APPENDIX AVAILABLE ON REQUEST

Research Report 155

The Impact of the Congestion Charging Scheme on Air Quality in London

Part 1. Emissions Modeling and Analysis of Air Pollution Measurements

Frank Kelly et al.

Appendix L. The Use of Ethane as a Dispersion Indicator

Note: Appendices Available on the Web may appear in a different order than in the original Investigators' Report, and some remnants of their original names may appear in Table and Figure numbers. HEI has not changed the content of these documents, only the letter identifier.

Appendix L was originally Appendix G.

Correspondence may be addressed to Dr. Frank Kelly, Professor of Environmental Health, Environmental Research Group, MRC-HPA Centre for Environment & Health, School of Biomedical Sciences, King's College London, 150 Stamford Street, London SE1 9NH, U.K.
Tel ++44 20 7848 4004 Fax ++44 20 7848 3891 frank.kelly@kcl.ac.uk.

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APPENDIX L

The Use of Ethane As a Dispersion Indicator

Introduction

Traffic movements alone do not control air pollutant concentrations in London. Rather, there are many other influences at work that act in concert to drive the hour-by-hour and day-by-day variability in observed air pollutant concentrations. Our initial approach was therefore to make a simple, observation-based analysis to remove the inherent variability in air pollutant concentrations in London caused by changes in meteorology and atmospheric dispersion to ascertain more accurately, the likely impacts of the CCS on London's air quality.

Methods

The approach adopted in this analysis envisaged that four major processes control air pollutant levels in central London:

- Air pollutant emissions, which drive up air pollutant concentrations.
- Vertical dispersion, which drives down air pollutant concentrations.
- Horizontal advection, which brings into London air pollutants from distant sources outside of London and, on occasions, from other countries.
- Horizontal advection, which removes pollutants by transporting them into the downwind environment.

To remove the influence of long-range and transboundary air pollutant transport, an estimate was made of the regional background concentration of the air pollutant and this was subtracted from the central London observations leaving a London excess concentration. This excess concentration should contain all of the local and London-scale signals but none of the regional and transboundary-scale signals.

Measurement of ethane as an indicator of atmospheric dispersion conditions

To remove the influence of atmospheric dispersion, the observed concentration behaviour of an inert tracer was used to allow for day-by-day variability in vertical dispersion and horizontal advection. The inert tracer chosen as an indicator of the daily atmospheric dispersion conditions in London is ethane, a component of natural gas, which leaks constantly from the natural gas distribution system buried under the streets. Nationally, natural gas leakage accounts for 28% of total ethane emissions but 58% of those from non-industrial sources (Dore et al., 2006; Passant, 2002). In contrast, motor vehicle emissions account for only 17% of non-industrial emissions, viz. traffic, natural gas leakage and domestic combustion sources. Natural gas leakage is likely to be the largest source, by a wide margin, in central London. During the period 1993-2000, hourly observations from up to 13 sites across the UK were made as part of the UK's national air quality monitoring network.

Measurement of PM_{10} and NO_2

Two sites were operational to monitor hourly PM_{10} concentrations by TEOM during the period from 1 February 2003 to 9 March 2003, inside or on the boundary of the CCZ. These sites were Marylebone Road (CCZ Boundary) and Shaftesbury Avenue (Within CCZ – Roadside). Four sites were identified within or on the boundary of the CCZ with continuous NO_2 data during the period from 1 February 2003 to 9 March 2003. In addition to sites on Marylebone Road and Shaftesbury Avenue described above, Horseferry Road (Within CCZ – Urban Background) and Senator House (Within CCZ – Urban Background) were used.

Unlike other analyses that assessed longer time periods, this analysis utilised data from background sites outside of the London urban area and therefore outside of the CCS database. These ten sites are located some considerable distance from central London in the counties of Hertfordshire, Kent, Surrey and Sussex on a largely north west–south east axis through central London. All were similarly equipped and calibrated as those in the CCS database and were operated, reported and quality assured using identical protocols.

Averaging the values from the 10 background sites derived composite regional background PM_{10} concentrations for each hour, and these were subtracted from the Marylebone Road (CCZ

Boundary) and Shaftesbury Avenue (CCZ – Roadside) observations to give an hourly picture of the excess PM_{10} concentrations at each site. Daily mean concentrations were calculated for each day between 1 February and 9 March and these were then averaged into two 14-day periods, immediately before (1 February to 14 February inclusive) and after (18 February to 3 March inclusive) the implementation of the CCS scheme. The process was repeated for NO_2 data utilising the 10 regional background sites and four CCS indicator sites.

