitrogen Dioxide and Mortality. https://www.gov.uk/government/publications/nitrogen-dioxide-interim-view-on-long-term-average-concentrations-and-mortality. (Accessed 7 June 2019).

COMEAP (2016) Minutes of the meeting held on Wednesday 24th February 2016 COMEAP/2016/MIN/1 'Choice of cut-off' under Item 5. Available from https://www.gov.uk/government/groups/committee-on-the-medical-effects-of-air-pollutants-comeap#minutes. (Accessed 7 June 2019).

COMEAP (2017) Annex A in Technical Report to Department for Environment Food & Rural Affairs (DEFRA). Air quality plan for nitrogen dioxide (NO2) in the UK, 2017, 'UK Plan for tackling roadside nitrogen dioxide concentrations – technical report'. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/632916/air-quality-plan-technical-report.pdf. (Accessed 7 June 2019).

COMEAP (2018a). Associations of long-term average concentrations of nitrogen dioxide with mortality. A report by the Committee on the Medical Effects of Air Pollutants. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf. (Accessed 7 June 2019).

COMEAP (2018b) Statement on quantifying mortality associated with long-term average concentrations of fine particulate matter (PM2.5) Available at: https://www.gov.uk/government/publications/particulate-air-pollution-effects-on-mortality. (Accessed 11 June 2019)

Crouse, D. L., Peters, P. A., Hystad, P., Brook, J. R., Van Donkelaar, A., Martin, R. V., Villeneuve, P. J., Jerrett, M., Goldberg, M. S. & Pope Iii, C. A. 2015a. Ambient PM2. 5, O3, and NO2 exposures and associations with mortality over 16 years of follow-up in the Canadian Census Health and Environment Cohort (CanCHEC). Environmental Health Perspectives, 123, 1180.

Dajnak D, Walton H, Smith J D and Beevers S (June 2018). Greater Manchester Health and Economic Impact Assessment study. This report was produced by King's College London for IPPR North. ATMOSPHERE TOWARDS A PROPER STRATEGY FOR TACKLING GREATER MANCHESTER'S AIR POLLUTION CRISIS (June 2018). IPPR North; Ed Cox and Dom Goggins. https://www.ippr.org/publications/atmosphere. (Accessed 7 June 2019).

Defra (2019) Impact Pathways Approach Guidance for Air Quality Appraisal. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770649/impact-pathway-approach-guidance.pdf. (Accessed 7 June 2019).

DfT (Department for Transport) (2017) Transport Analysis Guidance (TAG), March 2017. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/603277/webtag-databook-march-2017-release-v1-7.xls. (Accessed 7 June 2019).

ExternE (2005) ExternE – Externalities of Energy, Methodology 2005 update. http://www.externe.info/externe_d7/sites/default/files/methup05a.pdf. (Accessed 7 June 2019).

Fischer, P. H., Marra, M., Ameling, C. B., Hoek, G., Beelen, R., De Hoogh, K., Breugelmans, O., Kruize, H., Janssen, N. A. & Houthuijs, D. 2015. Air Pollution and Mortality in Seven Million Adults: The Dutch Environmental Longitudinal Study (DUELS). Environmental Health Perspectives, 123, 697-704.Fung K and Krewski D 1999. On Associations of long-term average concentrations of nitrogen dioxide with mortality 112 measurement error adjustment methods in poisson regression. Environmetrics 10, 213- 224.

Gowers A, Miller BG, Stedman JR, Estimating the mortality burdens associated with particulate air pollution, Public Health England, Report number PHE-CRCE-010, 2014.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332854/PHE_CRCE_010.pdf
http://www.hpa.org.uk/Publications/Environment/PHECRCEReportSeries/PHECRCE010/. (Accessed 7 June 2019).

HMT (2019) Valuing impacts on air quality: May 2013 Supplementary Green Book guidance. HM Treasury. https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent. (Accessed 7 June 2019).

HMT (2018). The Green Book: appraisal and evaluation in central government. Published by HMT. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf. (Accessed 7 June 2019).

Hoek, G., Krishnan, R. M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B. & Kaufman, J. D. 2013. Long-term air pollution exposure and cardio- respiratory mortality: a review. Environ Health, 12, 43.

Holland, M. (2014a) Implementation of the HRAPIE Recommendations for European Air Pollution CBA work. Report to European Commission DG Environment. January 2014.

