Air Quality: concentrations, exposure and attitudes in Waltham Forest

For: Waltham Forest

By: David Dajnak, Heather Walton, Gregor Stewart, James David Smith and Sean Beevers

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:** sean.beevers@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

Executive Summary and Key results

Waltham Forest (WF) commissioned King's College London (King's) to model a range of interventions around air quality, exposure and attitudes, and its impact on the public in Waltham Forest. The potential for health improvement is unique in Waltham Forest owing to increasing pedestrian and cycling infrastructure, priority and safety measures leading to increasing opportunities for improved physical activity in the borough, modal shifts removing short car trips, and some residential road closures. This report is the first of two, covering:

- Waltham Forest air quality modelling
- Emissions impacts of the School run
- Air quality exposure whilst cycling and walking
- Air Quality Health Impact Assessment

The second report will focus solely on the health benefits of physical activity such as cycling/walking in Waltham Forest.

Waltham Forest Air Quality modelling

We have enhanced the most recent London Atmospheric Emissions Inventory (LAEI) 2013 and 2020 air quality model runs, by incorporating extra information specific to Waltham Forest, such as road closures and 20 mph speed caps. The 2013 and 2020 Waltham Forest maps of NO_X, NO_2, PM_{10} and $PM_{2.5}$ air pollution concentrations were further refined using higher (5mx5m) resolution outputs, and are accessible via an interactive online interrogation tool: https://www.londonair.org.uk/modeling/waltham-forest/. The new WF-specific model results have been used in all subsequent analysis.

School run Impact in Waltham Forest

School run air quality impact
The contribution of the school run in Waltham Forest in 2013 was estimated to be just under 14% of the NO_x, PM_{10} and $PM_{2.5}$ emissions from all cars between 8 and 9 am.

School run modal shift impact
For the school run in 2020, the most effective modal shift scenario (from car journeys to bicycles, walking and public transport) was estimated to result in a 7% reduction in NO_x, PM_{10} and $PM_{2.5}$ emissions from cars from 8-9 am, relative to leaving the mode share at the same level as in 2013. Waltham Forest's interventions, such as the Mini-Holland scheme and additional infrastructure, accounted for two thirds of the reduction, with one third from the current trends in modal shift between 2013 and 2020.

Cycling and walking exposure assessment in Waltham Forest

Exposure to NO_X, NO_2, PM_{10} and $PM_{2.5}$ was modelled for a number of typical cycling and walking journeys across the borough. Due to improved air quality between 2013 and 2020, as well as the introduction of road changes, such as residential road closures and segregated cycle lanes, exposure reduced by between 15-25% for NO_2, and 6-13% for $PM_{2.5}$.

Health Impact Assessment (HIA) of Air Quality in Waltham Forest

In this study, for the first time King's have used the new COMEAP (2017) health impact recommendations to quantify the effects of air pollution on health outcomes in Waltham Forest. Mortality impact results for long-term exposure to air pollution in Waltham Forest are all expressed in terms of life years – the most appropriate metric for the health impact of air pollution concentration changes over time.

Despite projected changes in air pollution concentrations between 2013 and 2020, Waltham Forest's population would still be losing between 172,000 to 256,000 life years as a result of exposure to air pollution (a life year is one person living for one year). This represents as a loss of life expectancy from birth in 2013 of around 6 to 10 months.

The population in Waltham Forest will gain around 41,000 life years, and increase life expectancy by around 1.5 months, if air pollution concentrations improve as projected to 2020, compared with remaining at 2013 concentrations.

Table of Contents

1 Waltham Forest Air Quality Modelling (AQM)

AQM methods

LAEI2013 Reference model
The emissions and air quality modelling reference year, created as part of the London Atmospheric Emissions Inventory (LAEI), was 2013. This was later refined by King's with updated COPERT vehicle emissions factors and the updated LAEI2013 air quality model used to develop the London Ultra Low Emissions Zone (ULEZ). A future 2020 model was also created incorporating the impacts of ULEZ and other London policies. For a complete description of the model, the reader should refer to the LAEI 2013 Methodology[1].

2013 Waltham Forest-specific Air Quality Model (AQM)
To account for the new enforced speed limits in Waltham Forest, which were in place by 2013, the LAEI2013 reference model was updated. To do this, where the LAEI hourly average vehicle speed on a given road link, was greater than the speed limit (20 mph), the link was updated to use the 20 mph.

2020 Waltham Forest-specific AQM
Emissions were produced for the year 2020 in Waltham Forest, assuming the original central London ULEZ started in 2020, and including extra information specific to Waltham Forest, such as the Mini-Holland scheme, interventions aimed at reducing the dominance of motor traffic through traffic calming, strategic road closures in areas such as "town centres" and "The Villages", and further speed caps.

The road closures were almost exclusively on residential roads and the links provided by the Enjoy Waltham Forest Team. Traffic count data were provided on some roads before and after the road closure and, of these, nine were used to reduce the traffic on the affected links, and in some cases adjacent links. On the streets where there were road closures but no measured data, traffic was reduced by an average value (65.5%) of the nine that were measured. Figure 1 illustrates all of the links on which traffic was reduced for the emissions modelling as a result of these road closures.

Further speed caps, where the speed limit was restricted to 20 mph, were included on many roads after implementation of Mini-Holland and are shown in Figure 2. However, in the LAEI emissions model, all residential roads in Waltham Forest were already assumed to have an average speed of < 20 mph.

[1] https://data.london.gov.uk/dataset/london-atmospheric-emissions-inventory-2013

Figure 1 *Map of a section of Waltham Forest Roads. Those coloured red are the road links assumed to be affected by road closures in 2020*

Figure 2 *Map of all Waltham Forest Roads. Those coloured red are major roads with a 20 mph speed limit after Mini-Holland implementation. Blue roads are the major roads without this limit, and black roads are minor roads*

AQM results

2013 and 2020 Waltham Forest-specific AQM Maps

The 2013 and 2020 NO_X, NO_2, PM_{10}, $PM_{2.5}$ air quality data has been re-gridded from 20x20 m resolution to 5x5 m resolution and can be found in Figures 3 and 4 and as maps, available in an interactive online interrogation tool : https://www.londonair.org.uk/modeling/waltham-forest/

The new 2013 model, with capped speeds, and the 2020 model with capped speeds and road closures, have served as the basis for all of King's analysis in this study, including the emissions impacts of the School run, air quality exposure whilst cycling and walking and the air quality health impact assessment, all of which are presented in the following sections.

