Greater Manchester Health and Economic Impact Assessment study

For: IPPR North

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Executive Summary and Key results

IPPR North commissioned Kings College London (King's) to produce a health and economic Impact assessment associated with current and future pollution levels in Greater Manchester region. In this study, King's combined the relationships between Defra's Air Quality modelling concentrations and health outcomes for each local authority in Greater Manchester. King's has previously carried out similar studies for London but to our knowledge this is the first time that the new health impact recommendations (COMEAP, 2017) have been applied in practice in a full impact pathway approach in a large area.

Mortality impact (long –term exposure)

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 0.6 to 1.6 million life years as a result of air pollution changes in Greater Manchester (a life year is one person living for one year).

This can also be represented as a loss in life expectancy from birth in 2011 of around 2 to 6 months.

The population in Greater Manchester would gain around 930,000 life years over a lifetime if air pollution concentrations improved as projected, compared with remaining at 2011 concentrations.

This can also be represented as an improvement in average life expectancy from birth in 2011 of around 3.5 months.

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 overestimation (details in the report below).

Economic costs

Despite the projected future improvements in air pollution concentrations from 2011 to 2030, the annualised economic health impact costs between 2011 and 2030 are still between £0.3 - £1bn.

The monetary benefits 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 £0.5 billion on average/year (at 2014 prices).

Mortality burden (long –term exposure)

Greater Manchester's total mortality burden from anthropogenic $PM_{2.5}$ for the year 2011 is estimated to be equivalent to 1,459 attributable deaths mostly at older ages as is typical the ages for deaths in the general population.

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.

There will be further impacts from ozone concentrations and on effects of all pollutants on illness other than deaths but these were not assessed in this study.

Introduction

IPPR North (IPPRN) has asked King's College London (King's) to help produce an Health Impact assessment (HIA) and economic assessment of Greater Manchester (GM) formed of ten local authorities (LA) (Bolton, Bury, Manchester, Oldham, Rochdale, Salford, Stockport, Tameside, Trafford and Wigan). To do this, King's first downloaded the air quality data in each LA, 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 LA.

Method

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 GM, 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', 'Northern England' and 'Wales' 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 LA concentration

Population-weighting average concentration (PWAC): Population-weighting was done at Ward level. The ward concentrations were multiplied by the population aged 30 plus for each gender and the resulting population-concentration product summed across all wards in each local authority and then divided by the local authority population. The local authority population-weighted means were then used directly in the health impact calculations across all LA. (This process allows one health calculation per local authority rather than calculations in each separate ward).

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 tables A1 and A2 in the Appendix. The concentration-response functions are based on the latest advice from the Committee on the Medical Effects of Air Pollutants in 2017 (COMEAP, 2017).

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

Economic assessment

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[1], 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.[2] 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.

[1] Defra (2013) Impact pathway guidance for valuing changes in air quality
[2] HM Treasury (2011) The Green Book

Air Quality modelling

2011 and 2015 concentrations representing current reference years and any future years up to 2030 have been estimated. 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 LA is shown in Table 1 and 2 for anthropogenic $PM_{2.5}$ and NO_2, respectively.

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

Local authority	2011	2015	2020	2025	2030
Bolton	11.02	8.11	7.65	7.50	7.48
Bury	11.31	7.81	7.37	7.23	7.20
Manchester	11.90	8.39	7.87	7.71	7.69
Oldham	11.57	8.00	7.55	7.41	7.39
Rochdale	11.24	7.74	7.31	7.17	7.15
Salford	12.00	8.44	7.93	7.77	7.74
Stockport	11.33	7.98	7.49	7.34	7.31
Tameside	11.69	8.17	7.69	7.55	7.53
Trafford	11.19	7.96	7.48	7.33	7.30
Wigan	10.65	8.25	7.82	7.67	7.64

Table 2 NO_2 PWAC (in µg m^{-3}) by local authority

Local authority	2011	2015	2020	2025	2030
Bolton	20.75	17.72	14.00	11.33	10.00
Bury	22.14	18.36	14.60	11.70	10.23
Manchester	25.67	22.22	17.62	14.11	12.38
Oldham	22.42	18.44	14.77	12.09	10.77
Rochdale	21.20	17.22	13.74	11.16	9.83
Salford	26.17	21.89	17.30	13.80	12.02
Stockport	21.64	18.80	15.01	12.18	10.75
Tameside	22.84	18.70	14.99	12.36	11.05
Trafford	22.32	19.08	15.13	12.07	10.55
Wigan	18.71	15.39	12.25	10.03	8.91

Maps of $PM_{2.5}$ and NO_2 annual mean concentration by wards are shown in Figure 1 and 2, respectively.

