

London Atmospheric Emissions Inventory 2016: Regional and Rural Background Concentrations Update

For: Transport for London (TfL) and Greater London
Authorities (GLA)

By: David Dajnak, Louise Mittal, Gary Fuller 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>

Background Concentrations Update

Methodology

Introduction

Establishing a rural background concentration for the area surrounding London is hampered by the lack of measurement sites outside the capital. Rather than rely on this small number of sites a data analysis technique was created to use PM measurement sites in London based on the assumption that the primary emissions of PM from London are proportional to the emissions of NO_x. This was used successfully by Fuller et al, (2002) and Fuller and Green (2006) to apportion London PM between non-primary regional and primary PM. This technique also gives an emissions ratio of NO_x to PM₁₀ and PM_{2.5}.

However, the method was created before measurements of PM from wood burning in London and south east England began (Fuller et al 2014). The likely interference of wood burning in determining regional background PM also needs to be considered as a second step.

Regional background PM₁₀ and PM_{2.5}

Two methods were combined to establish regional non-primary concentrations of PM₁₀ and PM_{2.5}:

1. Annual mean NO_x concentrations from sites in London and south east England were plotted against annual mean PM₁₀ and PM_{2.5} concentrations for each year from 2010 to 2017. The slope and intercept were derived using the Reduced Major Axis (RMA) regression technique, reflecting the uncertainty in the measurements of both dependent and determinant variables (Ayers, 2001). The intercept gives the PM not associated with NO_x emissions which are assumed to be predominantly from road transport. Therefore, the intercept indicates the non-primary or regional PM₁₀ and PM_{2.5} concentrations. This method is detailed in Fuller and Green, 2006.

The annual mean concentrations used in this method were taken from sites that were part of networks run by King's College London (King's), including the London Air Quality Network (LAQN), Herts and Beds Air Pollution Monitoring Network (until 2011) and the Sussex Air Quality Network and from the UK Automatic Urban and Rural Network (AURN). Only sites that achieved a minimum of 75% data capture in each year for both of the paired pollutants were included. The analysis was carried out for sites in London and south east England and then separately for a subset of these sites using those in London boroughs only so that the results could be compared and the most suitable method chosen. Sites classified as industrial were excluded from the analysis.

2. Rural concentrations of PM₁₀ and PM_{2.5} were obtained from air quality monitoring sites in south east England. Again a 75% data capture threshold was used. A mean of all available sites was calculated for each year.

Rural primary background PM₁₀ and PM_{2.5}

This is calculated from multiplying the rural background NO_x concentrations by the PM₁₀ and PM_{2.5} emissions ratio to NO_x

- **Rural background NO_x:** concentrations Rural background NO_x concentrations were taken from rural measurement sites in south east England.
- **Emissions ratio:** The emissions ratio for PM₁₀ and PM_{2.5} to NO_x is derived from the beta (slope) from the RMA regression technique.

Correction for wood burning

Work to support the latest revision of the LAEI estimated rural background PM₁₀ and PM_{2.5} from wood burning along with concentrations in London.

Wood burning from within London would introduce a bias to the regression intercept and this was simply removed by subtraction. Similarly, measurements of rural PM would be affected by concentrations of wood burning in rural areas. These were removed from the mean rural measurement approach. To adjust the estimate from the regression using sites in London and south east England, the regression factors were recalculated after deducting the wood burning PM concentrations. The urban wood burning concentration was deducted from the sites within London boroughs and the rural concentration from the sites outside London.

Wood burning concentration data from 2017 is not yet available. The 2017 background concentrations adjusted for wood burning are therefore provisional. The provisional wood burning adjustment for 2017 used the average of the wood burning concentrations in the previous three years.

Results

Regional background PM₁₀ and PM_{2.5}

Three estimates of regional background concentrations for both PM₁₀ and PM_{2.5} were produced for each year: the intercept from the RMA regression using London sites only, the intercept from the RMA regression using sites in London and South East England and the measured rural concentrations. These are shown in Table 1 and Table 2. These are the results prior to the correction for wood burning.