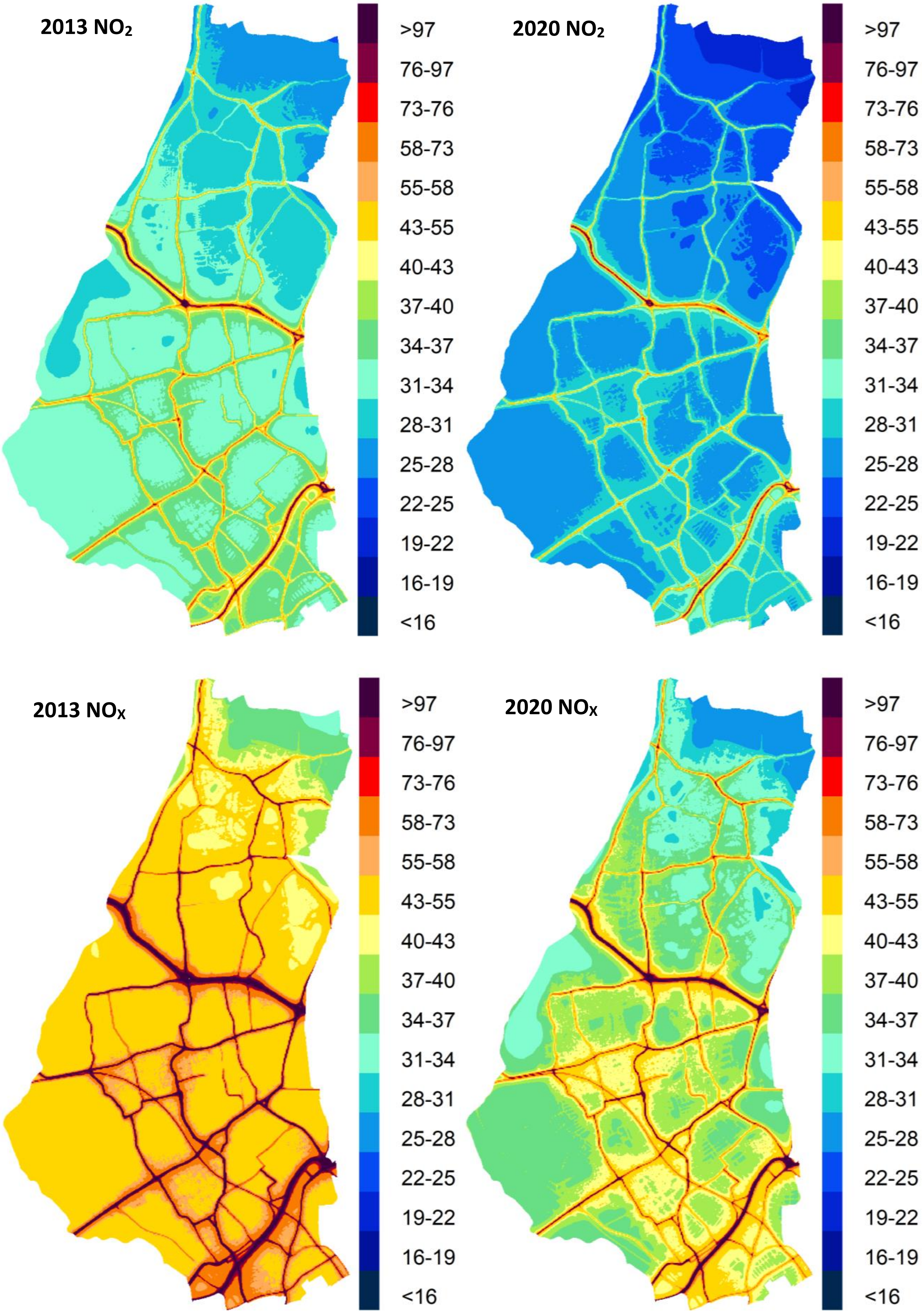


Figure 3 Annual mean NO_2 and NO_X concentrations (in $\mu g\ m^{-3}$) between 2013 and 2020

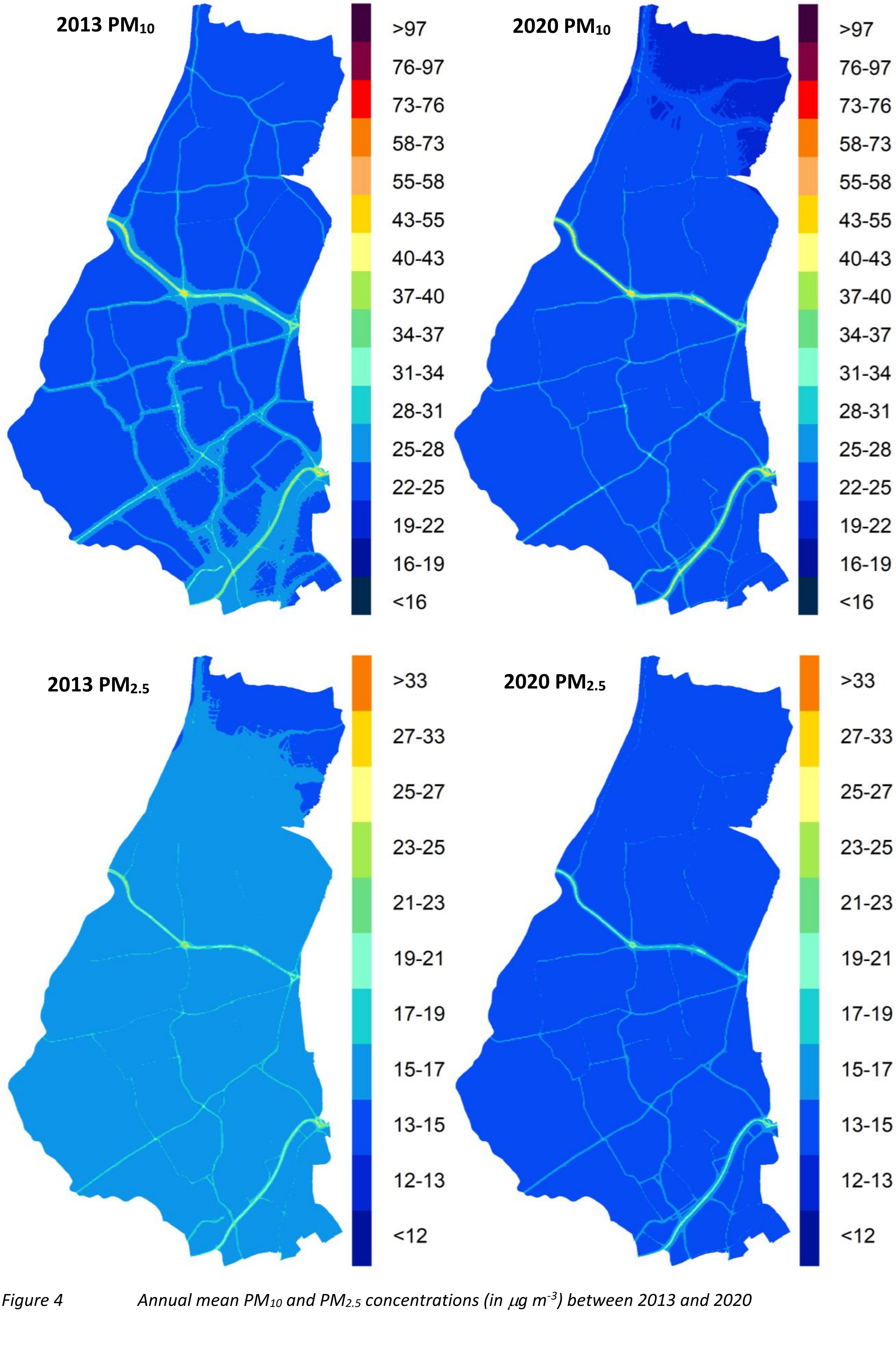


Figure 4 *Annual mean PM_{10} and $PM_{2.5}$ concentrations (in $\mu g\ m^{-3}$) between 2013 and 2020*

2 School Run Air Quality and Modal Shift Impacts

School run impact on emissions and air quality in Waltham Forest

In order to estimate the impact of the school run on emissions and air quality in 2013, a model run was carried out with the school run car traffic removed and compared to the 2013 reference run.

School run impact methods

Data on the vehicle km attributable to the school run were provided by Waltham Forest (personal communication with Enjoy Waltham Forest Team). These data estimated that the transport of pupils accounted for 8.49 million vehicle km, and that of staff accounted for 2.86 million.

On major roads, half of the estimated school run car vehicle km was removed from the 8-9am period, with one quarter removed from 3-4 pm, and the other quarter from 4-5 pm. Minor road vehicle km were adjusted as an annual value since this is how they are held in the emissions toolkit and cold starts adjusted in the same way as minor roads. Table 1 shows the reductions in car traffic (by hour and overall) after subtracting the school run.

Table 1 Reduction in car traffic applied to account for removal of the school run in 2013

Hour	% reduction in car traffic
8-9 am	13.48
3-4 pm	6.36
4-5 pm	6.36
24h average	1.77

Speed elasticity factors were used to account for an increase in speed on major roads corresponding to a reduction in traffic, using an approach which is consistent with the LAEI. Those relevant to Waltham Forest are shown in Table 2.

Table 2 Percent speed change in Outer London per 1 % increase in traffic flow, by period of the day

Hour	% reduction in car traffic
7-10 am	13.48
10 am-4 pm, 7 pm to 10 pm	6.36
4 pm to 7 pm	6.36
10 pm to 7 am	1.77

There was no specific information on which roads would be most affected by the school run; it was therefore assumed that schools were evenly spread across the borough, and that changes in traffic and speed were applied uniformly across the borough.

School run impact results

The emissions changes for key pollutants are shown in Table 3 and show that removing the school run completely in 2013 accounts for almost 14% of total NO_x/PM_{10}/$PM_{2.5}$ emissions between 8.00 and 9.00 am and the same during the afternoon.

Table 3 Car emissions reductions for various pollutants as a result of removing the school run in 2013 (by hours affected and overall)

Hour	Pollutant			
	NO_x	**NO_2**	**PM_{10}**	**$PM_{2.5}$**
8-9 am	13.72%	15.12%	13.36%	13.00%
3-4 pm	6.49%	7.02%	6.34%	6.20%
4-5 pm	6.65%	7.22%	6.38%	6.26%
24h average	1.94%	2.00%	1.83%	1.84%

The 24-hour reduction accounted for almost 2% of NO_x/PM_{10}/$PM_{2.5}$ emissions from cars. The impacts of the school run on annual mean air quality in 2013 were estimated, and all pollutant concentrations can be found in Figure 5. Overall, the air quality concentration changes are small as they represent the overall effect (over 24 hours).