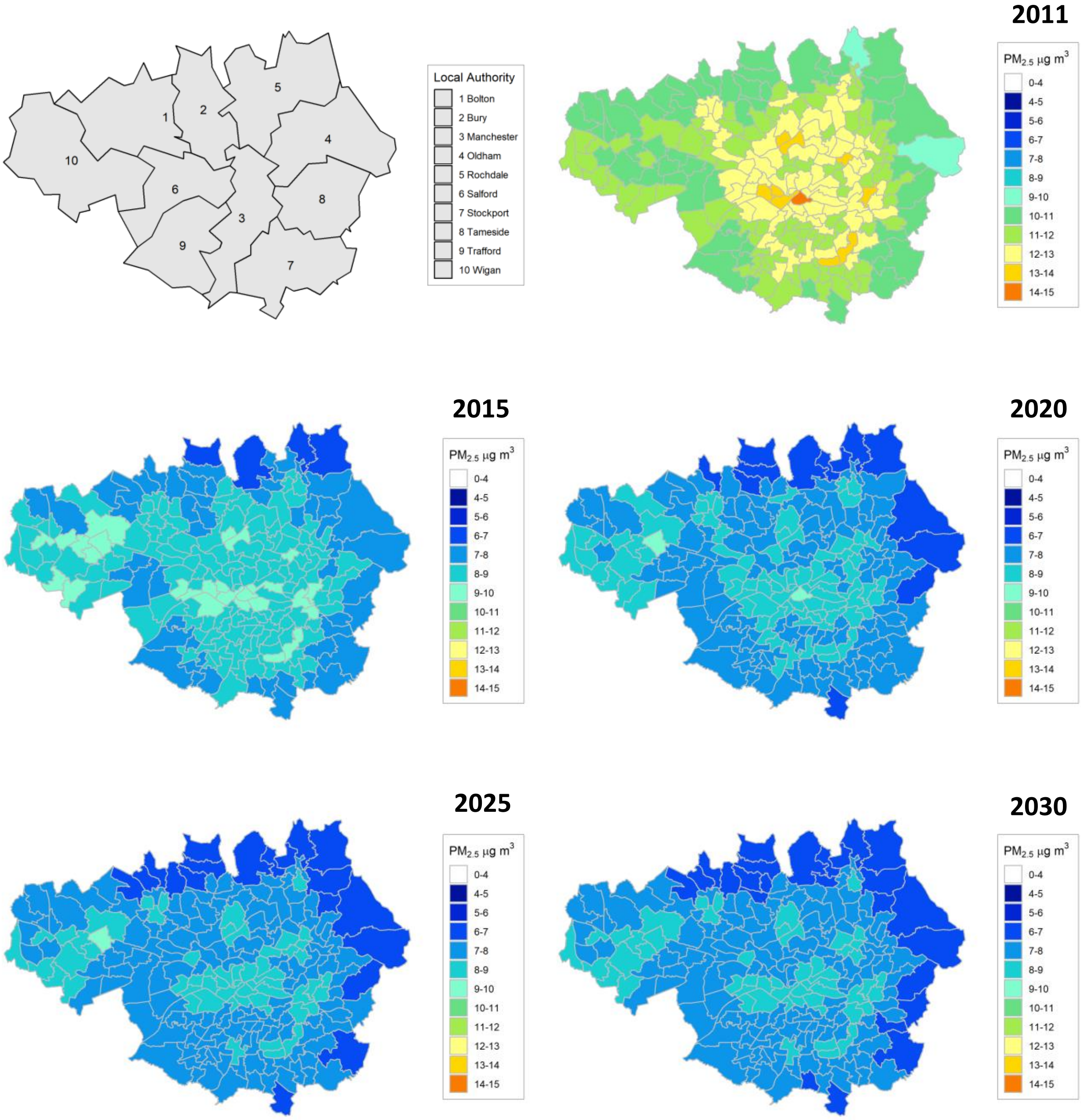

Figure 1 Annual mean $PM_{2.5}$ concentrations (in µg m^{-3}) by wards between 2011 and 2030