Regional background PM ₁₀ (µgm ⁻³)					
Year	London sites		London and South East sites		Mean measured rural
	Intercept	R	Intercept	R	
2010	17.29	0.73	17.26	0.71	14.10
2011	18.60	0.84	18.91	0.80	16.75
2012	16.12	0.84	16.45	0.80	16.10
2013	18.09	0.75	18.07	0.73	17.90
2014	17.31	0.74	17.12	0.78	15.95
2015	15.44	0.74	15.42	0.70	14.85
2016	15.50	0.73	15.00	0.66	15.40
2017	14.45	0.74	14.64	0.72	14.75

Table 1: PM₁₀ regional background concentrations estimated using three methods

Regional background PM _{2.5} (µgm ⁻³)					
Year	London sites		London and South East sites		Mean measured rural
	Intercept	R	Intercept	R	

	Intercept	R	Intercept	R	
2010	11.77	0.70	11.00	0.76	10.30
2011	14.44	0.82	13.77	0.81	12.95
2012	11.63	0.64	12.03	0.63	12.53
2013	13.15	0.77	12.00	0.65	12.70
2014	13.07	0.61	12.19	0.64	11.75
2015	9.80	0.84	9.15	0.83	8.70
2016	10.29	0.62	10.02	0.64	10.15
2017	10.36	0.61	10.22	0.62	8.35

Table 2: PM_{2.5} regional background concentrations estimated using three methods

The results were plotted to give a time series of the three estimates of regional background concentrations for the years 2010 to 2017 shown in Figure 1 and Figure 2. The error bars show the standard deviation of the intercept for the two estimates that used the RMA regression method. The results for PM₁₀ and PM_{2.5} are combined in Figure 3.

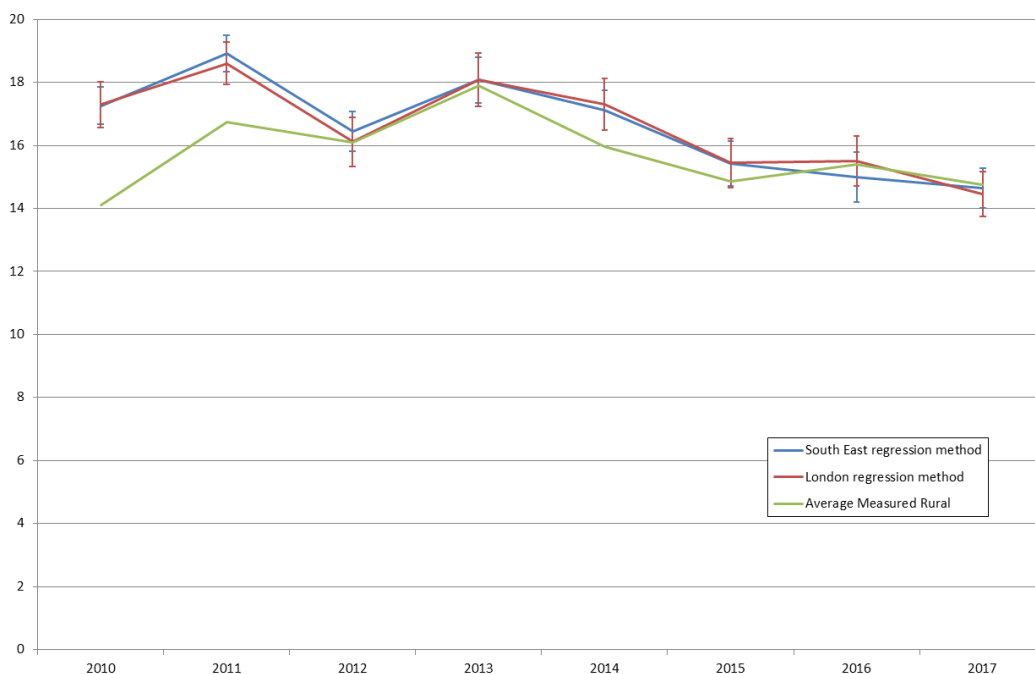


Figure 1: Time series of regional background PM₁₀ concentrations using three methods. The error bars show the standard deviation of the intercept.



Figure 2: Time series of regional background PM_{2.5} concentrations using three methods. The error bars show the standard deviation of the intercept.