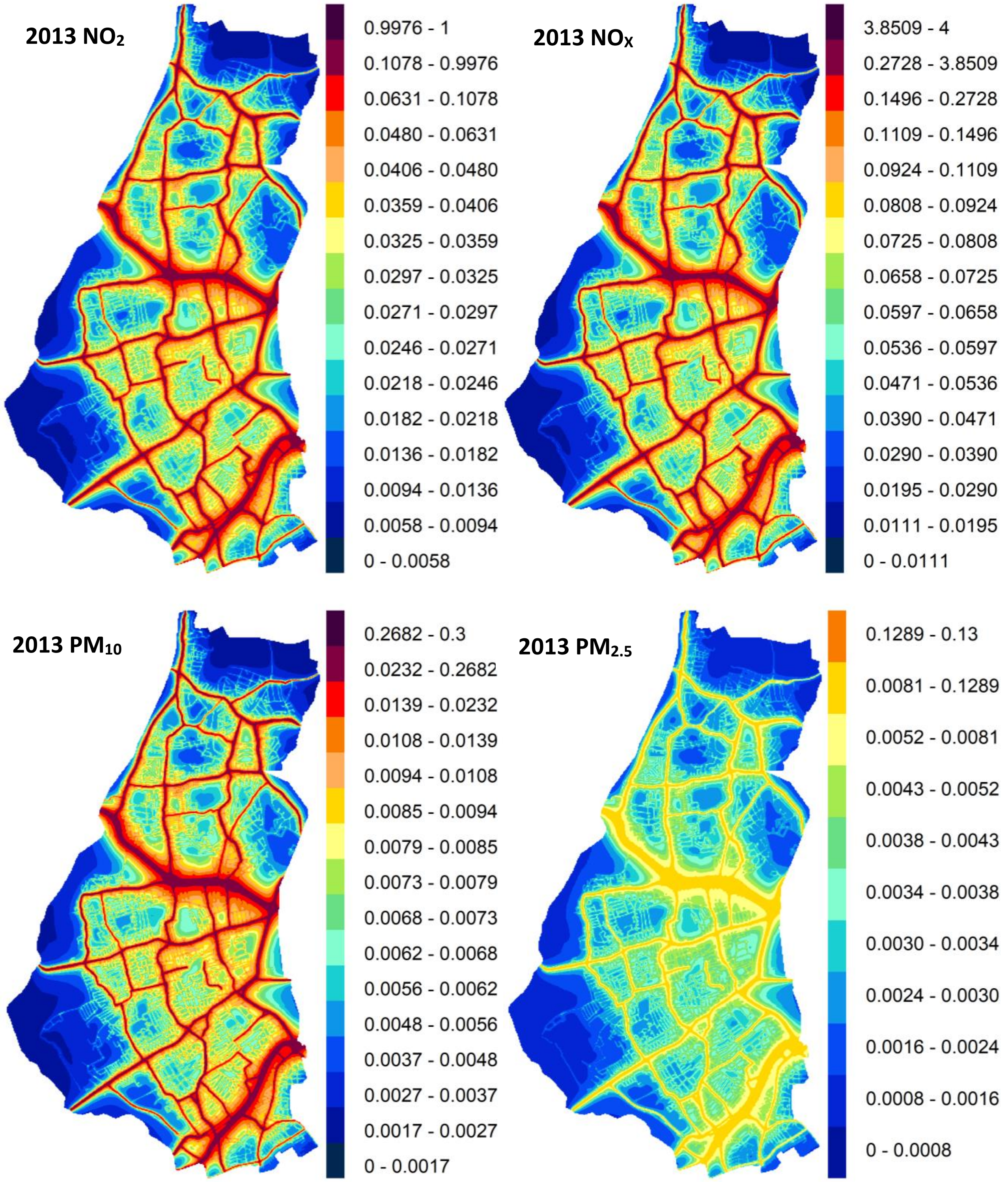


Figure 5 *School run contribution to Annual mean NO_X, NO_2, PM_{10} and $PM_{2.5}$ concentrations (in $\mu g\ m^{-3}$) in 2013*

School run modal shift impact in Waltham Forest

In a further analysis of the school run, King's evaluated the potential improvements in emissions and air quality resulting from a future modal change, from using the car to walking, cycling or using public transport.

School run modal shift impact methods

To establish the likely impact of different degrees of intervention in order to reduce the use of cars for the school run, King's were provided with three scenarios for a trend in the number of school run trips from 2013 to 2020. These were as follows:

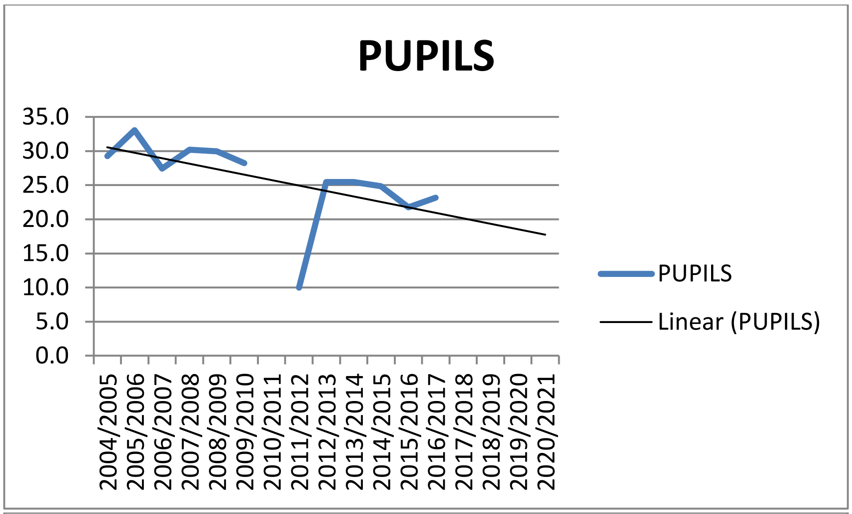
Scenario 1: the existing trend from 2013 through to 2018 will continue to 2020 (25% reduction in car trips for pupils, 15% increase for staff relative to 2013).

Scenario 2: borough interventions will bring about reductions relative to the existing trend (45.8% reduction for pupils, 2.5% increase for staff relative to 2013).

Scenario 3: Further borough interventions will lead to even further reductions in car use (66% reduction for pupils, 10% reduction for staff relative to 2013)

Scenario 1 was confirmed by WF as being business as usual, and thus the 2020 model revision described in Chapter 1 of this report was used to represent it. A scenario involving no change in school run traffic since 2013 was therefore also modelled for 2020. Scenarios 2 and 3 looked at the impact of further reductions in school run traffic in 2020.

In scenarios 2 and 3, the vehicle km to be removed from the school run hours in 2020 were calculated by the Enjoy Waltham Forest Team, using a combination of the 2013 school run total vehicle km and the respective % reductions by 2020. The reduction in car traffic in 2020 and corresponding speed changes were then applied in an analogous way to the previous section, where the whole school run in 2013 was removed; this again meant a uniform reduction across the borough. The scenario with no change since 2013 involved adding car traffic, corresponding to the difference in school run vehicle km from 2013 to 2020 under business as usual, to Scenario 1.



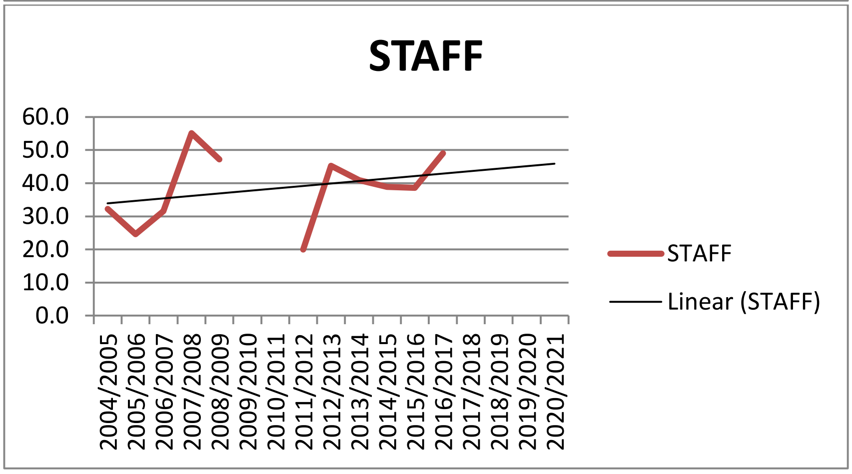


Figure 6 *Plots illustrating the existing trend in car mode share for pupils and staff on the school run (provided by Enjoy Waltham Forest Team)*

<u>School run modal shift impact results</u>

The car emission reductions for each scenario, in the morning period (8-9 AM) and overall, are shown in Table 4.