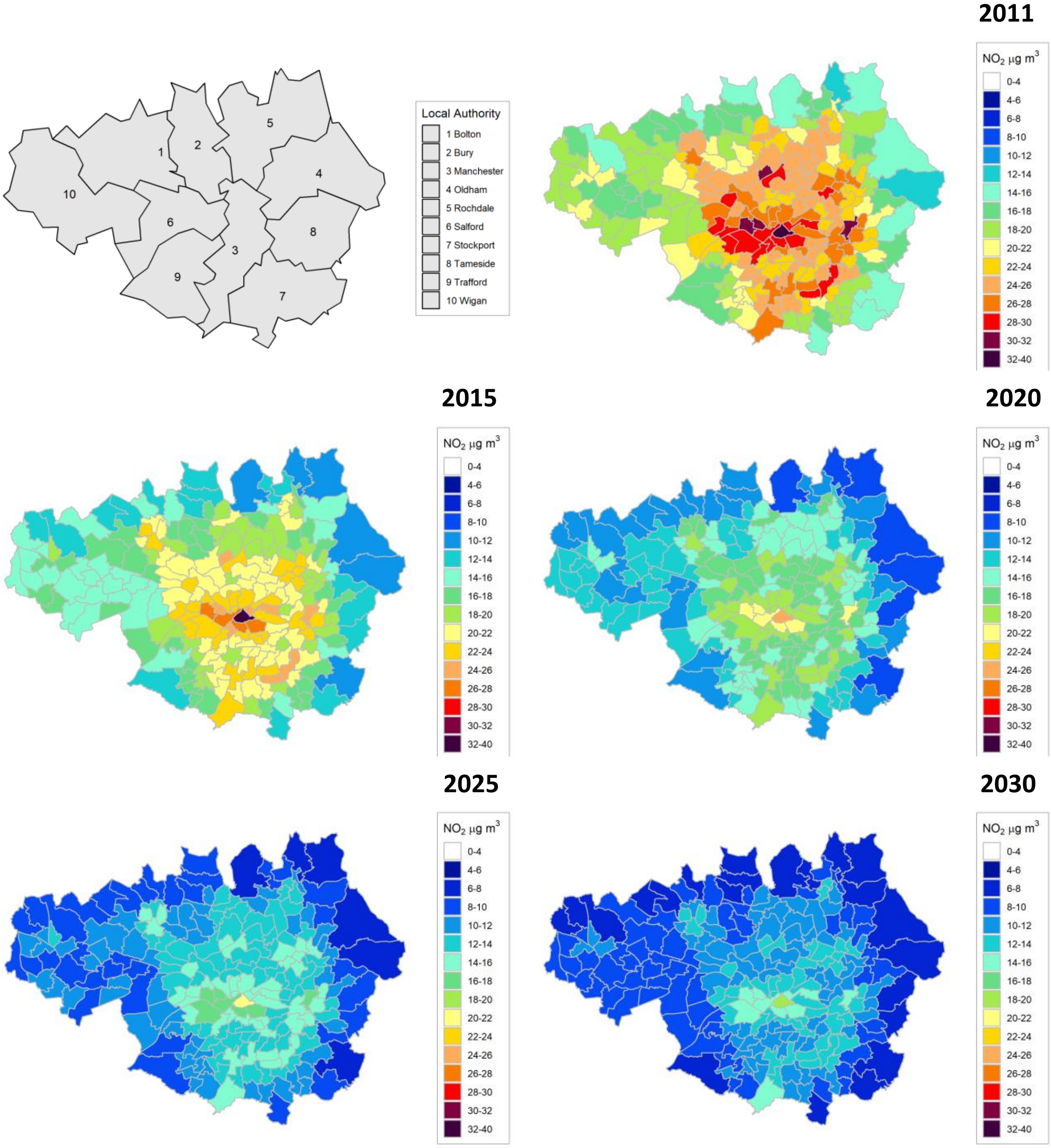

Figure 2 Annual mean NO_2 concentrations (in µg m^{-3}) by wards between 2011 and 2030

Health and economic impact results

Estimates of the mortality burden of air pollution

The 2011 mortality burden in GM of 2011 levels of anthropogenic $PM_{2.5}$ was estimated to be equivalent to 1,459 (range 993 to 1,906) attributable deaths at typical ages. Estimates for individual local authorities are provided in Table 3.

Table 3 Estimated burden of effects on annual mortality in 2011 of 2011 levels of anthropogenic $PM_{2.5}$

Zone	Anthropogenic $PM_{2.5}$ Attributable deaths		
	Central estimate	Lower estimate	Upper estimate
Bolton	154	105	201
Bury	106	72	139
Manchester	225	153	294
Oldham	129	88	169
Rochdale	116	79	151
Salford	142	97	185
Stockport	159	108	207
Tameside	142	96	185
Trafford	114	78	149
Wigan	172	117	225
GM	1,459	993	1,906

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

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 below and do not reflect the impact over many years. They are included here as a comparison with similar calculations presented elsewhere (COMEAP, 2010; Walton et al., 2015). The concentration-response functions used for these calculations are evolving over time. 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). Thus, we have not included NO_2 results here but for completeness, the 2011 mortality burden estimates for individual local authorities and GM of 2011 levels of NO_2 can be found the appendix in Table A3. New methods for burden calculations are being developed by COMEAP (COMEAP, 2018 in press) but these were not available at the time of preparation of this report.

[Burden calculations would normally include accompanying estimates of the burden life years lost[3]. 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.]

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[3] 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.

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).

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

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 4, for anthropogenic $PM_{2.5}$ and NO_2. Results for each local authority can be found in the Appendix in Table A4 (life table calculations for anthropogenic $PM_{2.5}$), Table A5 (life table calculations for NO_2) and Table A6a and Table A6b (annualised economic impact).

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 GM over 124 years. For context, the total life years lived with baseline mortality rates is around 409 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 1.01 - 2.46 million life years would be lost across GM's population over that period. This improves to around 0.2 - 1.6 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 1.5 - 1.9 million life years would be lost across GM's population over that period. This improves to around 0.6 - 1 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) 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 this case, for no cut-off, this is the result for $PM_{2.5}$. However, for the cut-off, this is the result for NO_2. 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 0.6 to 1.6 million life years lost for the population of Greater Manchester over 124 years.

Table 4 Total life years lost across GM population for anthropogenic $PM_{2.5}$ and NO_2 and 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	2,457,123 1,011,212	£1,419,199,403 £583,416,214
	Predicted concentration between 2011 and 2030	**1,638,043** 175,471	**£954,495,447** £109,582,547
NO_2 (representing the local mixture and the rural air pollution mixture)	Concentration does not reduce from 2011 levels	1,910,048 1,492,380	£1,101,749,453 £860,330,227
	Predicted concentration between 2011 and 2030	981,519 **561,169**	£586,562,264 **£343,719,554**

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[4], 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 4 also gives the economic impacts (economic costs). Note that these are derived from applying monetary valuation to the health impacts. The monetary values are derived from surveys of what people are willing to pay to avoid the risk of the relevant health impact. They do not represent the costs of the policies or the costs to the NHS.

If 2011 concentrations of anthropogenic $PM_{2.5}$ remained unchanged for 124 years, the annualised economic cost would be around £0.6 – 1.4 billion. This improves to around £0.1 – 1 billion with the projected baseline concentration changes examined here.

[4] 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.

If 2011 concentrations of NO_2 remained unchanged for 124 years, the annualized economic cost would be around £0.9 – 1.1 billion. This improves to around £0.3 – 0.6 billion 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 £0.3 to 1 billion.