Results

Ethane as an indicator of atmospheric dispersion conditions

At all sites, ethane concentrations showed an early morning maximum and a mid-afternoon minimum. This diurnal cycle corresponded to the daily cycle in the depth of the atmospheric boundary layer and the strength of atmospheric mixing, with better dispersion conditions in the afternoon and poorer conditions in the early morning. Figure L1 shows the mean diurnal variation curves for two background locations in London and a rural location, Harwell in Oxfordshire, for the period from 1993 to 2000. These diurnal cycles were clearly evident at all three locations. The mean diurnal curves are distinctly different to those found at these sites for motor vehicle-derived pollutants such as benzene which show both morning and evening peaks (Derwent et al., 2000).

On this basis, ethane observations provided important information on the strength of atmospheric dispersion and the daily mean ethane concentrations are an indicator of atmospheric dispersion conditions close to the ground. Figure L2 shows a scatter plot of the daily mean ethane concentrations at the two London urban background locations during the period from 1993 to 2000. The good correlation between the daily mean concentrations despite the locations being several kilometers apart, demonstrates that the day-to-day differences in daily mean ethane concentrations at urban background sites in London are similar across large distances of separation. This can only be the case if meteorological factors and atmospheric dispersion conditions control these day-to-day differences.

Application to PM_{10}

There will inevitably be a small contribution from local sources at each of the 10 regional background sites As a result, this local contribution will mean that the regional background levels have been overestimated and that the London excess concentrations have been underestimated.

At the site on Marylebone Road (CCZ Boundary), the average daily mean PM_{10} concentration was 37.1 μg m^{-3} before the implementation date and 53.3 μg m^{-3} after (Table L1). Soon after, the implementation of the CCS the weather situation changed and European regionally-polluted air masses were advected into London. PM_{10} levels rose dramatically and this is highlighted by the increase in PM_{10} levels observed. The London excess PM_{10} concentrations obtained by subtracting the composite regional background concentrations changed from 21.3 μg m^{-3} before the implementation date to 27.2 μg m^{-3} after.

To correct for the day-to-day changes in atmospheric dispersion, the London excess concentrations were divided by the daily mean ethane concentrations. The arrival of the European regionally-polluted air masses, with relatively warm and anticyclonic conditions brought a deterioration in atmospheric dispersion conditions as shown by the ethane concentrations in Tables L1 & L2. On applying this correction, the ratio of the London excess PM_{10} concentrations to daily mean ethane concentrations decreased from 1.66 before the implementation date to 1.48 after. This would suggest a decrease in excess PM_{10} concentrations by about 11% when corrections are made for atmospheric dispersion conditions after the implementation date compared with before.

On applying this methodology to the site in Shaftesbury Avenue (CCZ – Roadside) the ratio of excess PM_{10} concentration to that of ethane decreased by 24% before and after the implementation date (Table L1).

Taken together, these results suggest that excluding simultaneous day-to-day variations brought about by regional and long-range transport and atmospheric dispersion conditions, the implementation of the CCS per se would have decreased daily mean PM_{10} concentrations by

11% at Marylebone Road and 24% at Shaftesbury Avenue during February and March 2003. This analysis is based on average concentrations over 14-day periods. If it is assumed that the standard deviations of the 14 values are valid measures of the variance in these excess PM_{10} concentration to that of ethane (approximately ± 35%), it is likely that the differences before and after are not statistically significant in any of the quantities. Air pollutant data are however sometimes serially correlated, and can be strongly influenced by processes that are not random. As such standard deviations maybe overestimates of the true random errors. In this instance, they would need to have been overestimated by a factor of two to make the before and after differences in Table L1 statistically significant.

Application to NO_2

Table L2 presents the results for NO_2. All the sites showed a decrease in the ratio of the excess NO_2 concentration to that of ethane before and after the CCS implementation date by between 29 and 33%. There is good agreement between the within zone background sites (Horseferry Road and Senator House), within zone roadside site (Shaftesbury Avenue) and boundary kerbside site (Marylebone Road). On this basis, it is likely that the Scheme alone would have decreased daily mean NO_2 concentrations by about 30%, had there been no influence from the day-to-day variability in meteorology and atmospheric dispersion. As for PM_{10}, based on the standard deviations of the daily parameters, these differences are not likely to be statistically significant. Again as mentioned above, these standard deviations may be overestimates of the true random errors in the daily parameters and in this case would need to overestimate the true random errors by about 50% for the before and after differences in the daily mean NO_2 concentrations to be statistically significant.