Table 4 *Reduction in car emissions, between 8 and 9 AM and over all hours, of various pollutants in Waltham Forest in 2020, relative to keeping school runs at 2013 levels, for each school run scenario*

Scenario	Period	Pollutant			
		NO_x	NO_2	PM_{10}	$PM_{2.5}$
1	8-9 AM	2.04%	2.18%	1.95%	1.91%
	24h	0.29%	0.29%	0.27%	0.27%
2	8-9 AM	4.72%	5.04%	4.42%	4.35%
	24h	0.66%	0.67%	0.61%	0.61%
3	8-9 AM	7.18%	7.66%	6.81%	6.69%
	24h	1.02%	1.04%	0.94%	0.95%

With Scenario 3, the effect of the school run modal shift between 2013 and 2020, from car journeys to walking/cycling/public transport, on 2020 emissions was estimated to be a ~ 7% reduction of all NO_x/PM emissions from cars in Waltham Forest between 8.00 and 9.00 am. A

comparison with Scenarios 1 shows that Waltham Forest's interventions, such as the Mini-Holland scheme and additional infrastructures, accounted for two thirds of the reduction (one third was from the current trend in modal shift from 2013 to 2020).

Air quality impacts of the modal shift (Scenario 3) between 2013 and 2020 were estimated in 2020 and concentration reductions for all pollutants can be found in Figure 7. The 24-hour reduction accounted for 1% of NO_x/PM_{10}/$PM_{2.5}$ emissions from cars (Scenario 3). The reductions in pollutant concentrations are small as they represent the overall effect (over 24 hours).

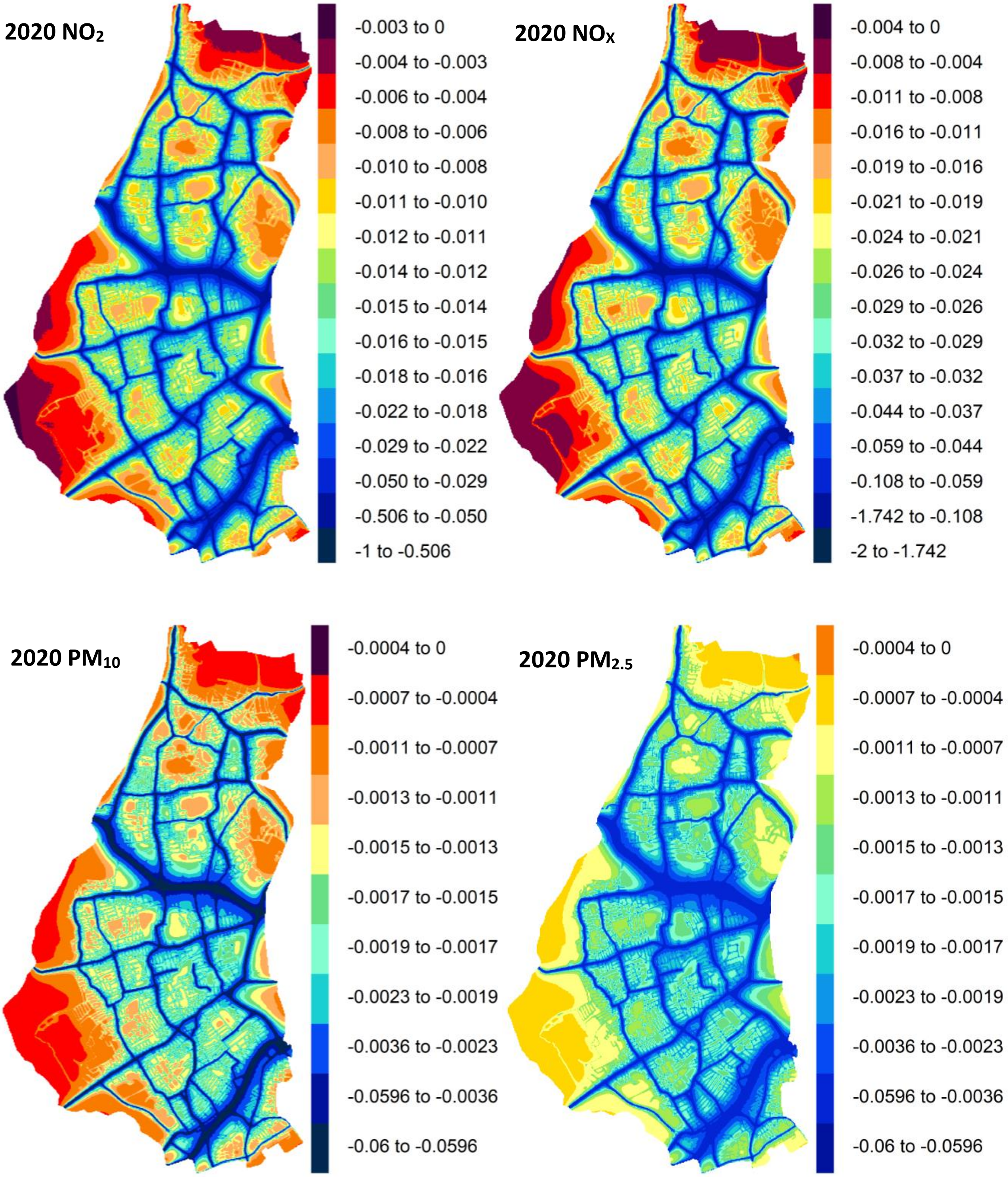


Figure 7 Annual mean NO_X, NO_2, PM_{10} and $PM_{2.5}$ concentrations reduction (in $\mu g\ m^{-3}$) from the school run modal shift in 2020

3 Exposure assessment of typical cycling and walking journeys

As part of the wider Mini-Holland schemes, Waltham Forest have introduced a number of residential road closures and segregated cycle lanes, and in conjunction with improved air quality across the borough seen in section 1 between 2013 and 2020, this should have a beneficial effect on the exposure of residents to air quality when making walking and cycling journeys across the borough. To demonstrate this, King's modelled the exposure on seven popular cycling journeys and six popular walking journeys in 2013, and in a projected 2020 year. The methods are similar to those used in the London Hybrid Exposure Model[2].

Exposure assessment methods

Using the 5m by 5m air quality maps of NO_2, NO_X, PM_{10} and $PM_{2.5}$ concentrations developed in section 1, exposure for members of the public taking walking and cycling trips in Waltham Forest were calculated. Exposure in 2013, 2020 without cycling segregation, and 2020 with cycling segregated on the following trips were considered:

Cycling

- Chingford Station to Leyton Station
- Lea Bridge Station to Whipps Cross
- Leyton Station to Blackhorse Road Station
- Wood Street Station to Blackhorse Road Station
- Coppermill Lane Waterworks to Wood Street Station
- Leytonstone Station to Stratford Station
- Leytonstone Station to Lea Bridge Station via Ruckholt Road

Walking

- Walthamstow Central to Lea Bridge Station via Selbourne Road and Markhouse Road
- Green Man Roundabout to Leytonstone High Road Station
- Wood Street Station to Waltham Forest Town Hall
- Walthamstow Central Station to Waltham Forest Town Hall
- Chingford Station to Chingford Police Station
- Leyton Tube Station to Drapers Fields

To calculate the route between the start and end of the trips the Google Maps routing API was used. Where the routes calculated did not align with Waltham Forest's presumed routes (likely due to Google Maps not having fully updated with the road changes/improvements), manual correction of the routes was done. Figure 8 (below) shows an example of a cycling route using the Google Maps API.

[2] London Hybrid Exposure Model: Improving Human Exposure Estimates to NO2 and PM2.5 in an Urban Setting. Smith, James David et al. *Environmental Science and Technology*, Vol. 50, No. 21, 06.10.2016, p. 11760–11768.