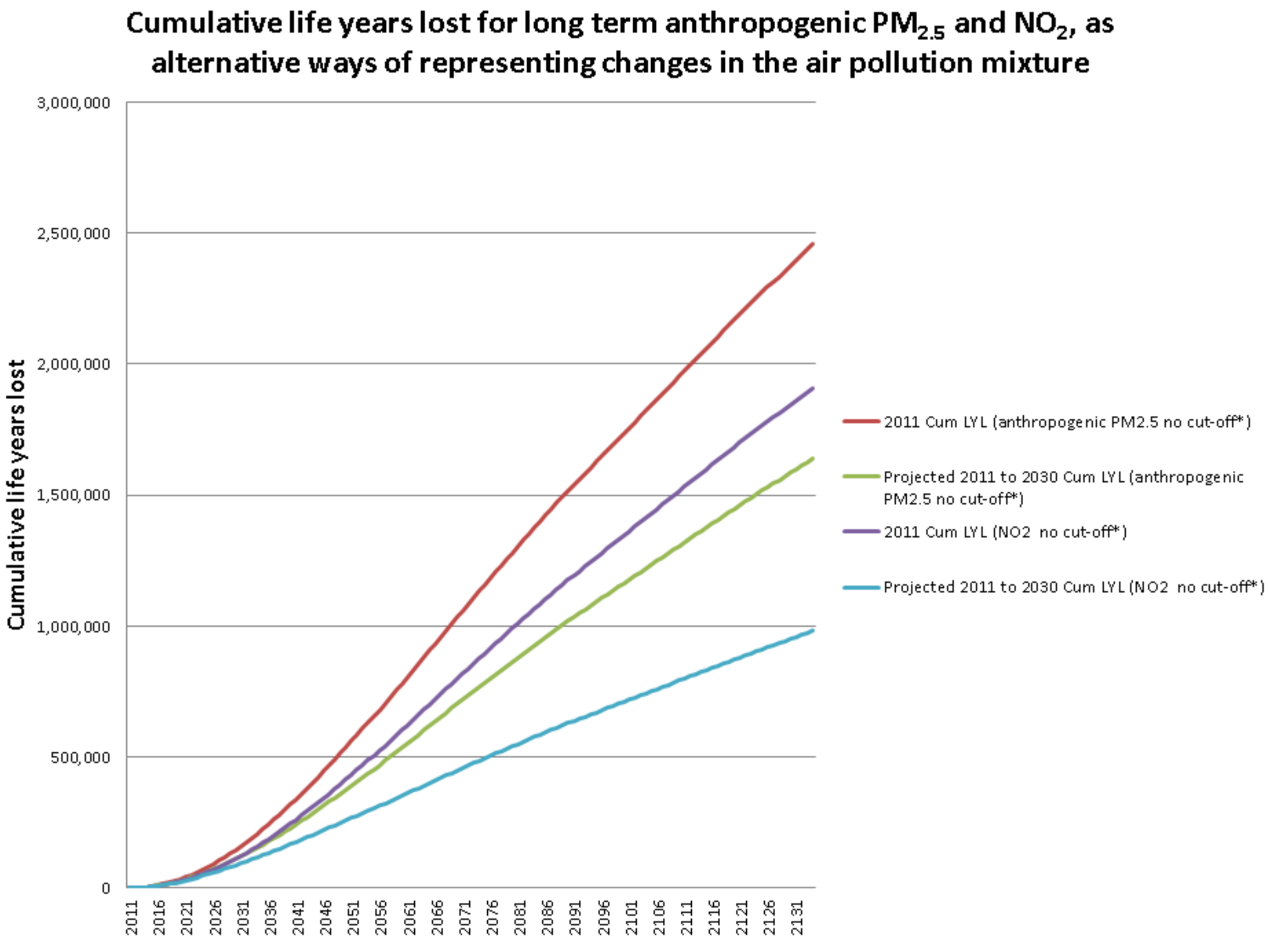

Figure 3 Cumulative life years lost for anthropogenic $PM_{2.5}$ and NO_2 2011 concentrations remained unchanged and the baseline (current policies 2011-2030) across GM population (no migration), with projected new births, compared with life years lived with baseline mortality rates (incorporating mortality 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 3 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 5 shows the differences between the predicted concentration 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 820,000 to 835,000 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 930,000 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 changes in the traffic pollution mixture seems more appropriate for future changes as presented here. This is a different indicator compared with the overall impact in terms of life years lost[5]. 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 overall summary would be that taking into account predicted air pollution concentration between 2011 and 2030, the population in Greater Manchester would gain around 930,000 life years over a lifetime.

Table 5 Life years saved (and associated monetised benefits) across GM 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	819,081 835,741	£464,703,956 £473,833,667
NO_2 (representing the local mixture and the rural air pollution mixture)	Predicted concentration between 2011 and 2030	**928,528** **931,211**	**£515,187,190** **£516,610,673**

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

[5] 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 5 also provides an estimate of the economic impact as a result of the improvements in pollution from 2011 to 2030 versus 2011 pollution remaining unchanged. The annualised monetary benefit of anthropogenic $PM_{2.5}$ and NO_2 improvements has been estimated to be up to £0.5 billion (at 2014 prices).