Discussion

On assessing the likely short-term impacts of the CCS on London's air quality using ratified PM_{10} and NO_2 data and a simple observation-based approach, it is concluded that if account is taken of the changing influences of meteorology and atmospheric dispersion, daily mean roadside PM_{10} levels may have improved by 11% on the zone boundary and 24% within the zone. Roadside and background NO_2 concentrations on the zone boundary and within the zone may have improved by between 29 and 33%. However, owing to the large day-to-day variability observed in daily mean PM_{10} and NO_2 concentrations, these before and after differences may not be statistically significant. While this novel method of accounting for dispersion parameters using ambient ethane monitoring results appeared promising over short time periods, a number of concerns were raised as to the spatial and temporal variability of ethane independent of meteorological conditions over longer time periods. Therefore it was concluded that this method should be investigated further but outside of the CCS project and more robust methodological approaches must be applied to the long-term dataset.

References

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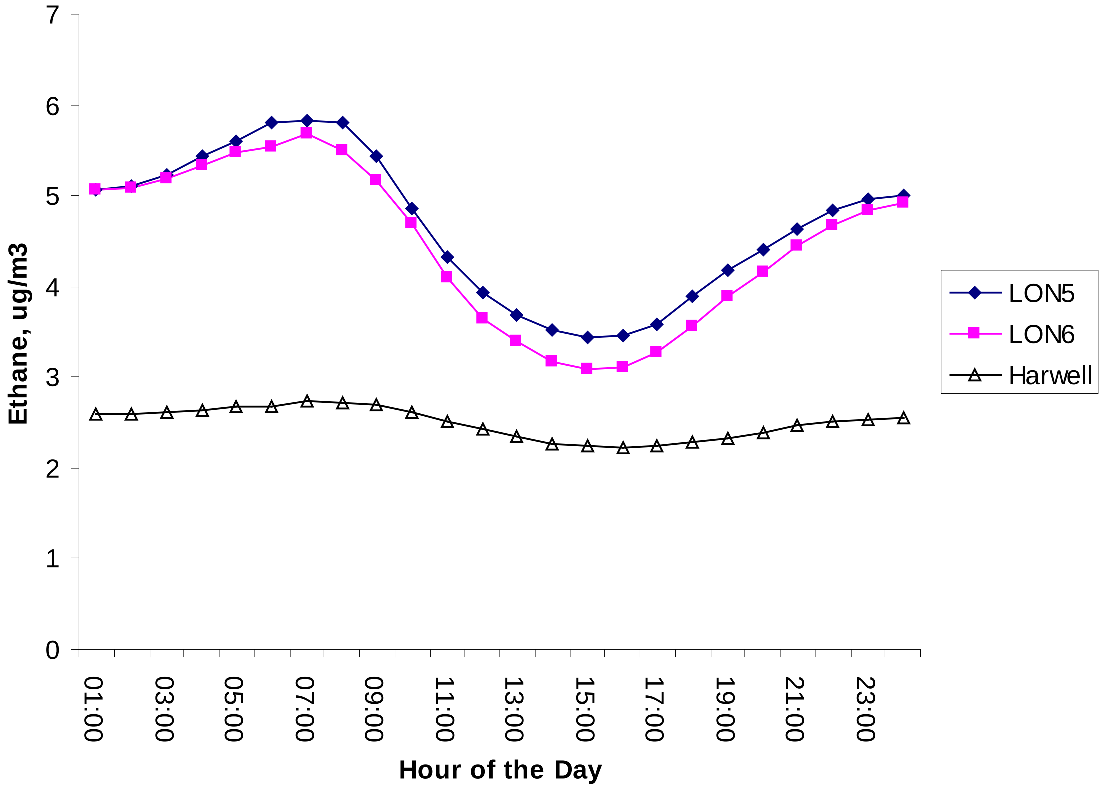

Figure L1. Mean diurnal curves for ethane at two urban background locations in London (LON5, London UCL; LON6, London Eltham) and a rural location, Harwell in Oxfordshire, for the period from 1993 to 2000.