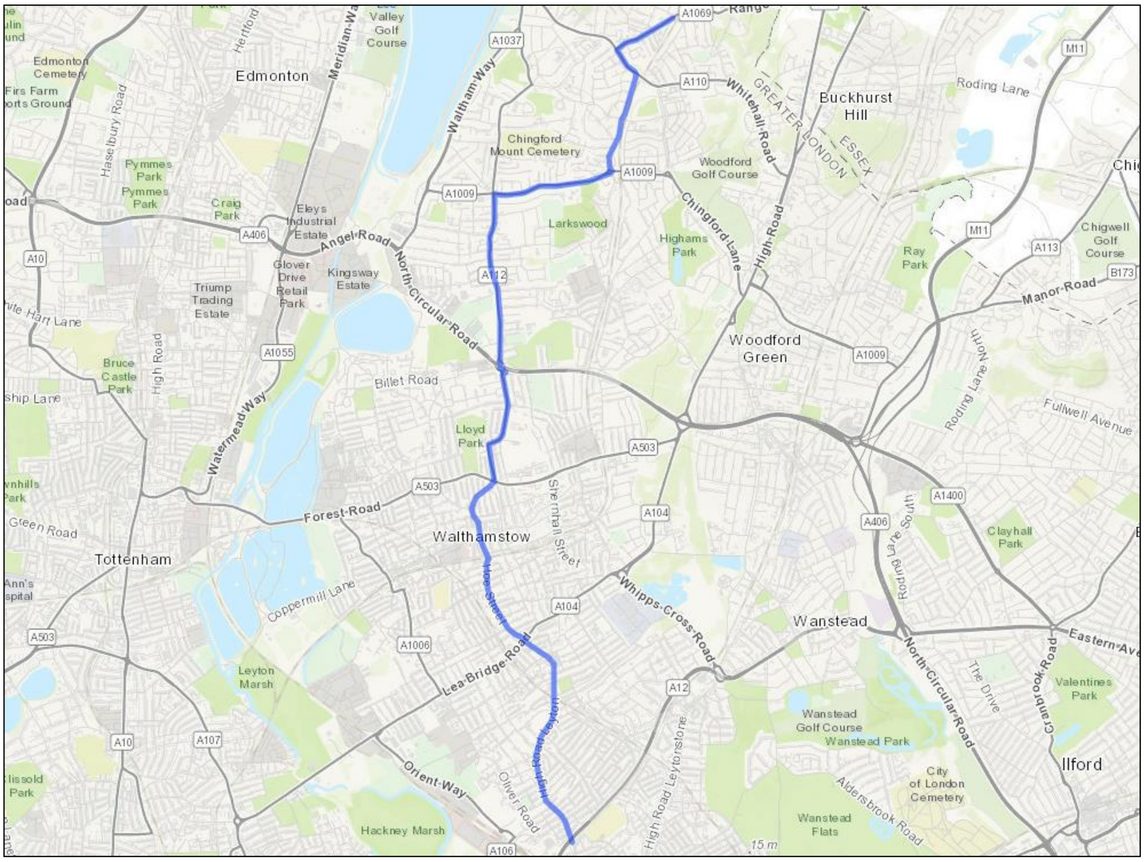


Figure 8 *Cycling route between Chingford Station and Leyton Station calculated by the Google Maps API*

As the Google API calculates a route driving down the centre of the road, each route-line was moved depending on the transport mode and whether segregated cycling lanes had been created. Where the route represented a walking journey the line was moved 6 metres away from the road centre-line to represent exposure on the pavement, and where the route represented cycling it was moved 4 metres to represent cycling next to the pavement. On journeys where segregated cycle lanes have been created, the cycling offset value was changed to 6 metres to model the increased distance between exposure and road centre.

To calculate the exposure along each route the duration of the route in minutes was taken, and then the route split into sampling points per minute, evenly spaced along the route. Concentrations at these points were extracted from the appropriate air quality map, and the summary statistics calculated.

Exposure assessment results

Exposure results for NO_2 and $PM_{2.5}$, the pollutants used in the health analysis, are shown below. Exposure results for PM_{10} and NO_X are not shown below but can be provided on request. Results for with and without segregated bicycle lanes can be found in the Appendix (Tables 15 and 16)

Exposure to NO_2 on the designated cycling routes has improved by between 15% and 25% (See Table 5, below).

Table 5 NO_2 exposures while cycling in Waltham Forest

Route	**2013 NO_2 (µg/m3)**	**2020 NO_2 (µg/m3)**	**Percent change**
Chingford Station to Leyton Station [Segregated*]	54	42	22%
Lea Bridge Station to Whipps Cross [Segregated*]	59	44	25%
Leyton Station to Blackhorse Road Station	56	44	21%
Wood Street Station to Blackhorse Road Station	42	35	17%
Coppermill Lane Waterworks to Wood Street Station	36	30	17%
Leytonstone Station to Stratford Drapers	58	48	17%
Leytonstone Station to Lea Bridge Station via Ruckholt	49	40	15%

Exposure to $PM_{2.5}$ on the designated cycling routes has improved by between 6% and 13% (See Table 6, below)

Table 6 $PM_{2.5}$ exposures while cycling in Waltham Forest

Route	**2013 $PM_{2.5}$ (µg/m3)**	**2020 $PM_{2.5}$ (µg/m3)**	**Percent change**
Chingford Station to Leyton Station [Segregated*]	17	15	12%
Lea Bridge Station to Whipps Cross [Segregated*]	18	16	11%
Leyton Station to Blackhorse Road Station	17	16	6%
Wood Street Station to Blackhorse Road Station	16	15	6%
Coppermill Lane Waterworks to Wood Street Station	16	14	13%
Leytonstone Station to Stratford Drapers	17	16	6%
Leytonstone Station to Lea Bridge Station via Ruckholt	17	16	6%

Exposure to NO_2 on the designated walking routes has improved by between 15% and 22% (See Table 7, below).

Table 7 NO_2 exposures while walking in Waltham Forest

Route	**2013 NO_2 (µg/m3)**	**2020 NO_2 (µg/m3)**	**Percent change**
Chingford to Chingford Police	40	34	15%
Green Man Roundabout to Leytonstone High Road Station	55	43	22%
Leyton to Drapers Fields	55	44	20%
Walthamstow Central to Waltham Town Hall	50	41	18%
Walthamstow to Lea Bridge via Selbourne and Markhouse	54	43	20%
Wood Street to Waltham Town Hall	47	40	15%

Exposure to $PM_{2.5}$ on the designated walking routes has improved by between 6% and 13% (See Table 8, below).

Table 8 $PM_{2.5}$ exposures while walking in Waltham Forest

Route	**2013 $PM_{2.5}$ (µg/m3)**	**2020 $PM_{2.5}$ (µg/m3)**	**Percent change**
Chingford to Chingford Police	16	14	13%
Green Man Roundabout to Leytonstone High Road Station	17	15	12%
Leyton to Drapers Fields	17	16	6%
Walthamstow Central to Waltham Town Hall	17	15	12%
Walthamstow to Lea Bridge via Selbourne and Markhouse	17	15	12%
Wood Street to Waltham Town Hall	17	15	12%

The following maps show examples of how the exposure has varied on two examples journeys, for NO_2 and $PM_{2.5}$. Other journeys and pollutants can be made available on request.
Figures 9 (NO_2 in 2013) and 10*Figure 10* (NO_2 in 2020) below, map how exposure has changed for a cycling journey between Chingford Station and Leyton Station (an overall improvement in exposure of 22%).