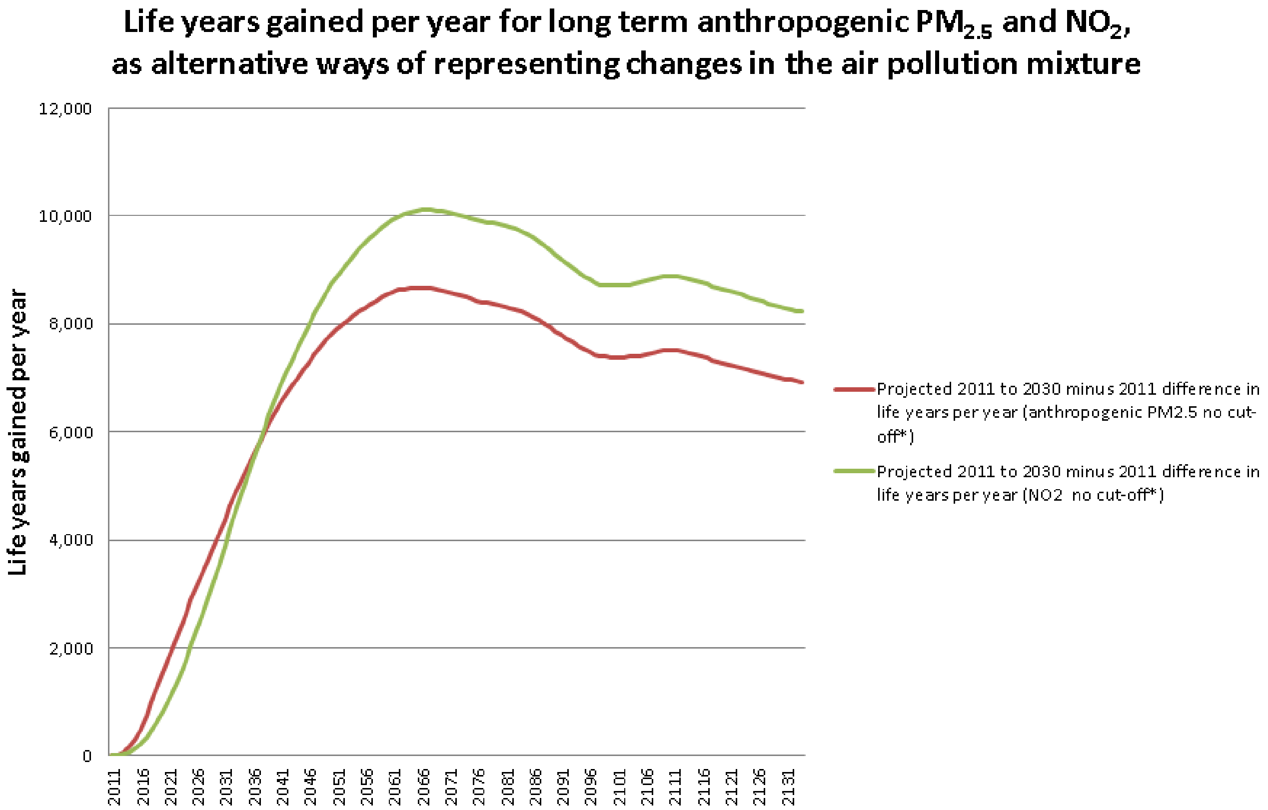

Figure 4 Life years gained per year from long-term exposure to the improvements in pollution from 2011 to 2030 of anthropogenic $PM_{2.5}$ and NO_2 relative to 2011 concentrations remaining unchanged

* Cut-off results not shown

Figure 4 shows the effect of the decrease in $PM_{2.5}$ and NO_2 concentration from 2011 to 2030 (as seen in Tables 1 and 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 6. Results for each local authority can be found in the Appendix in Table A7 (Loss of life expectancy for anthropogenic $PM_{2.5}$ and NO_2).

This shows that the average loss of life expectancy from birth in GM would be about 15 – 37 weeks for male and 13 – 32 weeks for female if 2011 $PM_{2.5}$ concentrations were unchanged but

improves to 2 – 24 weeks for male and 2 – 21 weeks for female for the predicted concentration between 2011 and 2030 (an improvement by about 11-13 weeks).
Using NO_2, the average loss of life expectancy from birth in GM would be about 22 – 29 weeks for male and 20 – 25 weeks for female if NO_2 concentrations were unchanged from 2011 but improves by about 13-15 weeks to 8 – 14 weeks for male and 7 – 12 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 3.5 months (13 – 15 weeks) but an average loss of life expectancy from birth in 2011 of around 2 to 6 months (7 – 24 weeks) remains even with the reduced concentrations.

Table 6 Loss of life expectancy by gender across GM 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	36.6 15.2	32.2 13.3
	Predicted concentration between 2011 and 2030	**24.1** 2.3	**21.2** 2.0
NO_2	Concentration does not reduce from 2011 levels	28.6 22.4	25.1 19.6
	Predicted concentration between 2011 and 2030	13.7 **7.5**	12.0 **6.5**

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 annualised economic impact and the loss of life expectancy lower and upper estimate and the full range of confidence intervals with and without counterfactual for both $PM_{2.5}$ and NO_2 are available upon request to the authors.

Appendix

Additional tables

Table A1 Concentration-response functions (CRFs) for long-term exposures and mortality

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	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)

Table A2 Geographic scales of health impact calculations

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

Additional 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 A3 Estimated burden of effects on annual mortality in 2011 of 2011 levels of NO_2

Zone	NO_2 Attributable deaths		
	Central estimate	Lower estimate	Upper estimate
Bolton	116	41	182
Bury	82	29	129
Manchester	190	68	298
Oldham	99	35	156
Rochdale	86	31	136
Salford	122	44	191
Stockport	119	42	187
Tameside	110	39	172
Trafford	89	32	140
Wigan	120	42	189
GM	1,132	404	1,781

Using COMEAP's recommended concentration-response coefficient of 1.023 per 10 µg m^{-3} of anthropogenic $PM_{2.5}$ for the central estimate (lower estimate RR of 1.008 and upper estimate RR 1.037)