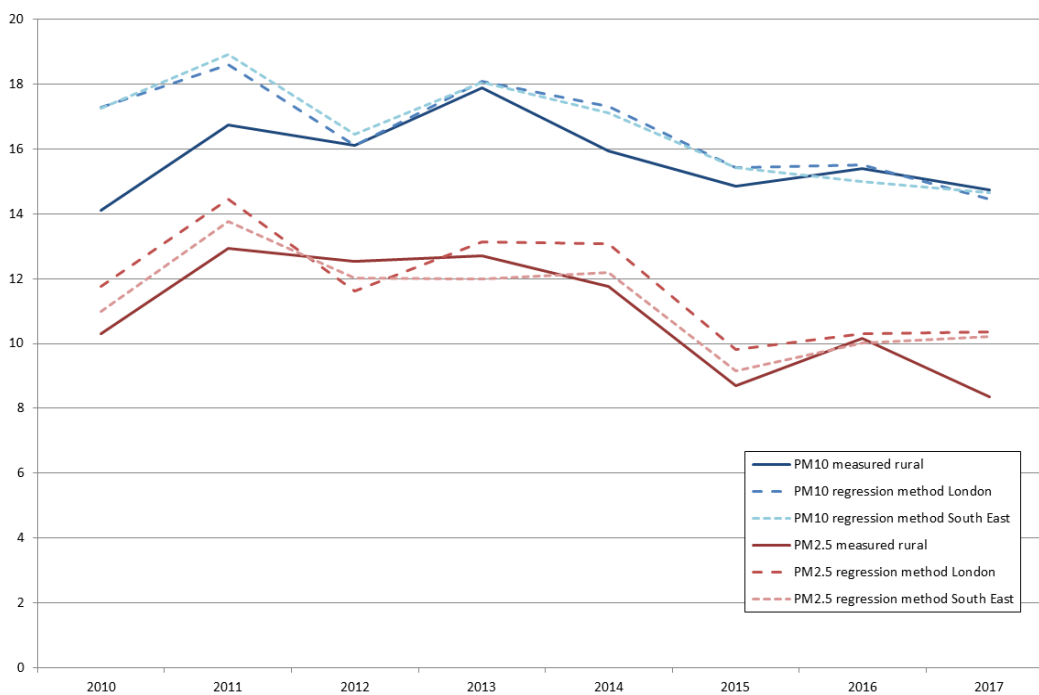


Figure 3: Time series of regional background PM₁₀ and PM_{2.5} concentrations using three methods.

Rural NO_x

There are no rural sites in greater London which measure NO_x, therefore measurements were taken from rural sites in South East England which are part of the UK AURN. The rural NO_x concentrations are shown in Table 3.

Year	Rural NOx (ppb)
2010	8.6
2011	9.1
2012	10.4
2013	7.2
2014	5.9
2015	5.8
2016	8.2
2017	7.6

Table 3: Rural NOx concentrations (ppb)

Emissions ratio

The emissions ratios for PM₁₀ to NOx prior to correcting for wood burning are shown in Table 4 and Table 5.

Emissions Ratio PM ₁₀ to NOx ($\mu\text{gm}^{-3}\text{ppb}^{-1}$)		
Year	London sites	London and South East sites
2010	0.106	0.115
2011	0.127	0.134
2012	0.134	0.137
2013	0.110	0.114
2014	0.088	0.090
2015	0.090	0.100
2016	0.097	0.114
2017	0.109	0.112

Table 4: PM₁₀:NOx emissions ratio derived from the beta (slope) of the RMA regression.

Emissions Ratio PM _{2.5} to NOx ($\mu\text{gm}^{-3}\text{ppb}^{-1}$)		
Year	London sites	London and South East sites
2010	0.100	0.116
2011	0.058	0.070
2012	0.069	0.070
2013	0.052	0.072
2014	0.041	0.054
2015	0.051	0.060
2016	0.061	0.065
2017*	0.046	0.050

Table 5: PM_{2.5}:NOx emissions ratio derived from the beta (slope) of the RMA regression.

Correction for wood burning PM

The regional background concentrations after correction for wood burning PM are shown in Table 6 and Table 7. The reduction in PM concentrations resulting from the subtraction of wood burning PM range from 0.36 $\mu\text{g m}^{-3}$ to 1.13 $\mu\text{g m}^{-3}$. This forms a higher proportion of the $\text{PM}_{2.5}$ than the PM_{10} .