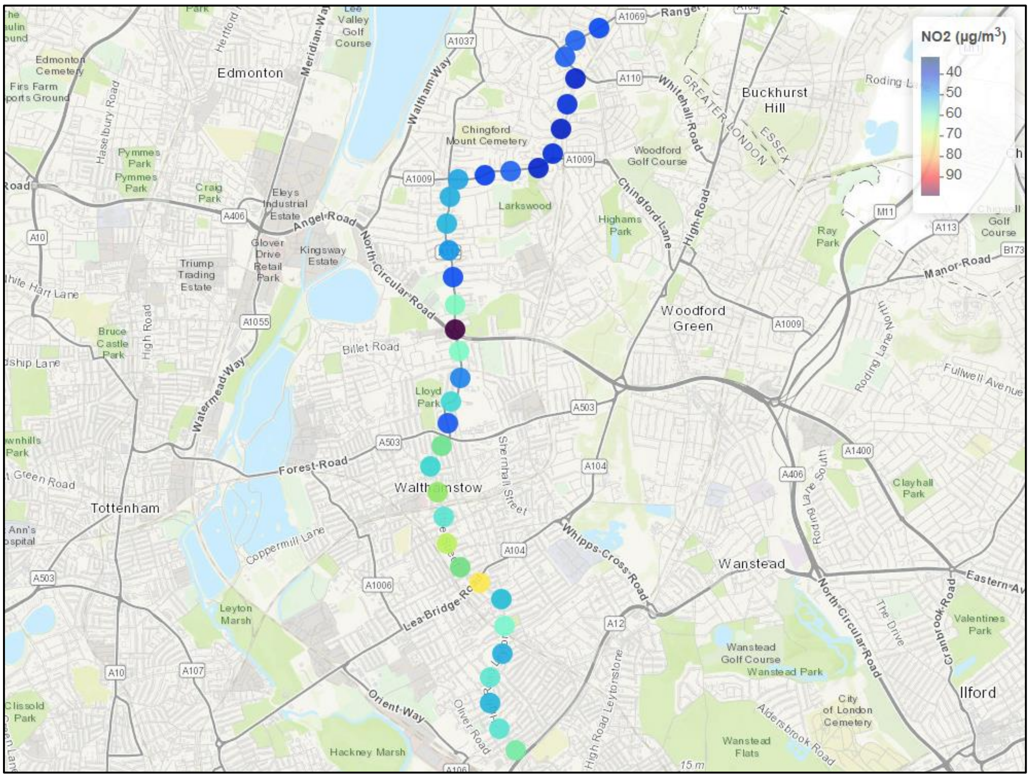


Figure 9 *NO_2 cycling exposure between Chingford and Leyton in 2013*

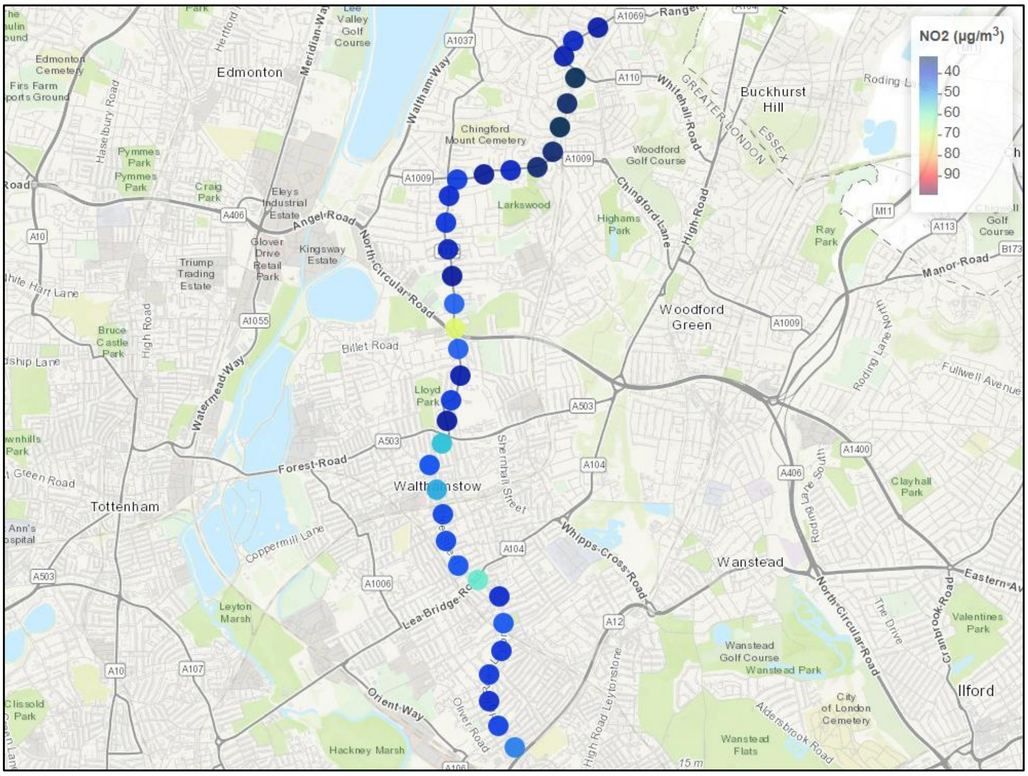


Figure 10 *NO_2 cycling exposure between Chingford and Leyton in 2020*

Figures 11 ($PM_{2.5}$ in 2013) and 12 ($PM_{2.5}$ in 2020) below, map how exposure has changed for a cycling journey between Leyton Station and Blackhorse Road Station (an overall improvement in exposure of 6%).

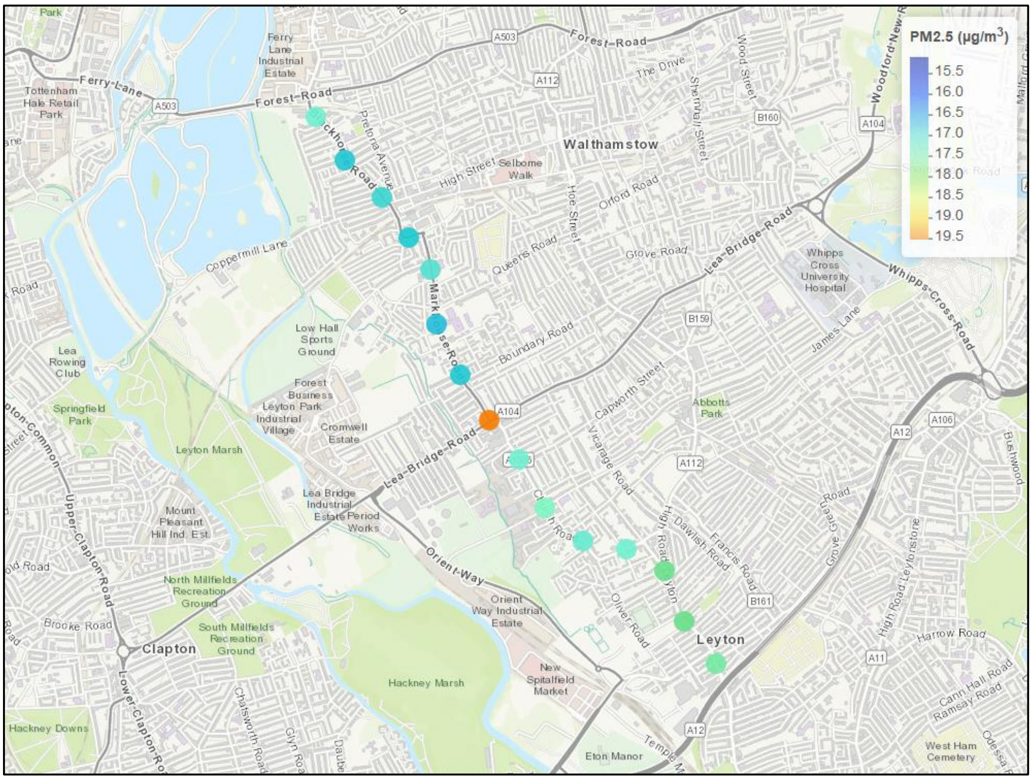


Figure 11 *$PM_{2.5}$ cycling exposure between Chingford and Leyton in 2013*

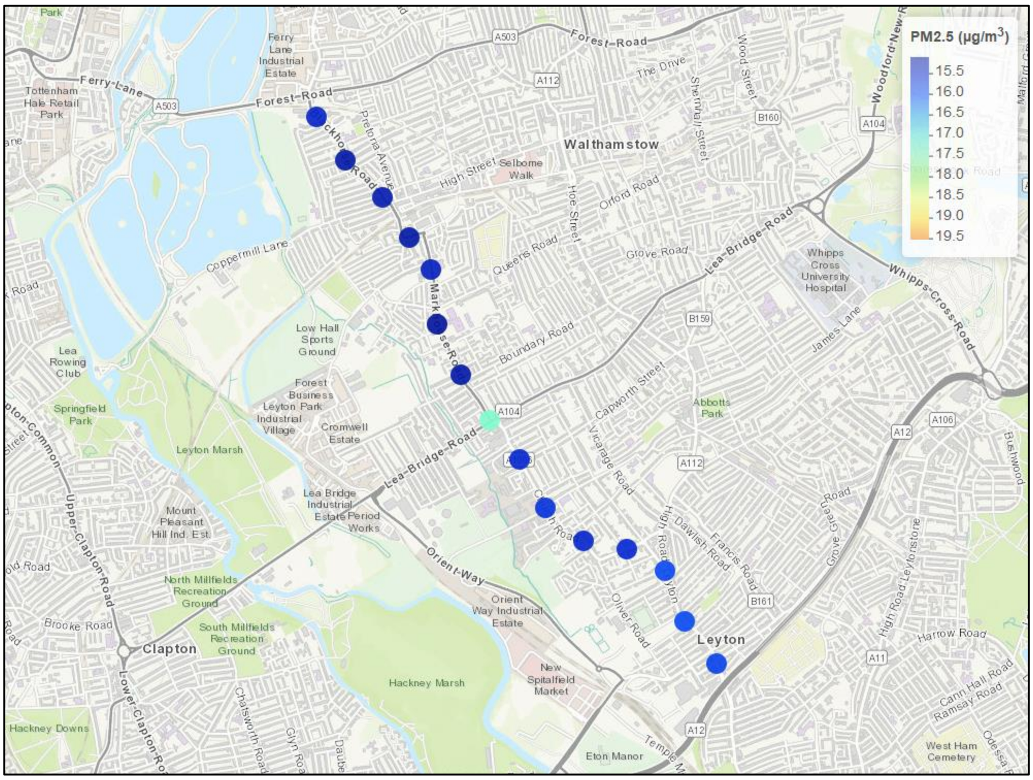


Figure 12 *$PM_{2.5}$ cycling exposure between Chingford and Leyton in 2020*

4 Health Impact Assessment (HIA) of Air Quality in Waltham Forest

Using the 5m by 5m air quality maps of NO_2 and $PM_{2.5}$ concentrations developed in section 1, King's produced a health impact assessment associated with current and future pollution levels in Waltham Forest borough. 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). This section 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.

HIA methods

From 5mx5m grid data to ward concentration:
Using the data of regular 5m by 5m pollutant points (see section 1 for further details) we 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 Waltham Forest and then divided by Waltham Forest total population. WF population-weighted means were then used directly in the health impact calculations. (This process allows one health calculation per local authority rather than calculations in each separate ward).

A summary of the population-weighted average concentration (PWAC) in 2013 and 2020 in WF is shown in Table 9 for anthropogenic $PM_{2.5}$ and NO_2.

Table 9 Anthropogenic $PM_{2.5}$ and NO_2 PWAC (in µg m^{-3}) in Waltham Forest

Local authority	**2013**	**2020**
Anthropogenic $PM_{2.5}$	15.5	14
NO_2	35	29

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 and cut-off (counter-factual) used and the spatial scales of the input data are given in Tables 13 and 14 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 1.