Table A4 Life years lost by gender across the local authorities and GM 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
Bolton	Female	110,214	74,363	145,221	76,013	51,247	100,235
Bolton	Male	125,992	85,008	166,012	86,925	58,604	114,625
Bury	Female	73,641	49,681	97,042	47,819	32,233	63,068
Bury	Male	82,653	55,763	108,915	53,687	36,190	70,805
Manchester	Female	257,517	173,998	338,835	169,058	114,072	222,748
Manchester	Male	304,577	205,573	401,181	199,758	134,693	263,378
Oldham	Female	98,252	66,323	129,398	63,973	43,139	84,342
Oldham	Male	110,444	74,527	145,505	71,828	48,424	94,719
Rochdale	Female	88,840	59,979	116,987	57,671	38,892	76,027
Rochdale	Male	99,675	67,253	131,335	64,683	43,605	85,303
Salford	Female	114,637	77,425	150,899	75,454	50,899	99,443
Salford	Male	128,822	86,953	169,672	84,632	57,068	111,581
Stockport	Female	107,348	72,482	141,342	70,860	47,791	93,405
Stockport	Male	117,500	79,301	154,780	77,430	52,207	102,094
Tameside	Female	93,826	63,293	123,650	61,567	41,499	81,202
Tameside	Male	104,690	70,610	137,992	68,725	46,320	90,652
Trafford	Female	88,146	59,523	116,046	58,666	39,571	77,325
Trafford	Male	94,163	63,563	124,014	62,555	42,184	82,469
Wigan	Female	122,876	82,902	161,912	89,596	60,408	118,140
Wigan	Male	133,310	89,911	175,719	97,147	65,484	128,127
GM	Female	1,155,296	779,970	1,521,332	770,674	519,751	1,015,935
GM	Male	1,301,827	878,461	1,715,125	867,368	584,780	1,143,753
GM	Total	2,457,123	1,658,431	3,236,458	1,638,043	1,104,530	2,159,688

Table A5 Life years lost by gender across the local authorities and GM 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
Bolton	Female	80,973	28,471	128,957	42,114	14,784	67,172
Bolton	Male	92,872	32,655	147,907	48,374	16,983	77,154
Bury	Female	56,366	19,818	89,768	28,266	9,922	45,088
Bury	Male	63,231	22,234	100,698	31,771	11,154	50,673
Manchester	Female	216,659	76,400	344,118	111,078	39,049	176,942
Manchester	Male	257,412	90,608	409,513	131,990	46,361	210,416
Oldham	Female	74,402	26,182	118,400	38,391	13,482	61,213
Oldham	Male	83,753	29,457	133,345	43,100	15,132	68,737
Rochdale	Female	65,525	23,060	104,266	32,885	11,549	52,434
Rochdale	Male	73,520	25,851	117,085	36,926	12,963	58,898
Salford	Female	97,595	34,393	155,098	48,538	17,056	77,348
Salford	Male	109,931	38,701	174,865	54,656	19,199	87,127
Stockport	Female	80,097	28,195	127,428	43,268	15,198	68,975
Stockport	Male	87,949	30,938	140,005	47,305	16,612	75,429
Tameside	Female	71,599	25,171	114,042	37,263	13,080	59,438
Tameside	Male	79,998	28,117	127,451	41,727	14,647	66,563
Trafford	Female	68,679	24,185	109,222	35,334	12,413	56,323
Trafford	Male	73,453	25,851	116,875	37,598	13,205	59,945
Wigan	Female	84,429	29,678	134,498	43,648	15,320	69,631
Wigan	Male	91,603	32,185	145,988	47,287	16,595	75,448
GM	Female	896,325	315,553	1,425,796	460,784	161,855	734,562
GM	Male	1,013,722	356,597	1,613,732	520,735	182,851	830,390
GM	Total	1,910,048	672,150	3,039,529	981,519	344,706	1,564,952

Table A6a Central Annualised economic impact estimate (in 2014 prices) across the local authorities and GM 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
Bolton	£137,066,674	£95,325,026	£100,870,878	£54,451,019
Bury	£91,373,983	£59,909,105	£69,914,314	£36,492,600
Manchester	£313,723,487	£207,335,151	£264,592,054	£139,793,276
Oldham	£120,160,112	£78,896,199	£91,051,381	£48,556,980
Rochdale	£109,672,208	£71,848,995	£80,886,238	£42,149,668
Salford	£138,907,493	£92,155,823	£118,398,649	£61,160,573
Stockport	£133,470,626	£88,885,069	£99,737,108	£55,785,561
Tameside	£116,193,614	£76,996,218	£88,727,173	£47,897,175
Trafford	£106,813,195	£71,654,496	£83,263,524	£44,368,472
Wigan	£151,818,011	£111,489,366	£104,308,133	£55,906,940
GM	£1,419,199,403	£954,495,447	£1,101,749,453	£586,562,264

Table A6b Lower and upper Annualised economic impact estimate (in 2014 prices) across the local authorities and GM 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
Bolton	£71,629,372	£119,293,195	£40,915,722	£68,141,979
Bury	£45,017,051	£74,972,427	£27,421,362	£45,668,163
Manchester	£155,796,302	£259,466,727	£105,043,816	£174,942,375
Oldham	£59,284,381	£98,733,565	£36,486,809	£60,765,966
Rochdale	£53,988,953	£89,914,438	£31,672,210	£52,747,624
Salford	£69,247,961	£115,327,139	£45,957,433	£76,538,560
Stockport	£66,790,243	£111,233,999	£41,918,527	£69,812,074
Tameside	£57,856,692	£96,355,859	£35,991,016	£59,940,262
Trafford	£53,842,802	£89,671,035	£33,339,469	£55,524,315
Wigan	£83,775,621	£139,521,836	£42,009,734	£69,963,972
GM	£717,229,378	£1,194,490,220	£440,756,097	£734,045,290

Table A7 Loss of life expectancy by gender across the local authorities and GM from birth in 2011 for anthropogenic $PM_{2.5}$ and NO_2