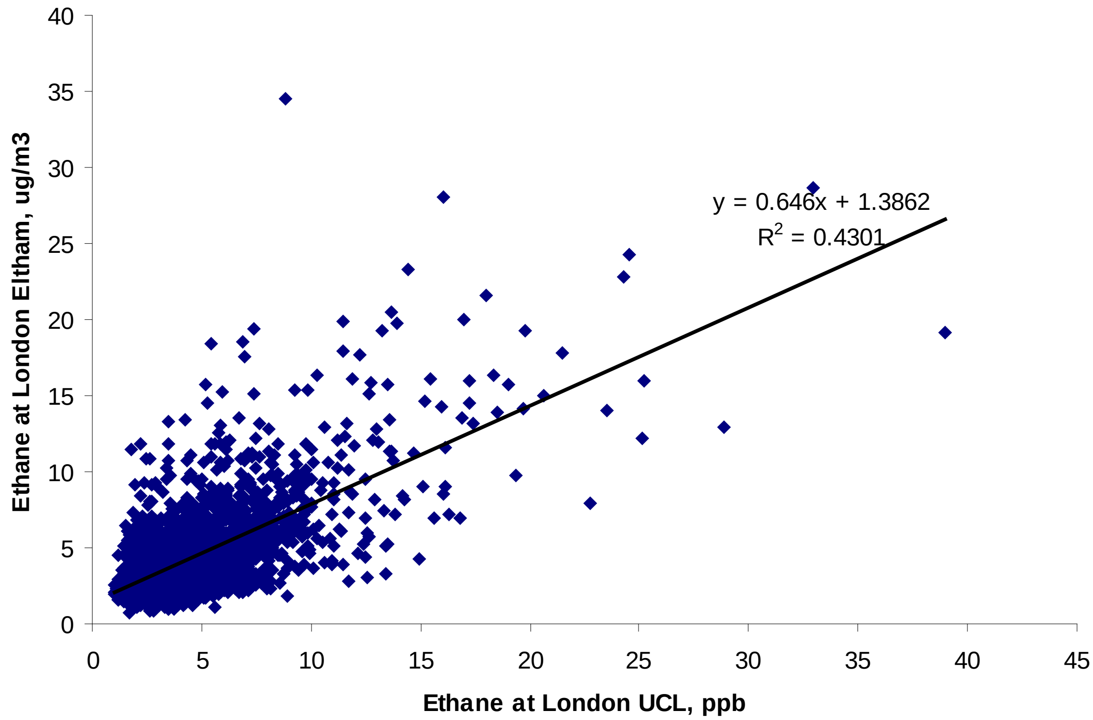

Figure L2. Scatter plot of the daily mean ethane concentrations observed at the London UCL and London Eltham background sites for the period from 1993 to 2000.

Table L1. PM_{10} concentrations, London excess concentrations and pollutant concentration ratios to ethane before (1 February to 14 February inclusive) and after (18 February to 3 March inclusive) the implementation of the CCS.

Marylebone Road (MY1, CCZ Boundary)

Parameter	Before the implementation of the CCS	After the implementation of the CCS
14 day mean	37.1 µg m^{-3}	53.3 µg m^{-3}
mean London excess	21.3 µg m^{-3}	27.2 µg m^{-3}
London excess/ethane	1.66	1.48

Shaftesbury Avenue (CD3, Within Zone – Roadside)

Parameter	Before the implementation of the CCS	After the implementation of the CCS
14 day mean	26.5 µg m^{-3}	39.3 µg m^{-3}
mean London excess	10.5 µg m^{-3}	13.4 µg m^{-3}
London excess/ethane	0.92	0.70

Table L2. NO_2 concentrations, London excess concentrations and pollutant concentration ratios to ethane before (1 February to 14 February inclusive) and after (18 February to 3 March inclusive) the implementation of the CCS.

Marylebone Road (MY1, CCZ Boundary)

Parameter	Before the implementation of the CCS	After the implementation of the CCS
14 day mean	52.9 ppb	61.6 ppb
mean London excess	35.2 ppb	38.0 ppb
London excess/ethane	2.7	1.9

Shaftesbury Avenue (CD3, Within Zone – Roadside)

Parameter	Before the implementation of the CCS	After the implementation of the CCS
14 day mean	37.6 ppb	43.0 ppb
mean London excess	19.9 ppb	19.9 ppb
London excess/ethane	1.5	1.0

Horseferry Road (WM0, Within Zone – Urban Background)

Parameter	Before the implementation of the CCS	After the implementation of the CCS
14 day mean	26.0 ppb	34.0 ppb
mean London excess	8.4 ppb	10.8 ppb
London excess/ethane	0.7	0.5

Senator House (CT1, Within Zone – Urban Background)

Parameter	Before the implementation of the CCS	After the implementation of the CCS
14 day mean	34.1 ppb	41.2 ppb
mean London excess	16.5 ppb	18.0 ppb
London excess/ethane	1.3	0.9