HIA Limitations

Although there are further mortality impacts from changes in ozone concentrations, as well as the effects of all pollutants on illness, these were not assessed in this study.

Estimates of the mortality impact of air pollution results

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 2013 levels and assuming the predicted concentration between 2013 and 2020 (concentrations were modelled at 2013 and 2020 but also interpolated for the intervening years) are shown in Table 10, for anthropogenic $PM_{2.5}$ and NO_2. The results are given as a range from using a cut-off (counter-factual) of 5 $\mu g\ m^{-3}$ for NO_2 and 7 $\mu g\ m^{-3}$ for $PM_{2.5}$ to assuming effects can be extrapolated down to zero.

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 Waltham Forest over 112 years. For context, the total life years lived with baseline mortality rates is around 44 million, so these losses of life years involve about 0.6% of total life years lived.

If 2013 concentrations of anthropogenic $PM_{2.5}$ remained unchanged for 112 years, around 162,000 – 283,000 life years would be lost across WF's population over that period. This improves to around 135,000 – 256,000 life years lost with the predicted concentration between 2013 and 2020 changes examined here.

Another way of representing the health impacts if air pollution concentrations remained unchanged (in 2013) compared with the projected future changes (2013 to 2020) is provided by the results for NO_2. If 2013 concentrations of NO_2 remained unchanged for 112 years, around 214,000 – 249,000 life years would be lost across WF's population over that period. This improves to around 172,000 – 208,000 life years lost with the predicted concentration between 2013 and 2020 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 2013 to 2020 would be around 172,000 to 256,000 life years lost for the population of Waltham Forest over 112 years.

Table 10 Total life years lost across WF population for anthropogenic $PM_{2.5}$ and NO_2 (central and lower-upper estimate)

Pollutant	Scenario	Life years lost Central estimate (without cut-off with cut-off)	Life years lost Lower-Upper Estimate (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 2013 levels	282,526 161,521	191,133-371,272 109,026-212,741
	Predicted concentration between 2013 and 2020	**256,411** 135,045	173,380-337,126 91,111-177,954
NO_2 (representing the local mixture and the rural air pollution mixture)	Concentration does not reduce from 2013 levels	248,818 213,670	87,952-394,267 75,431-338,998
	Predicted concentration between 2013 and 2020	207,660 **172,348**	73,293-329,535 60,752-273,833

For anthropogenic $PM_{2.5}$ assuming no net migration, with projected new births, 2013-2124, 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[3], with lags from the USEPA.
For NO_2 assuming no net migration, with projected new births, 2013-2124, 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.

[3] 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.

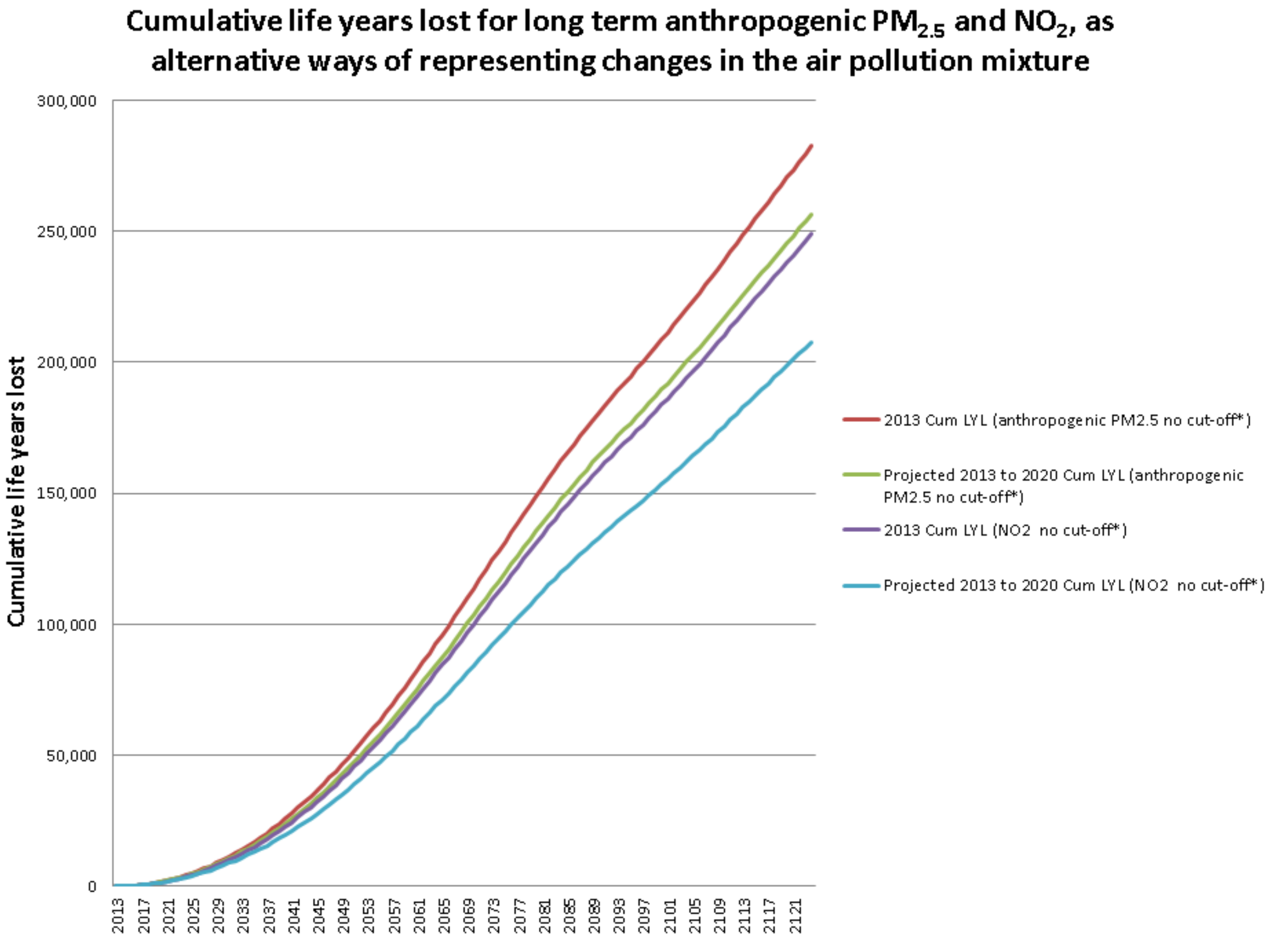


*Figure 13 Cumulative life years lost for anthropogenic $PM_{2.5}$ and NO_2 2013 concentrations remained unchanged and the baseline (current policies 2013-2020) across WF population (no migration), with projected new births, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) 2013-2124. RR 1.06 per 10 $\mu g\ m^{-3}$ for anthropogenic $PM_{2.5}$ and RR 1.023 per 10 $\mu g\ m^{-3}$ for NO_2, EPA lag. * Cut-off results not shown*

Figure 13 shows that the cumulative life years lost for the predicted concentration between 2013 and 2020 accumulates more slowly than the constant 2013 concentration results for both anthropogenic $PM_{2.5}$ and NO_2 as a result of the reduced concentrations from 2013 to 2020. 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 11 shows the differences between the predicted concentration between 2013 and 2020 and both particulate levels and NO_2 concentration constant at 2013 levels. Using $PM_{2.5}$ as an indicator of the regional pollution and some of the local pollution mixture gives an estimate of 26,000 life years gained as a result of the predicted concentration between 2013 and 2020. Using NO_2 as an indicator of mostly the local pollution mixture and the rural pollution gives a larger estimate of 41,000 life years gained. This makes sense because the concentration projected (2013 to 2020) 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[4]. 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 2013 and 2020, the population in Waltham Forest would gain around 41,000 life years over a lifetime.

Table 11 Life years saved across WF population of the predicted concentration between 2013 and 2020 compared with 2013 anthropogenic $PM_{2.5}$ concentrations and NO_2 remaining unchanged

Pollutant	**Scenario**	**Total life years saved compared with 2013 concentrations maintained Central estimate (without cut-off with cut-off)**	**Total life years saved compared with 2013 concentrations maintained Lower-Upper estimate (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 2013 and 2020	26,115 26,476	17,754-34,147 17,915-34,787
NO_2 (representing the local mixture and the rural air pollution mixture)	Predicted concentration between 2013 and 2020	**41,158** **41,323**	14,659-64,732 14,679-65,165

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

[4] 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.