Holland, M. (2014b) Cost-benefit analysis of final policy scenarios for the EU Clean Air Package. Corresponding to IIASA TSAP report no.11. Report to European Commission DG Environment. March 2014. http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf. (Accessed 7 June 2019).

IOM (2013) IOMLIFET: A Spreadsheet System For Life table Calculations For Health Impact Assessment Available at: https://www.iom-world.org/research/our-expertise/iomlifet/. (Accessed 7 June 2019). (Accessed 7 June 2019).

Jerrett, M., Burnett, R. T., Beckerman, B. S., Turner, M. C., Krewski, D., Thurston, G., Martin, R. V., Van Donkelaar, A., Hughes, E., Shi, Y., Gapstur, S. M., Thun, M. J. & Pope, C. A., 3rd 2013. Spatial analysis of air pollution and mortality in California. Am J Respir Crit Care Med, 188, 593-9.Kim, J.Y., et al., 2007. Panel discussion review: session two--interpretation of observed associations between multiple ambient air pollutants and health effects in epidemiologic analyses. J Expo Sci Environ Epidemiol 17 Suppl 2, S83-9. doi: 10.1038/sj.jes.750062

Morgan, O. and A. Baker (2006). "Measuring deprivation in England and Wales using 2001 Carstairs scores." Health Statistics Quarterly **31**: 28-33.

OECD (2012) Mortality Risk Valuation in Environment, Health and Transport Policies. OECD, Paris.

ONS (Office for National Statistics) (2012) Dataset(s):2011 Census: Population and Household Estimates for Wards and Output Areas in England and Wales https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/2011censuspopulationandhouseholdestimatesforwardsandoutputareasinenglandandwales. (Accessed 7 June 2019).

ONS - Office for National Statistics (2015a) All data related to national population projections 2014-based statistical bulletin
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2015-10-29/relateddata. (Accessed 7 June 2019).

ONS - Office for National Statistics (2015b) Compendium: Mortality assumptions (2014-based national population projections)
http://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/compendium/nationalpopulationprojections/2015-10-29/mortalityassumptions. (Accessed 7 June 2019).

ONS - Office for National Statistics (2016a) Dataset: Lower Super Output Area Mid-Year Population Estimates (supporting information)
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/lowersuperoutputareamidyearpopulationestimates. (Accessed 7 June 2019).
110 Office for National Statistics (2016b) VS4: Births and Mortality data by ward; 2011 Email to H Walton 5/8/2016.

ONS - Office for National Statistics (2016c) User requested data: Deaths by LSOA, single year of age and sex, England and Wales, 2014 registrations
https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/005453deathsbylsoasingleyearofageandsexenglandandwales2014registrations. (Accessed 7 June 2019).

ONS - Office for National Statistics (2016d) Dataset: Births by mothers' usual area of residence in the UK. https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/livebirths/datasets/birthsbyareaofusualresidenceofmotheruk. (Accessed 7 June 2019).

ONS - Office for National Statistics (2016e) Sub-national population projections, local authorities in England SNPP Z1 – 2014 based
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/localauthoritiesinenglandz1. (Accessed 7 June 2019).

Walton H, Dajnak D, Beevers SD, Williams ML, Watkiss P, Hunt A, Understanding the Health Impacts of Air Pollution in London, King's College London 2015 available at: https://www.london.gov.uk/sites/default/files/hiainlondon_kingsreport_14072015_final.pdf. (Accessed 7 June 2019).

Williams ML, Lott MC, Kitwiroon N, Dajnak D, Walton H, Holland M, Pye S, Fecht D, Toledano MB, Beevers SD (2018a) The Lancet Countdown on health benefits from the UK Climate Change Act: a modelling study for Great Britain. Lancet Planetary Health 2 (5): e202-e213

Williams ML, Lott MC, Kitwiroon N, Dajnak D, Walton H, Holland M, Pye S, Fecht D, Toledano MB, Beevers SD (2018b) Public health air pollution impacts of different pathways to meet the UK Climate Change Act commitment to 80% reduction on CO2 and other greenhouse gas emissions by 2050. Full report in press, summary at https://www.journalslibrary.nihr.ac.uk/programmes/phr/11300513/#/. (Accessed 7 June 2019).

World Health Organisation (2013), Health risks of air pollution in Europe-HRAPIE project, WHO Regional office for Europe,. Available at:http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project.-recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide. (Accessed 7 June 2019).