Regional background PM_{10} ($\mu\text{g m}^{-3}$)					
Year	London sites		London and South East sites		Mean measured rural
	Intercept	R	Intercept	R	
2010	16.25	0.73	16.39	0.71	13.50
2011	17.68	0.84	18.18	0.80	16.29
2012	14.98	0.84	15.58	0.80	15.58
2013	17.15	0.75	17.29	0.73	17.39
2014	16.43	0.74	16.40	0.78	15.51
2015	14.64	0.74	14.75	0.70	14.49
2016	14.65	0.73	14.20	0.66	14.70
2017*	13.61	0.74	13.89	0.71	14.25

Table 6: PM_{10} regional background concentrations corrected for wood burning PM. * Provisional

Regional background $\text{PM}_{2.5}$ ($\mu\text{g m}^{-3}$)					
Year	London sites		London and South East sites		Mean measured rural
	Intercept	R	Intercept	R	
2010	10.73	0.70	10.15	0.76	9.70
2011	13.52	0.82	13.10	0.80	12.49
2012	10.49	0.64	11.19	0.58	12.02
2013	12.21	0.77	11.37	0.63	12.19
2014	12.19	0.61	11.59	0.63	11.31
2015	9.01	0.84	8.61	0.83	8.34
2016	9.44	0.62	9.25	0.64	10.60
2017*	9.52	0.61	9.53	0.60	9.20

Table 7: $\text{PM}_{2.5}$ regional background concentrations corrected for wood burning PM. * Provisional

The time series of the results are plotted in Figure 4, Figure 5 and Figure 6.

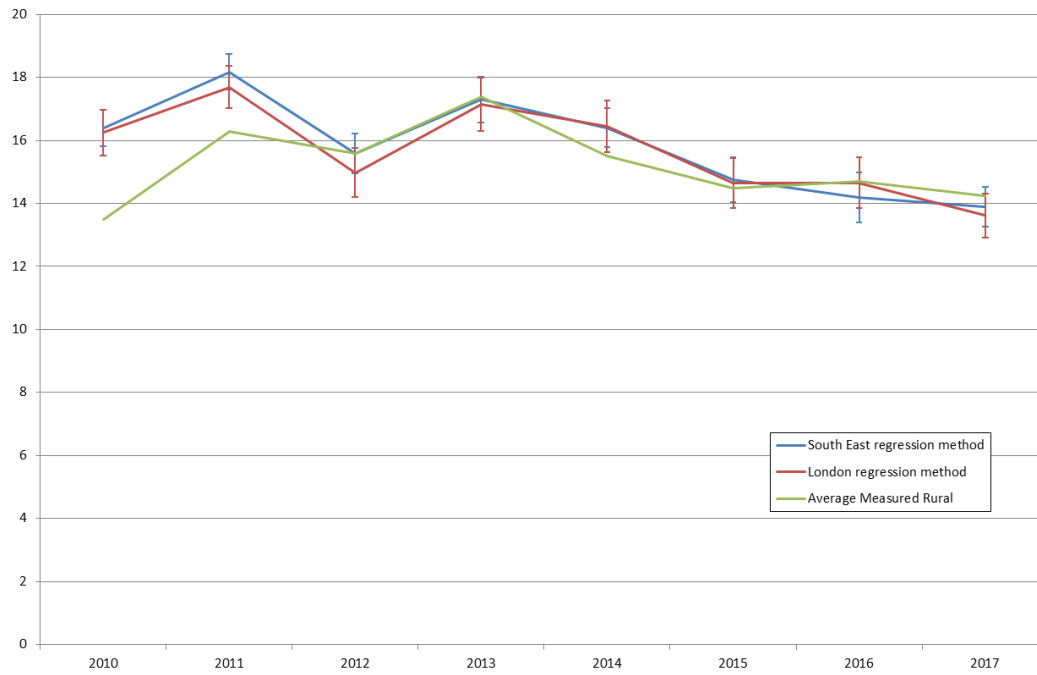


Figure 4: Time series of regional background PM₁₀ concentrations using three methods, after correcting for wood burning. The error bars show the standard deviation of the intercept.