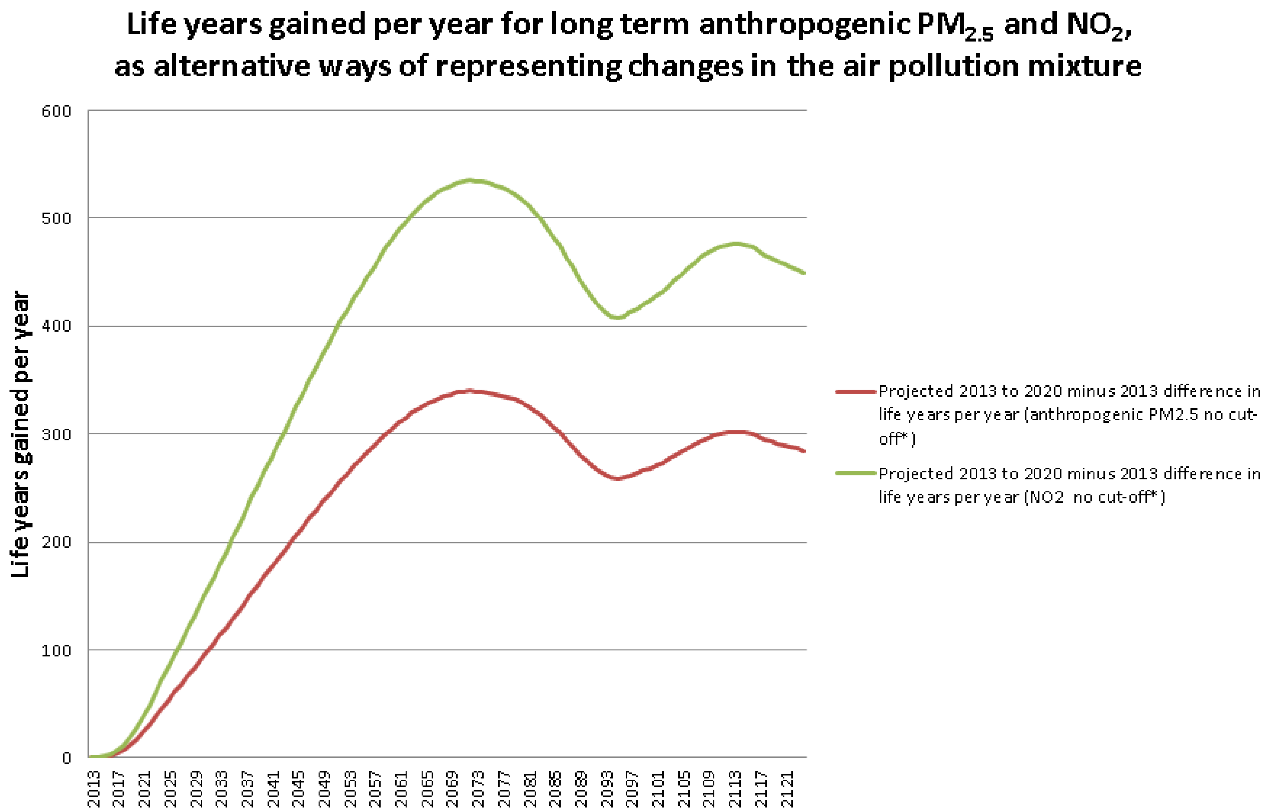


Figure 14 *Life years gained per year from long-term exposure to the improvements in pollution from 2013 to 2020 of anthropogenic $PM_{2.5}$ and NO_2 relative to 2013 concentrations remaining unchanged. * Cut-off results not shown*

Figure 14 shows the effect of the decrease in $PM_{2.5}$ and NO_2 concentration from 2013 to 2020 (as seen in Figures 3 and 4 and Table 9).

Life-expectancy from birth in 2013:
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 12.

This shows that the average loss of life expectancy from birth in WF would be about 26 – 45 weeks for male and 22 – 38 weeks for female if 2013 $PM_{2.5}$ concentrations were unchanged but improves to 21 – 41 weeks for male and 18 – 35 weeks for female for the predicted concentration between 2013 and 2020 (an improvement by about 3-5 weeks).
Using NO_2, the average loss of life expectancy from birth in WF would be about 34 – 40 weeks for male and 29 – 34 weeks for female if NO_2 concentrations were unchanged from 2013 but improves by about 6-7 weeks to 27 – 33 weeks for male and 23 – 28 weeks for female with projected future changes between 2013 and 2020 included.

The overall summary would be that the projected future changes provide an improvement in average life expectancy from birth in 2013 of around 1.5 months (6 – 7 weeks) but an average loss of life expectancy from birth in 2013 of around 6 to 10 months (23 – 41 weeks) remains even with the reduced concentrations.

Table 12 Loss of life expectancy by gender across WF from birth in 2013 (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, 2013 birth cohort (in weeks) Central (Lower-Upper) estimate (without cut-off with cut-off)	
		Male	**Female**
Anthropogenic $PM_{2.5}$	Concentration does not reduce from 2013 levels	45 (30.4-59) 25.7 (17.4-33.9)	38.1 (25.8-49.9) 21.8 (14.8-28.7)
	Predicted concentration between 2013 and 2020	**40.7** (27.5-53.5) 21.4 (14.5-28.2)	**34.5** (23.4-45.3) 18.2 (12.3-23.9)
NO_2	Concentration does not reduce from 2013 levels	39.7 (14-62.8) 34.1 (12.1-54)	33.5 (11.9-52.9) 28.8 (10.2-45.5)
	Predicted concentration between 2013 and 2020	32.9 (11.6-52.2) **27.3** (9.6-43.4)	27.9 (9.9-44.1) **23.1** (8.2-36.6)

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

Appendix

Additional tables

Table 13 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 14 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	LA level

Table 15 Effect of segregation on the Chingford to Leyton cycling route

Route	Year	Segregated	Pollutant	Minimum (µg m^{-3})	Mean (µg m^{-3})	Maximum (µg m^{-3})
Chingford to Leyton	2013	No	$PM_{2.5}$	15.9	17.1	21.4
Chingford to Leyton	2013	No	NO_2	39.6	53.7	101.3
Chingford to Leyton	2020	No	$PM_{2.5}$	14.8	15.4	19.1
Chingford to Leyton	2020	No	NO_2	32.6	43.1	76.8
Chingford to Leyton	2020	Yes	$PM_{2.5}$	14.4	15.3	18.9
Chingford to Leyton	2020	Yes	NO_2	31.8	42.1	74.2

Table 16 Effect of segregation on the Lea Bridge to Whipps Cross route

Route	**Year**	**Segregated**	**Pollutant**	**Minimum ($\mu g\ m^{-3}$)**	**Mean ($\mu g\ m^{-3}$)**	**Maximum ($\mu g\ m^{-3}$)**
Lea Bridge to Whipps Cross	2013	No	$PM_{2.5}$	15.8	17.5	18.7
Lea Bridge to Whipps Cross	2013	No	NO_2	34.5	58.6	73.7
Lea Bridge to Whipps Cross	2020	No	$PM_{2.5}$	14.4	15.8	16.6
Lea Bridge to Whipps Cross	2020	No	NO_2	28.6	44.6	54.7
Lea Bridge to Whipps Cross	2020	Yes	$PM_{2.5}$	14.4	15.7	16.5
Lea Bridge to Whipps Cross	2020	Yes	NO_2	28.5	43.9	53.3

Additional Health and economic assessment method

Anthropogenic $PM_{2.5}$: Non-anthropogenic $PM_{2.5}$ was derived bysubtracting 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 WF: 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 WF: 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 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 2124.

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 (2013, 2020). 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 2013, and 2020and 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 (IOM, 2013) with the following amendments:

- Extension to 2124 (105 years after 2020)

- 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 were then produced for WF. We also used the life tables to calculate changes in life expectancy.

References

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 4 May 2018).

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: 4 May 2018

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: 4 May 2018.

Defra (2013) Impact Pathway Guidance for Valuing Changes in Air Quality.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197900/pb13913-impact-pathway-guidance.pdf (Accessed 9 May 2018).

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 9 May 2018).

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 4 May 2018).

IOM (2013) IOMLIFET: A Spreadsheet System For Life table Calculations For Health Impact Assessment Available at: http://www.iom-world.org/research/iom-research-disciplines/statistical-services/iomlifet/. (Accessed 4 May 2018).

London Hybrid Exposure Model: Improving Human Exposure Estimates to NO2 and PM2.5 in an Urban Setting. Smith, James David; Mitsakou, Christina; Kitwiroon, Nutthida; Barratt, Ben M.; Walton, Heather A; Taylor, Jonathon G; Anderson, Hugh Ross; Kelly, Frank J.; Beevers, Sean D. In: ENVIRONMENTAL SCIENCE AND TECHNOLOGY, Vol. 50, No. 21, 06.10.2016, p. 11760–11768.

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 4 May 2018).

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 4 May 2018).

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 4 May 2018).

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 4 May 2018).
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 4 May 2018).

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 4 May 2018).

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 4 May 2018).

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 4 May 2018).

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 10 May 2018).

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 4 May 2018).