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
Bolton	Female	30.4	20.7	22.4	10.8
Bolton	Male	34.9	23.8	25.8	12.5
Bury	Female	30.4	19.5	23.3	10.8
Bury	Male	34.9	22.3	26.7	12.4
Manchester	Female	35.6	23.1	30.0	14.5
Manchester	Male	41.5	26.9	35.1	17.0
Oldham	Female	32.3	20.8	24.5	11.8
Oldham	Male	36.8	23.6	28.0	13.5
Rochdale	Female	31.4	20.1	23.2	10.8
Rochdale	Male	36.4	23.3	26.9	12.5
Salford	Female	35.3	22.9	30.0	13.9
Salford	Male	39.3	25.5	33.6	15.5
Stockport	Female	28.6	18.6	21.4	10.7
Stockport	Male	32.5	21.1	24.3	12.1
Tameside	Female	33.1	21.4	25.3	12.3
Tameside	Male	37.5	24.2	28.7	13.9
Trafford	Female	28.9	19.0	22.6	10.7
Trafford	Male	31.6	20.7	24.7	11.7
Wigan	Female	30.7	22.1	21.1	10.1
Wigan	Male	33.4	24.1	23.0	11.0
GM	Female	32.2	21.2	25.1	12.0
GM	Male	36.6	24.1	28.6	13.7

Table A8 Life years lost by gender across the local authorities and GM 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
Bolton	Female	42,635	28,723	56,263	7,889	5,311	10,417
Bolton	Male	48,888	32,936	64,514	9,187	6,185	12,132
Bury	Female	29,759	20,049	39,272	3,838	2,584	5,068
Bury	Male	33,402	22,503	44,078	4,317	2,907	5,700
Manchester	Female	112,098	75,575	147,822	20,903	14,075	27,599
Manchester	Male	132,922	89,573	175,362	25,285	17,024	33,387
Oldham	Female	40,902	27,563	53,962	6,232	4,196	8,229
Oldham	Male	46,029	31,014	60,734	7,020	4,726	9,270
Rochdale	Female	35,511	23,931	46,849	4,532	3,051	5,984
Rochdale	Male	39,831	26,835	52,560	5,119	3,447	6,760
Salford	Female	50,437	33,998	66,521	10,084	6,790	13,314
Salford	Male	56,807	38,282	74,941	11,402	7,677	15,055
Stockport	Female	43,505	29,319	57,391	6,166	4,151	8,142
Stockport	Male	47,745	32,171	62,997	6,802	4,580	8,982
Tameside	Female	39,592	26,673	52,246	6,763	4,553	8,930
Tameside	Male	44,247	29,807	58,394	7,666	5,161	10,122
Trafford	Female	35,326	23,808	46,600	4,875	3,283	6,438
Trafford	Male	37,772	25,453	49,834	5,170	3,481	6,827
Wigan	Female	45,005	30,318	59,394	10,676	7,188	14,097
Wigan	Male	48,798	32,869	64,407	11,546	7,773	15,246
GM	Female	474,770	319,957	626,318	81,957	55,181	108,218
GM	Male	536,442	361,443	707,820	93,514	62,961	123,481
GM	Total	1,011,212	681,399	1,334,139	175,471	118,142	231,698

Table A9 Life years lost by gender across the local authorities and GM 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
Bolton	Female	61,487	21,601	98,002	22,526	7,902	35,953
Bolton	Male	70,639	24,817	112,591	26,027	9,131	41,539
Bury	Female	43,691	15,350	69,635	15,523	5,446	24,777
Bury	Male	49,006	17,218	78,103	17,469	6,129	27,879
Manchester	Female	174,621	61,498	277,683	68,627	24,098	109,437
Manchester	Male	207,776	73,070	330,840	82,009	28,783	130,835
Oldham	Female	57,872	20,346	92,182	21,754	7,633	34,713
Oldham	Male	65,189	22,908	103,875	24,430	8,571	38,989
Rochdale	Female	50,139	17,627	79,863	17,393	6,103	27,756
Rochdale	Male	56,259	19,765	89,667	19,572	6,866	31,238
Salford	Female	79,032	27,821	125,733	29,805	10,463	47,539
Salford	Male	89,105	31,341	141,863	33,675	11,820	53,720
Stockport	Female	61,637	21,673	98,160	24,683	8,662	39,383
Stockport	Male	67,782	23,822	107,997	27,023	9,482	43,122
Tameside	Female	55,967	19,661	89,207	21,553	7,561	34,400
Tameside	Male	62,577	21,979	99,761	24,228	8,500	38,668
Trafford	Female	53,363	18,770	84,958	19,901	6,984	31,751
Trafford	Male	57,103	20,077	90,948	21,138	7,417	33,728
Wigan	Female	61,938	21,753	98,750	21,049	7,383	33,601
Wigan	Male	67,198	23,593	107,169	22,784	7,991	36,373
GM	Female	699,747	246,100	1,114,173	262,813	92,235	419,311
GM	Male	792,634	278,590	1,262,814	298,355	104,690	476,092
GM	Total	1,492,380	524,691	2,376,987	561,169	196,925	895,403

Table A10 Annualised economic impact (in 2014 prices) across the local authorities and GM 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
Bolton	£53,099,013	£10,706,018	£76,659,153	£30,126,413
Bury	£36,918,988	£5,337,130	£54,185,931	£20,688,424
Manchester	£136,750,687	£27,353,615	£213,424,541	£88,219,427
Oldham	£50,041,347	£8,352,029	£70,843,363	£28,236,656
Rochdale	£43,824,533	£6,265,755	£61,891,647	£23,048,854
Salford	£61,176,254	£13,131,904	£95,920,609	£38,511,962
Stockport	£54,147,647	£8,602,703	£76,803,787	£32,726,014
Tameside	£49,066,044	£9,209,554	£69,378,730	£28,466,207
Trafford	£42,813,772	£6,569,698	£64,707,300	£25,691,218
Wigan	£55,577,927	£14,054,143	£76,515,165	£28,004,378
GM	£583,416,214	£109,582,547	£860,330,227	£343,719,554