Figure 5: Time series of regional background PM_{2.5} concentrations using three methods, after correcting for wood burning. The error bars show the standard deviation of the intercept.



Figure 6: Time series of regional background PM₁₀ and PM_{2.5} concentrations using three methods, after correcting for wood burning.

The emissions ratios after correcting for wood burning are shown in Table 8 and Table 9.

Emissions Ratio PM ₁₀ to NO _x ($\mu\text{g m}^{-3} \text{ppb}^{-1}$)		
Year	London sites	London and South East sites
2010	0.106	0.115
2011	0.127	0.133
2012	0.134	0.135
2013	0.110	0.113
2014	0.088	0.089
2015	0.090	0.099
2016	0.097	0.114
2017*	0.109	0.112

Table 8: PM₁₀ emissions ratio corrected for wood burning. * Provisional

Emissions Ratio PM _{2.5} to NO _x ($\mu\text{g m}^{-3} \text{ppb}^{-1}$)		
Year	London sites	London and South East sites
2010	0.100	0.114
2011	0.058	0.070
2012	0.069	0.070
2013	0.052	0.072
2014	0.041	0.054
2015	0.051	0.060
2016	0.061	0.065
2017*	0.046	0.048

Table 9: PM_{2.5} emissions ratio corrected for wood burning. * Provisional

Discussion

Regional background PM₁₀ and PM_{2.5}

Having corrected for wood burning PM there was good agreement between the three methods for estimating the region background PM₁₀ and PM_{2.5}. In most cases differences between the results from each method are within the uncertainty indicated by the standard deviation of the intercept. There was a discrepancy between the mean measured concentrations and the regression method in 2010 and 2011 for PM₁₀ with the rural measured concentrations being lower. The number of rural measurement sites is small and in some cases, due to poor data capture or sites opening and closing, the mean was calculated from only one or two sites. Therefore, the regional background concentrations calculated using the regression method are preferred over the mean rural concentrations.

Apart from the expected differences in regional background concentrations due to the wood burning correction, there are some small differences compared to the values used in previous LAEI. The results from the regression method are sensitive to changes relating to the choice of sites used in the calculation. Addition or removal of sites can lead to changes in the slope (emissions ratio) and offset (regional background concentration). This is particularly the case for PM_{2.5} due to the smaller number of sites, so each site has a larger influence. The choice of sites has previously included some subjective assessment of sites which may not have typical NO_x and PM ratios. For this latest update, a fixed set of rules has been followed in the site selection to enable the method to be reproducible going forwards. These are:

1. Sites were chosen from within the same radius of Harwell from London
2. Only sites with minimum annual data capture of 75% were included
3. Only sites using a reference equivalent measurement method were included
4. Industrial classification sites were excluded
5. All sites on networks managed by King's or the UK AURN that met the above criteria are included. Sites were not excluded for any other reasons

By keeping as large a dataset as possible, the analysis could include some sites with atypical NO_x:PM emissions ratios, for example sites which may have been excluded from previous analysis due to known road or building works thereby having a lower NO_x:PM ratio, or sites which are known to have a large number of buses passing by which may be expected to emit more direct NO₂ and therefore have a higher NO_x:PM ratio. However, it is hoped that by following set rules and maximising the size of the dataset, the best average NO_x:PM relationship can be arrived at and the method will be less susceptible to subjective changes.

The earlier years included in this report are also affected by changes in equipment used at site. FDMS instruments were rolled out across the AURN and some sites may previously have been excluded due to suspected operational issues. However, for this report, for consistency and reproducibility, all ratified data is assumed to be correct.

For the same reasons it is recommended to use the results of the analysis which include sites in London and south east England rather than restricting to London sites only. The basis of the method is the assumption that the NO_x:PM emissions ratio is uniform over this area.

Rural NOx

In previous years, the rural NOx concentration has been calculated from the mean of three sites, namely Harwell in Oxfordshire, Lullington Heath in East Sussex and Wicken Fen in Cambridgeshire. The Harwell site closed at the end of 2015 so this can no longer be included in the calculation. A new site, Chilbolton Observatory, opened in 2016.

The calculation of the rural NOx concentration has therefore been changed slightly to include two additional sites which cover the full time-series (except for years with data capture < 75%). These are Rochester Stoke in Kent and St Osyth in Essex. Although NOx concentrations at these sites are slightly higher than at Lullington Heath or Harwell, the larger number of sites covering the full time-series will reduce the effect on the means of site changes.

Implications and impacts on future projection

Total background PM_{2.5} in 2013 and 2016

PM_{2.5} regional background (corrected for wood burning), primary rural background and regional background wood burning (see wood burning emissions update report for more details) were added together in 2013 and 2016 to produce total background PM_{2.5} such as

- **Regional background PM_{2.5}** corrected for biomass wood burning (table 7, London and South East sites)
2013: 11.37 µg m⁻³
2016 9.25 µg m⁻³
- **Rural PM_{2.5}** uses a combination of rural NOx (table 3) and emissions ratio PM_{2.5} to NOx (table 9)
2013: 0.52 µg m⁻³
2016: 0.53 µg m⁻³
- **Rural background biomass wood burning PM_{2.5}** (see details in the wood burning emissions update report)
All years 2013/2016: 0.39 µg m⁻³
- **Total background PM_{2.5}** (regional background PM_{2.5} corrected for biomass + rural background PM_{2.5} + regional background biomass)
2013: 12.28 µg m⁻³
2016: 10.17 µg m⁻³

Projected total background PM_{2.5} in 2030

The total background PM_{2.5} was projected forward from 2013 and 2016 to 2030 using the trend between 2011 and 2035 from the CMAQ results extracted from King's climate change policy scenarios modelling study (Williams et al., 2018). Note that the CMAQ modelling scenarios predicted the future using the best knowledge at the time; views on biomass increase, renewable energy, nuclear energy use, vehicle fleet electrification might have changed since this study was completed. We would therefore recommend that a more realistic range of climate change scenarios of the future must be modelled and used to predict future change in PM_{2.5} by 2030.

- **Total background PM_{2.5}** projected forward using the trend from CMAQ modelling (2011 to 2035 using scenarios from Williams et al., 2018):

2030 (projected from 2013): 10.39 $\mu\text{g m}^{-3}$

2030 (projected from 2016): 8.65 $\mu\text{g m}^{-3}$

The choice of “meteorological year” on future background concentrations

The time series of regional background PM_{2.5} concentrations in Figure 5 shows that air pollution concentrations are highly sensitive to the prevailing meteorology within a year, such as wind speed, wind direction, precipitation, radiation and temperature, as well as the associated long-range transport of pollutants from outside London during this year. Figure 5 does not show a clear trend between 2010 and 2017 and we would recommend using alternative projected total background PM_{2.5} in 2030 (using base years 2013 and 2016) to establish a range of 2030 outcomes. Also, to remain vigilant to the PM_{2.5} concentrations and in the coming years to establish whether there is a clear downward trend. Finally, to support and grow the measurement of PM_{2.5} throughout the south east and UK.

References

Ayers, G.P., 2001. Comment on regression analysis of air quality data Atmospheric Environment 35, 2423-2425

Fuller, G.W., Carslaw, D.C., Lodge, H.W., 2002. An empirical approach for the prediction of daily mean PM10 concentrations. Atmospheric Environment 36, 1431–1441

Fuller, G.W. & Green, D., 2006. Evidence for increasing concentrations of primary PM10 in London. Atmospheric Environment, 40, 6134-6145.

Fuller, G.W., Tremper, A.T., Baker, T.D., Espen Yttri, K., Butterfield, D., 2014. Contribution of wood burning to PM10 in London. Atmospheric Environment 87, 87-94

Williams, M. L., Lott, M. C., Kitwiroon, N., Dajnak, D., Walton, H., Holland, M., Pye, S., Fecht, D., Toledano, M. B., Beevers, S. D. (2018). The Lancet Countdown on health benefits from the UK. Climate Change Act: a modelling study for Great Britain. Lancet Planet Health 2018 May;2(5):e202-e213. [https://www.thelancet.com/journals/lanpla/article/PIIS2542-5196\(18\)30067-6/fulltext](https://www.thelancet.com/journals/lanpla/article/PIIS2542-5196(18)30067-6/fulltext)