Table A11 Loss of life expectancy by gender across the local authorities and GM from birth in 2011 for anthropogenic $PM_{2.5}$ and NO_2

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
Bolton	Female	11.8	1.9	17.0	5.4
Bolton	Male	13.6	2.2	19.6	6.3
Bury	Female	12.3	1.3	18.1	5.5
Bury	Male	14.1	1.4	20.7	6.4
Manchester	Female	15.5	2.6	24.2	8.6
Manchester	Male	18.1	3.1	28.3	10.2
Oldham	Female	13.5	1.7	19.1	6.3
Oldham	Male	15.4	2.0	21.8	7.3
Rochdale	Female	12.6	1.3	17.8	5.3
Rochdale	Male	14.6	1.5	20.6	6.2
Salford	Female	15.5	2.7	24.3	8.1
Salford	Male	17.4	3.1	27.2	9.1
Stockport	Female	11.6	1.3	16.5	5.7
Stockport	Male	13.2	1.5	18.8	6.5
Tameside	Female	14.0	2.0	19.8	6.7
Tameside	Male	15.9	2.3	22.4	7.6
Trafford	Female	11.6	1.3	17.5	5.7
Trafford	Male	12.7	1.4	19.2	6.2
Wigan	Female	11.3	2.3	15.5	4.4
Wigan	Male	12.3	2.5	16.9	4.8
GM	Female	13.3	2.0	19.6	6.5
GM	Male	15.2	2.3	22.4	7.5

Additional Health and economic assessment method

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

Mortality Burden

The calculations followed COMEAP (2010) and Gowers et al (2014). The relative risk (RR) per 10 µg m^{-3} was scaled to a new relative risk for 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 local authority. This allows different death rates in different wards and LA to influence the results.

The process was repeated for the lower and upper confidence intervals around the relative risks.

Mortality Impact

Projections for the baseline life tables before applying concentration changes

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

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

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

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

Lags: The approach allowed for a delay between exposure and effect using the recommended distribution of lags from COMEAP (COMEAP, 2010) i.e. 30% of the effect in the first year, 12.5% in each of years 2-5 and 20% spread over years 5-20. An analogous approach was used for the effects of long-term exposure to 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 local authority for each scenario and year. The equation used (for the example coefficient of 1.06) was: RR(x) = 1.06x/10 where x is the concentration of interest (with a negative sign for a reduction). Concentrations were assumed to reduce linearly between the years in which modelled concentrations were available (2011, 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 2030and 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 (IOM, 2013) and Gowers et al. (2014) in taking into account the uneven distribution of deaths over the course of the first year when calculating the survival probability. (The survival probability (the ratio of the number alive at the end of the year to the number alive at the beginning) is derived by the equivalent of adding half the deaths back onto the mid-year population to give the starting population and subtracting half the deaths from the mid-year population to give the end population, assuming deaths are distributed evenly across the year. This is not the case in the first year where a weighting factor based on 90% of the deaths occurring in the first half of the year and 10% in the second half is used instead. After rearrangement the actual formula is (1- 0.1 x hazard rate)/(1+ 0.9 x hazard rate) rather than the (1- 0.5 x hazard rate)/(1+ 0.5 x hazard rate) used in other years.)

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

Economic valuation[6]

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.

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

Early work in this field was affected by various biases. Considerable effort has been taken over the last three decades to identify these biases and refine CV approaches to reduce them, with some success.
In the context of health valuation, the underlying calculations are similar whichever of the three methods just mentioned is used. In the case of the wage risk studies, for example, it may be observed that construction workers operating at height will accept an additional risk of death annually of 1 in 1,000 (0.001), for an additional wage of £1000. The value of statistical life (VSL) calculated from these figures would be £1000/0.001 - £1,000,000. A review by OECD gives an averaged VSL for EU Member States of €3million. UK Government, via the Department for Transport, adopts a value that is lower by about 40% of £1.56 million (DfT, 2017).

Opinion is divided as to whether valuation of mortality should concern 'deaths' or 'life years lost'. The OECD is firmly committed to use of the VSL (OECD, 2012). UK government, through the Interdepartmental Group on Costs and Benefits, however, values mortality in terms of the loss of life expectancy expressed as the 'Value of a Life Year' (VOLY), taking a value of £36,379 in 2014 prices. The basic approach to quantification, however, is the same, with values elicited against a change in the risk of a health outcome, in this case, the loss of a life year. The large difference between the unit values for VSL and VOLY is partly mitigated in subsequent analysis by the number of life years lost being about 10 times higher than the number of deaths. However, the UK government position generates estimates of air pollution damage that are significantly lower than estimates made using the OECD position. Given that the UK government position is followed here, results should be considered to be at the conservative end of plausible ranges.
Similar calculations can be made to assess the WTP to avoid ill health more generally, such as development of respiratory or cardiovascular disease. The total impact for morbidity has a number of elements:
WTP to avoid lost utility (being well, and enjoying the opportunities that good health offers)
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 (2013).
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, 2011).
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 A12) is so slight this will still make little difference.

Table A12 Schedule of declining long term discount rates from HMT, 2011

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, 2013) recommends that future values should be uplifted at 2% per annum given that “It is expected that as people’s incomes rise, so too does their willingness to pay to reduce health risks such as those associated with air pollution.” However, it is unclear whether the uplift of 2% is still appropriate. It is notable that it was first developed before the economic crash of 2008, and so does not account for any change in growth since that time. However, the present analysis is based on a long time-frame, so short-term perturbations to growth seem likely to be factored out in the longer term.

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

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